NATIONAL BUREAU OF STANDARDS REPORT

5905

DETERMINATION OF THE EFFECTIVE INTENSITY AND THE VISUAL RANGE OF FLASHING LIGHTS IN RESTRICTED VISIBILITY

by

Visual Landing Aids Field Laboratory
Photometry and Colorimetry Section
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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

This report gives the results of measurements in fog of effective intensity and visual range of four types of flashing lights designed for approach and identification lighting at airports. The effective intensity of these lights was determined by finding the intensity of a single steady burning light which had the same visual range as the test light. The observation distances covered a range of 600 to 6300 feet for both daytime and nighttime conditions.

The results of this study show no significant deviations from the Blondel-Rey law. For night conditions a value of 0.35 was found for the value of the constant a in the Blondel-Rey equation. For day conditions the value of a was 0.15.

1. INTRODUCTION

Flashing lights are frequently used in aviation lighting. For example, high-intensity, "condenser-discharge" lights are used in airfield approach-lighting systems. These lights are installed as single units in a row along the extended centerline of the runway and are flashed in sequence. The present aircraft anticollision lights are rotating lights. Anticollision-light systems using condenser-discharge lights are being studied.

The effective intensity of a flashing light is generally computed by means of the relation developed by Blondel and Rey[1/]. Although the results of laboratory investigations confirm the form of this relation[2/], the applicability of this law to the flashes of short duration and the applicability of a law based upon laboratory results to field conditions have been questioned. Much of the questioning of the validity of the Blondel and Rey relation has arisen from experience with approach-light systems which used both steady burning incandescent and "condenser-discharge" lights. For this reason direct measurements in the field in conditions of restricted visibility of the visual range and effective intensity of lights of this type were considered desirable.

2. DEFINITIONS OF TERMS USED

Regularly transmitted light - the light from the source that reaches the eye of the observer without being scattered by the fog particles. This light appears to come from the source.

Glow - the light from a source reaching the eye of the observer after being scattered by the fog particles. This light appears to come from an area surrounding the source.

Visibility - By day, the maximum distance at which the observer can see and identify a large black object seen against a sky or fog background. In the test an 8-foot by 8-foot black target was used as the daytime visibility mark.

By night, the maximum distance at which the observer can see and identify a light with an intensity of 25 candles by means of the regularly transmitted light from the source; that is, the source appears as a point which may or may not be surrounded by a glow.

These definitions of visibility are analogous to those used by the weather services for reporting visibility in a particular direction.

Indicated visibility - the prevailing visibility over the test distance computed from transmissometer measurements.

Visual range (or test distance) - the maximum distance at which the regularly transmitted light of the test source can be seen and identified.

Detection range - the maximum distance at which the presence of a particular object or light can be detected by either regularly transmitted light or by glow. (Note: By day the glow from the light is generally not visible when the regularly transmitted light is at threshold and the visual range and the detection range are identical. At night the detection range of a projector in fog is generally considerably greater than the visual range.)

Comparison light - a light, approximately a point source, the intensity of which is adjusted so that the visual range of this light is equal to that of the unit under test. The intensity is determined from the intensity-current relation of the light, and from the bearing of the observer with respect to the light.

Effective intensity - the intensity of the comparison light when its visual range is equal to that of the test source.

Equivalent point source intensity - the intensity of a point-source which would have a visual range equal to that of the test source.

3. EQUIPMENT TESTED

The lights used in the study were as follows:

3.1 Condenser-Discharge Light with 20-Microsecond Flash Duration.

This light consisted of a Westinghouse type FGL-1 krypton flash tube in a 25-inch aperture reflector, and a power supply. The power supply consisted of a full-wave rectifier using high-vacuum rectifier tubes to charge

a 30-microfarad capacitor to a nominal voltage of 2000 volts and an ignition circuit to generate a high-voltage pulse to trigger the flash tube.

The flashing of this light was controlled by a special electronic timer to provide a triggering pulse short enough to avoid multiple discharges for each flash of the light. This timer was adjustable over a wide range of flash rates, but was adjusted for 40 flashes per minute during this study.

A plot of the instantaneous intensity, in relative units, against time is given in figure 1. Distribution measurements of the light output in a flash as a function of angle of view were made in the laboratory using a photometric system developed for this purpose[3]. The results of these measurements are shown in figure 2. The beam of this light is axially symmetric.

3.2 Condenser-Discharge Light with 200-Microsecond Flash Duration.

The light consisted of a Sylvania type R4336 flash tube in a 13-inch aperture reflector, and a power supply. The power supply consisted of a full-wave rectifier using mercury-vapor rectifier tubes to charge a 30-microfarad capacitor to a nominal voltage of 2000 volts, and an ignition circuit which generated a high-voltage pulse to trigger the flash tube. An exterior housing was constructed to protect the components from the elements. A sheet of clear plastic 1/16-inch thick was used as a cover glass for the light for these tests. The flashing of this light was controlled by a code-beacon flasher adjusted to 60 flashes per minute.

A plot of the instantaneous intensity, in relative units, against time is given in figure 3. The distributions of the light output in a flash as a function of angle of view are shown in figure 4.

3.3 Approach Beacon with 0.3-Second Flash Duration.

This light consisted of six 120-volt, 300-watt, PAR-56, type 300PAR56/SP lamps mounted on a turntable with equal angular spacing. The lamps were energized continuously during tests. The turntable was rotated by a beacon drive at 12 revolutions per minute, which provided a flash rate of 72 flashes per minute.

The intensity distribution of a lamp of the type used in this light is given in figure 5.

3.4 Approach Beacon with 0.5-Second Flash Duration.

This light was similar to the light described in paragraph 3.3 except that six 115-volt, 400-watt, PAR-56, type 400PAR approach-light lamps were used. The intensity distribution of a lamp of this type is shown in figure 6.

4. TEST INSTALLATION AND TEST PROCEDURE

4.1 Test Site.

A visibility test site was established at the NBS Field Laboratory, Arcata Airport, California, approximately 500 feet from the northern end of the taxiway paralleling runway 31-13. Observations were made from near the centerline of the taxiway where distances from the visibility test site were marked at 100-foot intervals. The taxiway provided a test range with observation distances of 400 to 6300 feet.

A 2400-volt feeder and a 5-kva distribution transformer supplied power to the site. An 8-foot square black visibility mark and two 25-candle lamps, mounted at a height sufficient to be visible the length of the taxiway, were used to determine the visibility. Figure 7 is a photograph of the equipment at the visibility test site. Two of the flashing lights tested are shown.

Four transmissometers installed at intervals along the test range recorded measurements of transmission from which the indicated visibility was computed.

Three comparison lamps were installed at the test site 6 feet to the west of the extended centerline of the taxiway and about 6 feet above the plane of the taxiway. The comparison lamps were as follows:

1) a projector with a 14-inch aperture, a parabolic reflector, and a 12.5-volt, 250-watt, C-8 filament lamp (a modified 14-inch course light);

2) a PAR-64, 115-volt, 600-watt, landing lamp (Type 4569); and

3) a PAR-46, 26-volt, 5.3-ampere flashing signal lamp (Type 4521).

The intensity of the comparison lights could be adjusted by varying the voltage applied to the lamps by means of a continuously variable autotransformer. The intensity-current relations of these lamps had been measured in the laboratory and were checked periodically.

The lights under test were mounted below the visibility mark and to the right of the extended centerline of the taxiway, with the axis of the beam directed along the centerline of the taxiway. These lights were energized directly from the power line. Line voltage was measured and recorded.

4.2 Observational Procedure.

In determining the effective intensity of the light under test the observer moved to a distance at which the regularly transmitted light of the unit was just visible. With the unit still operating, the observer directed

the operator at the visibility test site to adjust the current in one of the comparison lights until the regularly transmitted light from this light was also just visible. The current through the comparison light and the input voltage applied to the light under test were recorded. The intensity corresponding to the comparison-light current was obtained later from the current-intensity curve for this light. If the atmospheric conditions were sufficiently stable, a number of intensity comparisons were made and the average current required in the comparison lamp was determined.

The observer used an automobile to provide sufficient mobility to keep at the visual range of the test unit as the fog density varied. A mobile radio set mounted in the vehicle was used to communicate with the test site. A minimum of lights were used on the vehicle during nighttime tests in order to maintain dark adaptation of the observer.

Measurements of the brightness of the sky background of the lights were made at intervals throughout the test periods.

4.3 Complicating Factors.

4.3.1 Variability of Fogs.

In fogs in which the visual range of the high-intensity lights being tested is less than 6000 feet, the moment-to-moment and point-to-point changes in the fog density are generally large. The variations generally restrict the number of intensity matches which can be made at a given time and location, and make mandatory the use of the test procedure described above in order that the comparison light and the test light may be observed through paths having essentially the same transmittance. It is not possible to use such factors as the visibility of a standard object or light, measurement of atmospheric transmittance over a shorter path, etc., together with visual range of the test unit to determine the effective intensity of the test unit because of the great effect of variations in these factors on the effective intensity. It is, however, desirable to know the relation between the visual range of the test unit and visibility or transmittance; therefore, the visibility and the atmospheric transmittance measured with the four transmissometers installed along the test range were observed periodically during tests.

4.3.2 Effects of Glow.

During daytime conditions the visual range of the flashing lights was relatively easy to determine because glow was not apparent. During night conditions the glow from these flashing lights could be detected, by most observers, at distances considerably greater than the distance at which the regularly transmitted light could be seen. The distance that glow can be detected is a complex function of the particle size distribution of the

fog, the number of particles, the background brightness, and the intensity-distribution pattern of the source. It should be noted that glow is primarily a function of the intensity of the source in directions other than the line of sight, while the visual range of the light (the distance at which regularly transmitted light can be perceived) is determined by the intensity in the direction of the line of sight. If it were possible to block the line of sight between the observer and the lights under test so that only the direct light would be obscured, the distance at which the glow could be detected would be substantially unchanged, although the visual range of the light would then be zero. The background brightness has a much greater effect on the detection range of the glow than on the visual range of the regularly transmitted light. Since the distance that glow can be seen cannot be treated quantitatively at present, all observations were confined to the distance at which the regularly transmitted light could be seen.

5. REDUCTION OF DATA

Since the atmospheric conditions are continually changing, it is not possible to make enough observations at any one condition to obtain a satisfactory average of the effective intensity for that condition. Moreover, the atmospheric conditions along the line of sight are not always sufficiently uniform to use either the visibility or the transmissometer readings as an index of the conditions. Therefore, the data were classified according to the visual range of the light under test. The test range was divided into nine intervals by a geometric series, the limits of which are given in table 1.

Table 1

Visual Range Intervals
Used in Reduction of
Flashing-Light Effective-Intensity Data

Interval		Interval	
No.	Limits (Feet)	No.	Limits (Feet)
1	600 - 799	6	2200 - 2899
2	800 - 999	7	2900 - 3799
3	1000 - 1299	8	3800 - 4899
4	1300 - 1699	9	4900 - 6300
5	1700 - 2199		

The average effective intensity and visual range for each observer for each interval were then obtained for each flashing light. The effective intensity as a function of visual range is given in figures 8 to 15. The number of observations used in obtaining each point is indicated. The hori-

zontal straight lines shown in the figures are drawn through the mean of all observations. Note that the results for individual observers may vary considerably from the average result. The results of the observations are summarized in table 2.

Table 2

Observed Effective Intensities

Light	Kilocandles Day	Kilocandles Night
20-microsecond	62	34
200-microsecond	15	5.8
0.3-second	18	13
0.5-second	30	22

It should be noted that these values represent the performance of the lights as they were aligned and operated in this study and, while they are representative of service conditions, do not necessarily represent the performance of a new light operated at design voltage and viewed in precisely the direction of the peak of the beam. (See Section 6 below).

Knowledge of the visual range of the lights as a function of visibility is often useful. Visibility observations were made periodically throughout the tests but systematic sampling errors, especially those created by the bluff near the visibility marks, made the value of these observations questionable. Therefore the indicated visibility, determined from the transmissometer readings, was used as well as direct observations of visibility. The average transmission of the light path between the observer and the test site was computed by weighting the transmission measurements of each transmissometer as they applied to the particular light path. The indicated visibility was then obtained from this average transmission from the usual transmission-visibility conversion curves. The visual range of the test lights as a function of the observed visibility is given in figures 16 and 17 and of the indicated visibility in figures 18 and 19.

6. ANALYSIS OF RESULTS

Blondel and Rey[1/] found that the threshold illuminance for an abrupt flash (a flash producing a relatively constant illuminance throughout its duration) is

$$E = E_0(a + t)/t, \tag{1}$$

where E_0 is the threshold illuminance for a steady light, t is the flash

duration, and a is a constant. It is convenient to evaluate flashing lights in terms of their effective intensity, as is done in this study. Then

$$I_e = IE_o/E \quad \text{or} \quad I_e = It/(a + t) \qquad (2)$$

where I_e is the effective intensity and I is the instantaneous intensity producing the illuminance E.

In a subsequent paper[4] Blondel and Rey proposed the following modification of equation (2)

$$I_e = \int_{t_1}^{t_2} I dt/(a + t_2 - t_1) \qquad (3)$$

for flashes which were not abrupt. The limits t_1 and t_2 are the times at the beginning and end of flash respectively. This proposal was based on intuitive grounds. There has been little or no experimental verification of equation (3) reported in the literature.

Values of a may be computed by means of equation (3) using the effective intensities given in table 2 and the photometric data of the lights. The results of these computations are given in table 3.

Table 3

Values of the Blondel-Rey Constant

Light	Day a	Day (Number of Observations)	Night a	Night (Number of Observations)
20-microsecond	0.24	(317)	0.44	(258)
200-microsecond	0.13	(407)	0.33	(253)
0.3-second	0.23	(175)	0.40	(152)
0.5-second	0.18	(50)	0.39	(92)
Weighted Average*	0.19	(949)	0.39	(755)

*Weighted in accordance with the number of effective intensity observations used in the determination of the value of a.

These values of a were computed using the following procedures and considerations.

For lights with flash durations as short as those of the two condenser-discharge lights, the value of a is given by

$$a = \frac{\int_{t_1}^{t_2} Idt}{I_e} \qquad (4)$$

since the flash duration, $t_2 - t_1$, is small in comparison to a3/. The integral of Idt is equal to the light output, in candle-seconds, of the flash. This light output of the flash as a function of angle of view is given in figures 2 and 4 for the 20-microsecond and 200-microsecond lights respectively. These data were obtained by photometry in Washington of the lights used in the field tests at Arcata.

The beam of the 20-microsecond light is so narrow that small changes in the angle at which the light is viewed cause significant changes in the intensity of the flash. Periodic checks during the course of the field observations of the direction of the peak of the beam showed that the average angle between the line of sight and the peak of the beam was one degree. Therefore, for this light 15,000 candle-seconds was taken as the value of the integral of equation (4).

The change in intensity of the 200-microsecond light with small changes in the angle of view is insignificant. Therefore, no correction is needed. The value of the integral of equation (4) is 1900 candle-seconds.

The flash duration, $t_2 - t_1$, for the incandescent lights is not negligible. Hence equation (4) is not applicable and equation (3) must be used. In applying this equation, the times t_1 and t_2 were chosen as the times when the instantaneous intensity I was equal to the effective intensity. This procedure maximizes the value of I_e obtained from equation (3) for a given a or minimizes the value of a obtained for a given I_e5/. It is also in accord with the suggestion of Blondel and Rey that only the period when the instantaneous intensity is above the steady-light threshold intensity should be considered in the solution of equation (3).

The 0.3-second light was viewed at an elevation of approximately 1.5 degrees above the peak of the beam. The value of the integral of equation (3) was therefore computed from horizontal traverses through an elevation of 1.5 degrees instead of from the horizontal traverse through the peak of the beam shown in figure 5. Values of 7600 candle-seconds and 7900 candle-seconds were obtained for the day and night conditions respectively.

The distribution curves shown in figure 6 are typical of new lamps of the type used to produce the 0.5-second flashes when operated at rated voltage. Measurements were made at the test site of the maximum intensity in the direction of view of the lamps of this type which were used in the test. These measurements showed that because of blackening

of the reflectors and lenses of the test lamps during other tests and because the peak of the beam was not directed precisely along the line of sight the average maximum intensity in the direction of view was 50 kilocandles, not 65 kilocandles, as shown in figure 6.* The integral of equation (3) was evaluated on this basis. Values of 16,000 candle-seconds and 18,000 candle-seconds were obtained for the day and night conditions respectively.

7. DISCUSSION

7.1 Blondel-Rey Constant.

The values of the Blondel-Rey constant, a, obtained from this study for night conditions are approximately twice the generally accepted value, 0.21. Because of the difficulties encountered in field tests of this type, this difference is not considered very significant. Note that the values of a obtained for the 200-microsecond light are lower than those obtained for the other lights. The values obtained with this light are considered more reliable than those obtained with the other lights because with this light there were no uncertainties caused by alignment of the light. Also the flash durations of the incandescent lights were such that the denominator of equation (4) is considerably larger than a. Hence with these lights an uncertainty in the observed effective intensity will produce a considerably greater uncertainty in the value of a. Thus it is considered that the "best" values of a resulting from this study are 0.3_5 for nighttime conditions and 0.1_5 for daytime conditions.

7.2 Differences in Visual Range of Approach Lights.

There have been repeated reports from pilots that the condenser-discharge approach lights have a significantly greater visual range than the incandescent approach lights. It is apparent from this study that the reported difference in visual range cannot be explained on the basis of the failure of the Blondel-Rey Law. Neither can this difference be explained on the basis of some extraordinary fog-penetrating power of the condenser-discharge light since the intensity required for the steady-burning incandescent comparison light to have a visual range equal to that of the condenser-discharge lights was about equal to that of the beam of in-

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*Photometric measurements of the lamps used in the test could not be made in Washington. Photometry of these lamps was attempted but the lamps had become unstable because of air leaks or were damaged in shipment so that the peak intensities at the time measurements were attempted were of the order of 30 kilocandles and drifted rapidly for about an hour. Then the lamps burned out.

candescent approach lights. Similarly the results shown on figures 16-19 show no unusual differences between the visual range of the condenser-discharge and the incandescent lights. On the other hand the pilot reports have been too frequent to be explained on the basis of pilot bias or chance observations. It will now be shown that there is a rational, straight-forward explanation of these reported differences in visual range.

The causes of these differences in visual range are: 1) differences in intensity, 2) differences in the visual range of the glow, 3) differences in the ease of identification. The latter two factors are of minor importance in comparison to the first. The factors will now be considered in order.

7.2.1 Effects of Differences in Intensity.

The causes of differences in intensity are two: 1) differences in intensity with direction of view and 2) differences in the relative intensity (brightness setting) at which the incandescent and condenser-discharge systems are operated. Each can produce a significant effect on the visual range of the systems.

There have been frequent reports during the last several years that the condenser-discharge lights at Newark airport were sighted 4 to 7 seconds before the incandescent lights were sighted. This effect is primarily the result of differences in intensity with angle of view. As shown in figure 4 the effective intensities of these condenser-discharge lights do not change significantly with the angle of view.

The beam pattern of the condenser-discharge lights used at Newark was essentially the same as that shown in figure 4 but the effective intensity in the beam was of the order of 10,000 candles. The incandescent lights used there until recently were type 250PAR sealed-reflector lamps having a peak intensity of about 80,000 candles, a horizontal beam spread of about 35°, and a vertical beam spread at 5000 candles of only 8 degrees[2/]. The lamps were aimed so that the peak of the beam intersected the glide path at a distance of 1200 feet, and later 1600 feet, from the light. This narrow vertical beam spread seriously affected the performance of the lights. For example, the intensity directed toward an aircraft on the glide path by the outermost incandescent lamps was only 2500 candles when the aircraft was 3000 feet from the light and only 1600 candles when the aircraft was 5000 feet from the light. Thus the pilot, though on the glide path, was in the stray-light region of the incandescent lights for most of his approach but was within the main beam of the condenser-discharge lights. Computation of the difference in sighting times gives differences of 3 to 13 seconds when the visibilities by day are 0.5 to 2 miles and 20 to 40 seconds under VFR conditions. Newer approach systems use incandescent lamps with a wider

vertical beam spread based on those obtained by the National Bureau of Standards for the Bureau of Aeronautics. With these wide-beam lamps, a pilot will be within the main beam of the incandescent lights throughout his approach. Hence, if these lamps are operated at full intensity their beam intensity will be somewhat higher than that of the condenser-discharge lights. Hence, the visual range of a single lamp should be somewhat greater than that of the condenser-discharge lights. Because of the additive effect of the several lamps in the barrettes used in U. S. approach-light systems, the visual range of the barrettes will be somewhat greater than that of the single lamps comprising the barrettes[7/].

As shown in a previous report[8/] when the visual range of an approach-light system is so low that the distance from threshold at which the approach lights are first seen is determined by the cockpit cutoff of the aircraft, a small change in the visual range of the lights will make a large change in the distance from the threshold at which the lights are first seen. For example, with present transport aircraft and glide slopes, if the contact distance is not limited by the length of the approach-light system, the change in contact distance will be approximately five times the change in visual range.

It is frequently necessary to reduce the intensity of the incandescent approach lights at night in order to avoid troublesome glare, even though the reduction in intensity will produce a significant decrease in the distance at which these lights are first seen. For example, when the visibility is 1000 feet, the visual range of an incandescent approach light operating at full intensity (20,000 candles in the beam) will be about 1400 feet. Thus the pilot should be able to locate the outermost light in the system soon after he comes within 4400 feet of the threshold and will see a 500-foot segment of lights when he comes within 2800 feet of the threshold. However, if the lights are operated at 5% intensity (1000 candles in the beam) in order to reduce glare in the inner approach zone, the visual range will be reduced to slightly less than 1100 feet, and the pilot will see no lights until he comes within 2800 feet of the threshold. The outermost light which can be seen will be a light 1700 feet from the threshold. He will not see 500 feet of lights until he is within 1500 feet of the threshold.

The differences in the distance at which the condenser-discharge and the incandescent approach lights were first seen in the flight tests of April 26, 1957 at Andrews Air Force Base were the result of this effect. The incandescent approach lights were operated on step 3, 5% intensity, during the night flights because of power limitations. All, or nearly all, of the condenser-discharge lights were seen, but only the inner half of the incandescent lights of the system were seen. This difference is almost exactly the difference computed in the preceding paragraph.

The intensity of the condenser-discharge lights in the directions in which the lights will be seen from an aircraft on the downwind leg of an approach is about 1000 candles. The intensity of the incandescent approach lights for this condition of view is also about 1000 candles but only when the lights are operated at full intensity. However, when visibility is great enough so that circling approaches are permissible, the incandescent lights are generally operated at 0.2% or 1% relative intensity.* Hence, the intensity of these lights in the direction of the downwind leg is only 2 or 10 candles. Hence, the visual range of the condenser-discharge lights under these conditions is several times that of the incandescent lights.

7.2.2 Differences in the Visual Range of Glow.

Under some conditions at night the difference in the distance at which the glow of the condenser-discharge and steady burning incandescent lights can be seen (see paragraph 4.3.2) is a secondary explanation of the reported differences in visual range of the lights. During these tests the glow of the condenser-discharge lights could be detected and identified at distances considerably greater than the visual range of the direct light of any of the lights used, and at greater distances than could the glow of the approach beacons or of the comparison light. Because of the glow it is difficult for even a stationary observer to determine at night the nearest point at which direct light can no longer be seen. Hence it is probable that when the pilot sees a strong localized glow, he receives an impression of a greater visual range of the direct light of the condenser-discharge lights than exists.

Note: The glow from the condenser-discharge lights appears to come from points at larger angles from the source as the distance is increased beyond that at which the regularly transmitted light can be seen. The flash of the glow may appear as a semicircular arc whose radius subtends an angle, at the observer's eye, of from a few degrees to more than 45 degrees. The location of the light may not be detectable, even as to approximate direction, except from an estimate of the position of the center of the arc.

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*Experience has shown that the maximum tolerable effective illuminance at the pilot's eye from a flashing light is significantly higher than the maximum tolerable illuminance from a steady burning light. (As will be shown in a subsequent report[9] this effect is characteristic of flashing lights in general and is not a unique characteristic of condenser-discharge lights.) For this reason no provision for intensity control is made for the condenser-discharge approach-light system. It should be noted, however, that recommended practice requires that in clear weather the condenser-discharge lights be turned off before the aircraft enters the approach zone[10].

Under conditions of non-uniform fog the glow is brightest in the direction of the most dense fog, and gives the impression that the light is located in this direction.

7.2.3 Differences in the Ease of Identification.

The third factor in producing reports of the differences in visual range is the identification provided by the condenser-discharge lights. Langmuir and Westendorp[11] found that the presence of steady burning lights in the field of view had little effect on the time required to find a flashing light even when the intensity of the steady burning lights was considerably greater than that of the flashing light. Hence the condenser-discharge lights of an approach-light system are readily located despite the presence of a background of city lights while the incandescent lights, if operated on step 1 or 2, are not conspicuous.

Hence even though the maximum visual ranges of the condenser-discharge and the incandescent lights are of the same order, there are many operational conditions in which the condenser-discharge lights will be located and identified before the incandescent lights.

8. CONCLUSIONS

Field tests of lights having flash durations ranging from 20 microseconds to 0.5 second indicate no significant deviation from the law developed by Blondel and Rey for the determination of effective intensity. The value of the constant a of the Blondel-Rey law was found to be different for night and daylight conditions. The value for night conditions was found to be 0.3_5 and for daylight conditions to be 0.1_5. No systematic change was found in the value of a with flash duration or with visual range.

REFERENCES

1. A. Blondel and J. Rey: Sur la Perception des Lumières Brèves a la Limite de Leur Portée, Journal de Physique, 1 (5th Series), 530 (1911).*

2. T. M. Projector: Effective Intensity of Flashing Lights, Ill. Eng. LII, 630 (1957).

3. C. A. Douglas: Photometer for the Measurement of Effective Intensity of Condenser-Discharge Lights, Ill. Eng. LIII, 205 (1958).

4. A. Blondel and J. Rey: Application aux Signaux de la Loi de Perception des Lumières Brèves a la Limite de Leur Portée, Journal de Physique, 1 (5th Series), 643 (1911).*

5. C. A. Douglas: Computation of the Effective Intensity of Flashing Lights, Ill. Eng. LII, 641 (1957).

6. NBS Test Report 15A-2/49 - Performance Characteristics of a Special 250-Watt, PAR-56 Reflector Lamp (May 1949).

7. NBS Report 5644 - The Determination of the Effective Intensity of Composite Light Units in Restricted Visibility (November 1957).

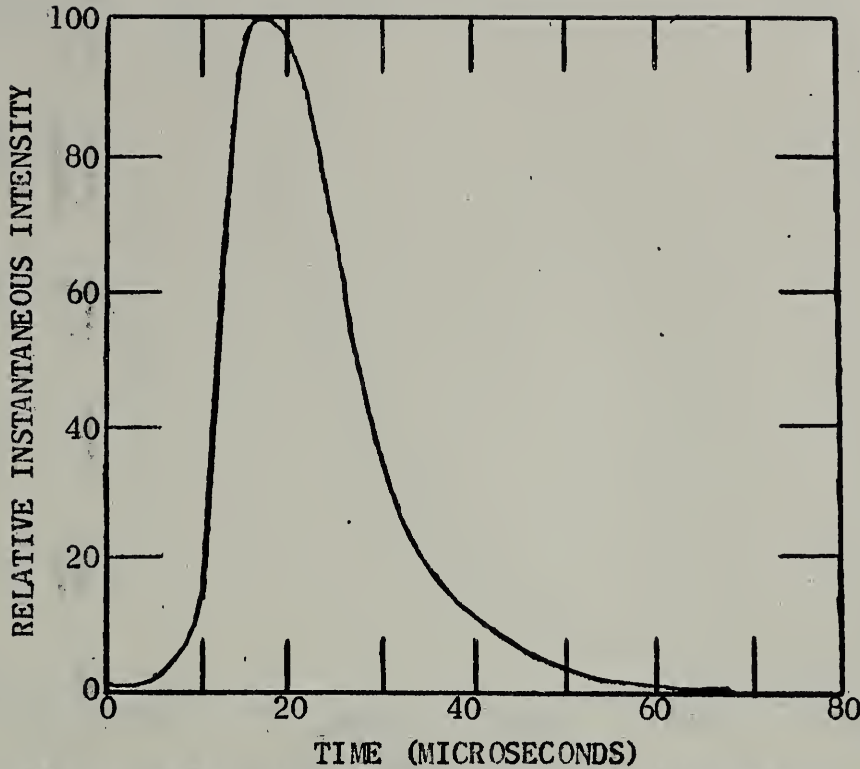
8. C. A. Douglas: NBS Report 5747 - Problems in the Control of Glare in Approach- and Runway-Light Systems (January 1958).

9. NBS Report 5901 - Development and Field Tests of a System of Approach Beacons. (To be issued August 1958).

10. Headquarters Fifteenth Air Force Final Report on Operational Suitability Test of Airfield Approach Lighting Configurations, March Air Force Base, California.

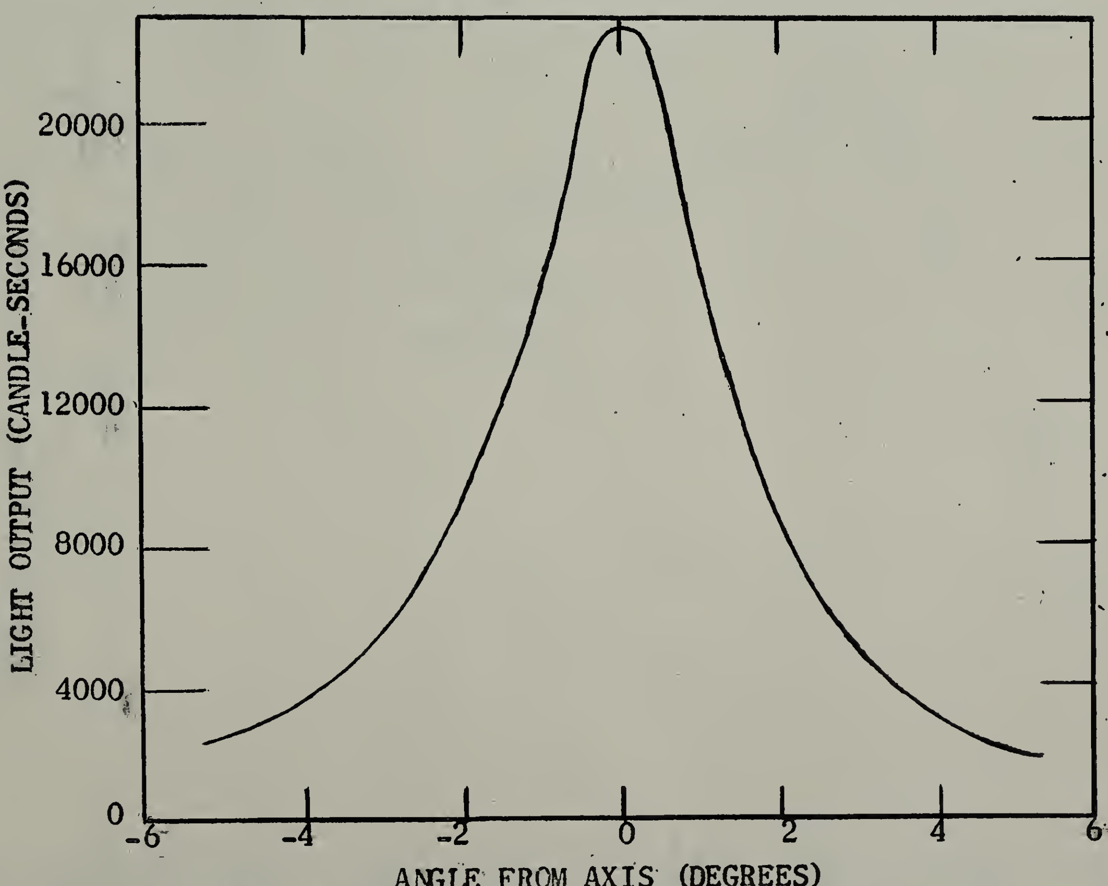
11. I. Langmuir and W. F. Westendorp: A Study of Light Signals in Aviation and Navigation. Physics 1, 273 (1931).

*A complete account, in English, of the material in references 1 and 4 is given in the following paper: A. Blondel and J. Rey, Transactions IES, London VII, 625 (1912).



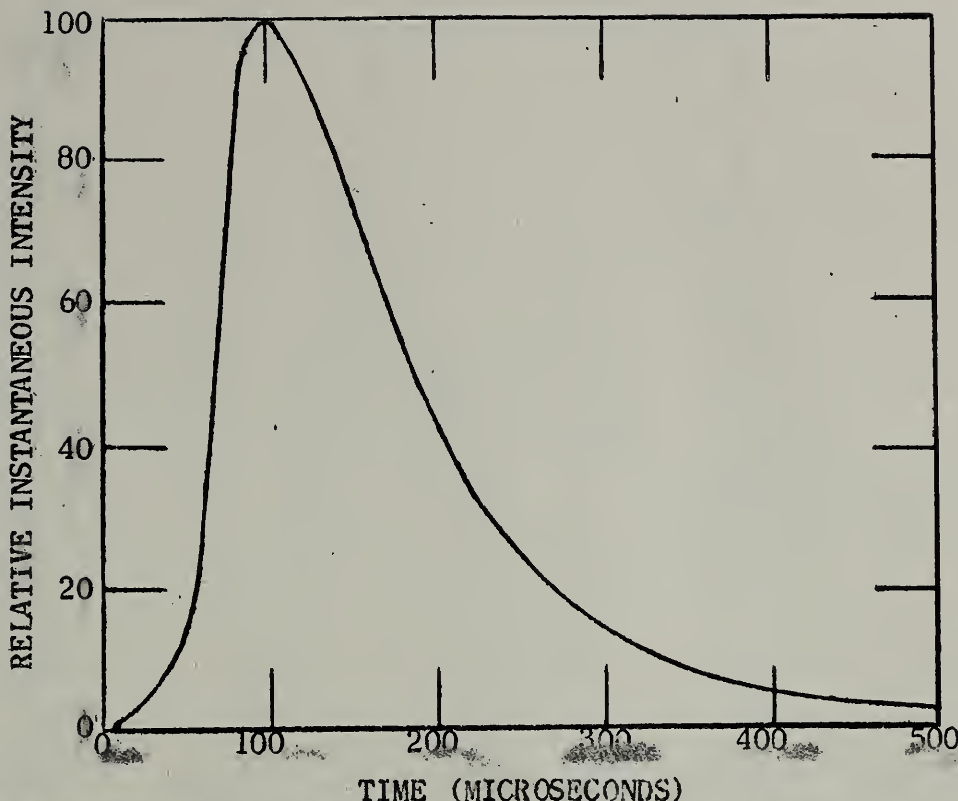
INTENSITY-TIME RELATION OF 20-MICROSECOND CONDENSER-DISCHARGE LIGHT

Figure 1



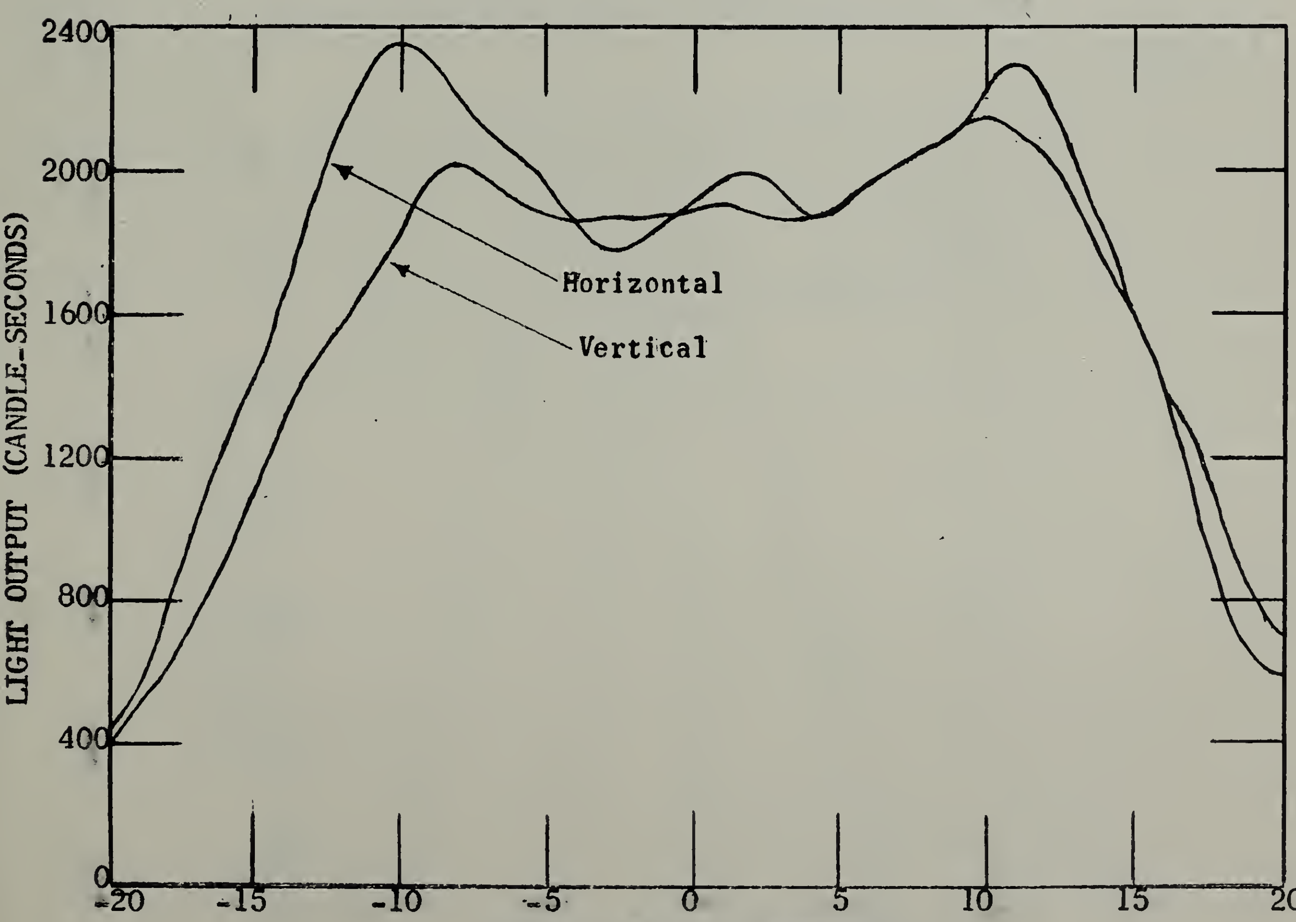
LIGHT OUTPUT DISTRIBUTION OF 20-MICROSECOND CONDENSER-DISCHARGE LIGHT

Figure 2



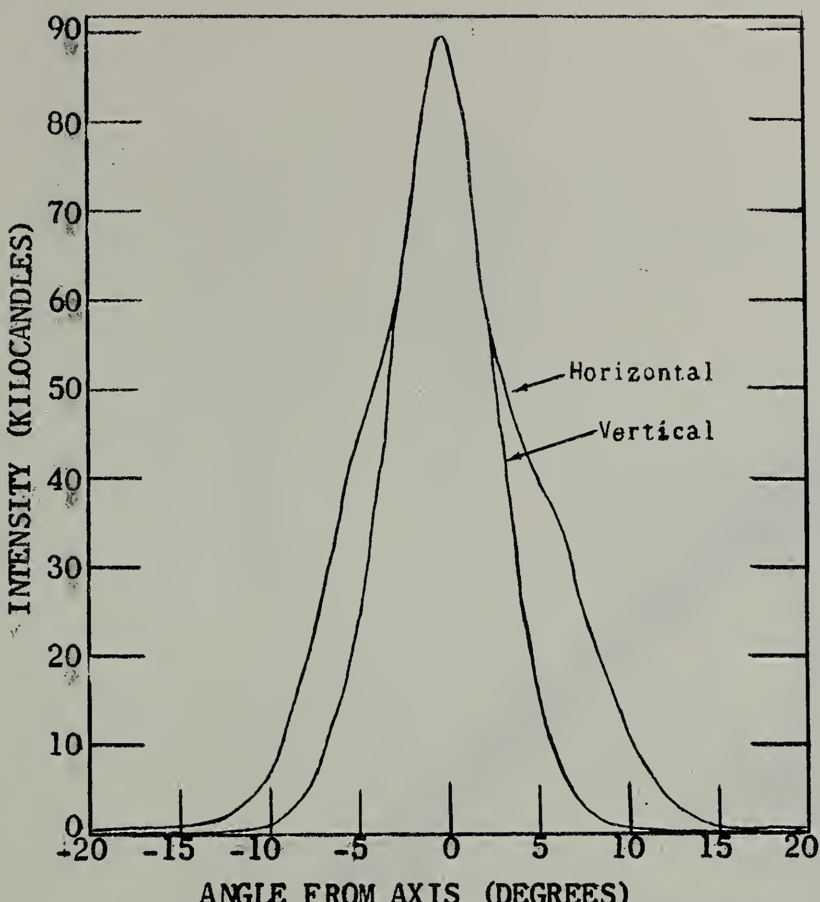
INTENSITY-TIME RELATION OF 200-MICROSECOND CONDENSER-DISCHARGE LIGHT

Figure 3



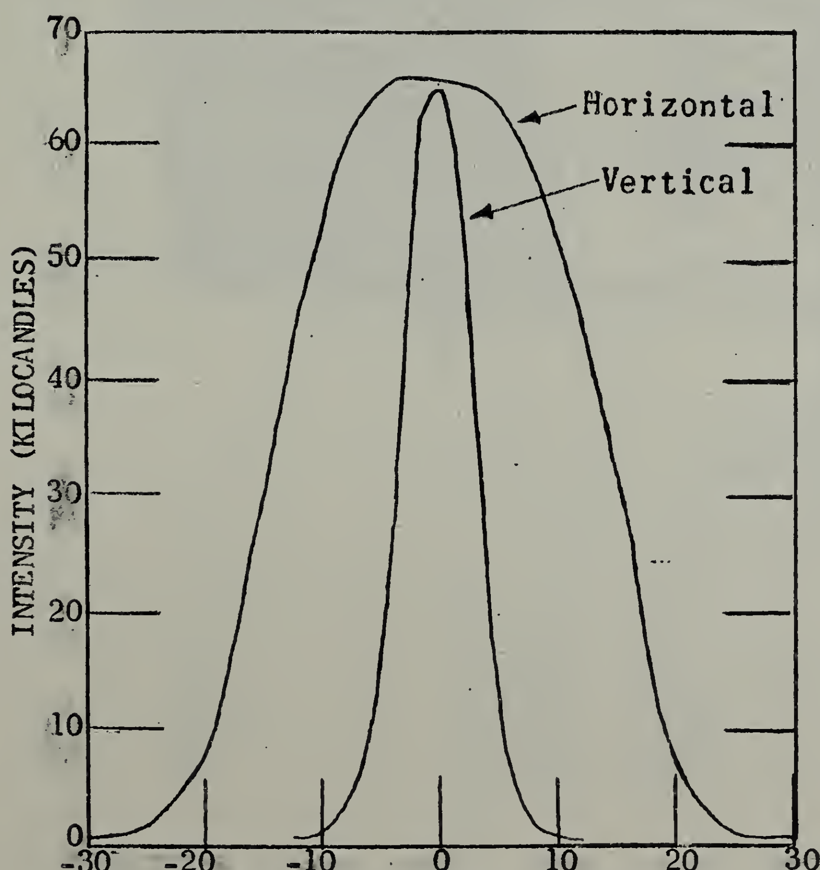
LIGHT OUTPUT DISTRIBUTION OF 200-MICROSECOND CONDENSER-DISCHARGE LIGHT

Figure 4



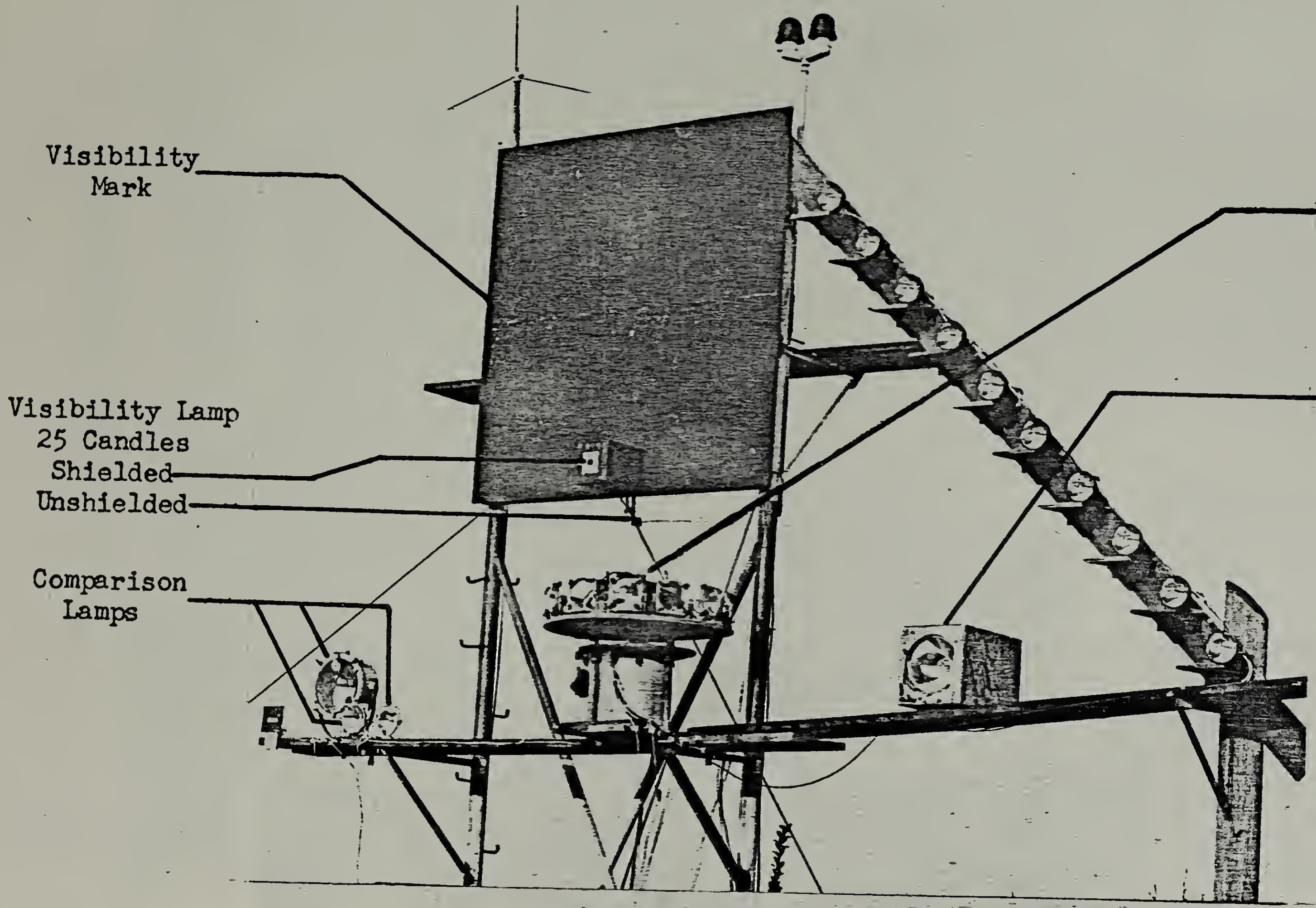
INTENSITY DISTRIBUTIONS OF TYPE 300PAR/SP LAMP

Figure 5



INTENSITY DISTRIBUTIONS OF TYPE 400PAR LAMP

Figure 6



EQUIPMENT AT VISIBILITY TEST SITE

Figure 7

EFFECTIVE INTENSITY OF LIGHT WITH 20-MICROSECOND FLASH DURATION
DAYTIME

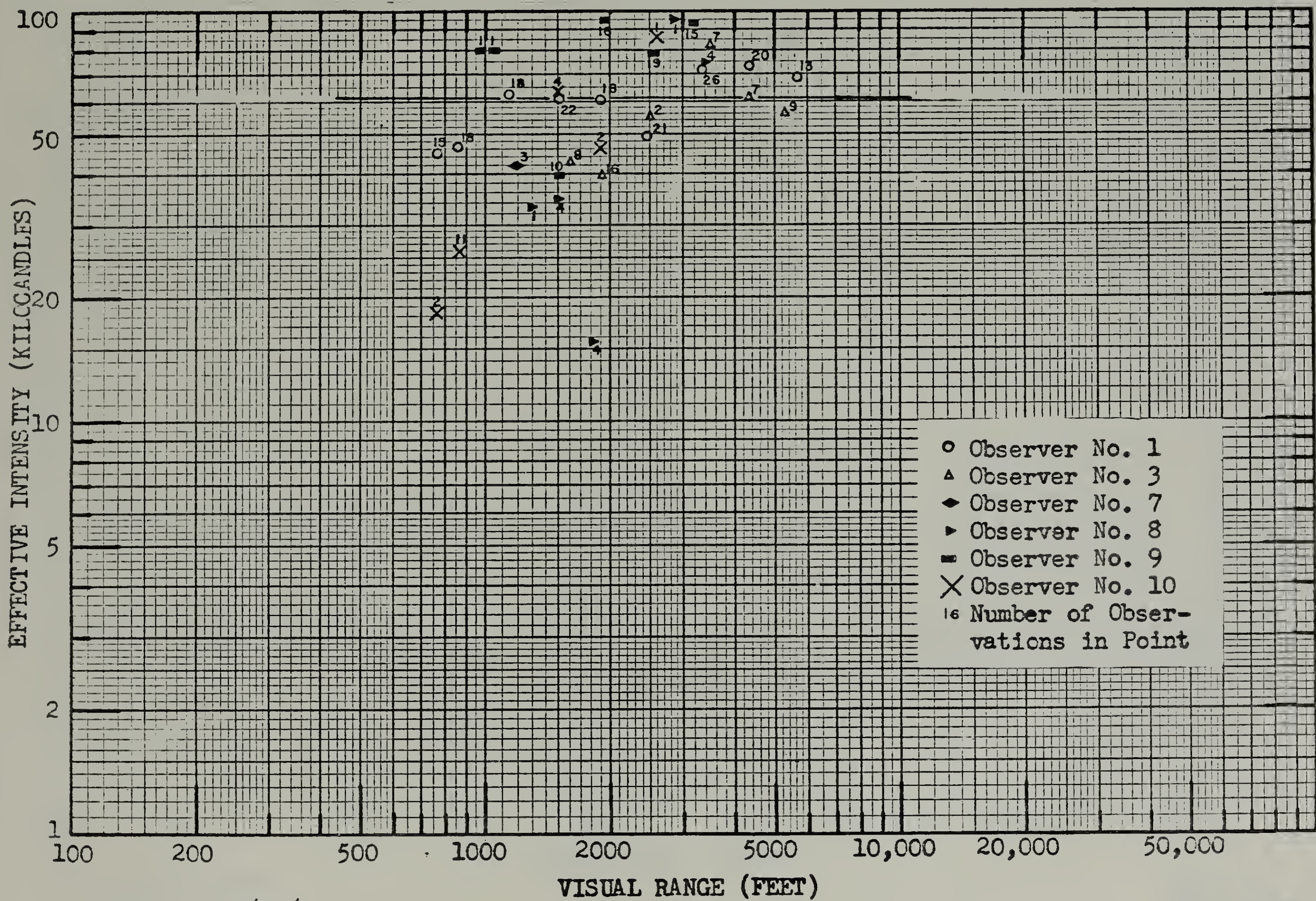


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Figure 8

EFFECTIVE INTENSITY OF LIGHT WITH 20-MICROSECOND FLASH DURATION
NIGHTTIME

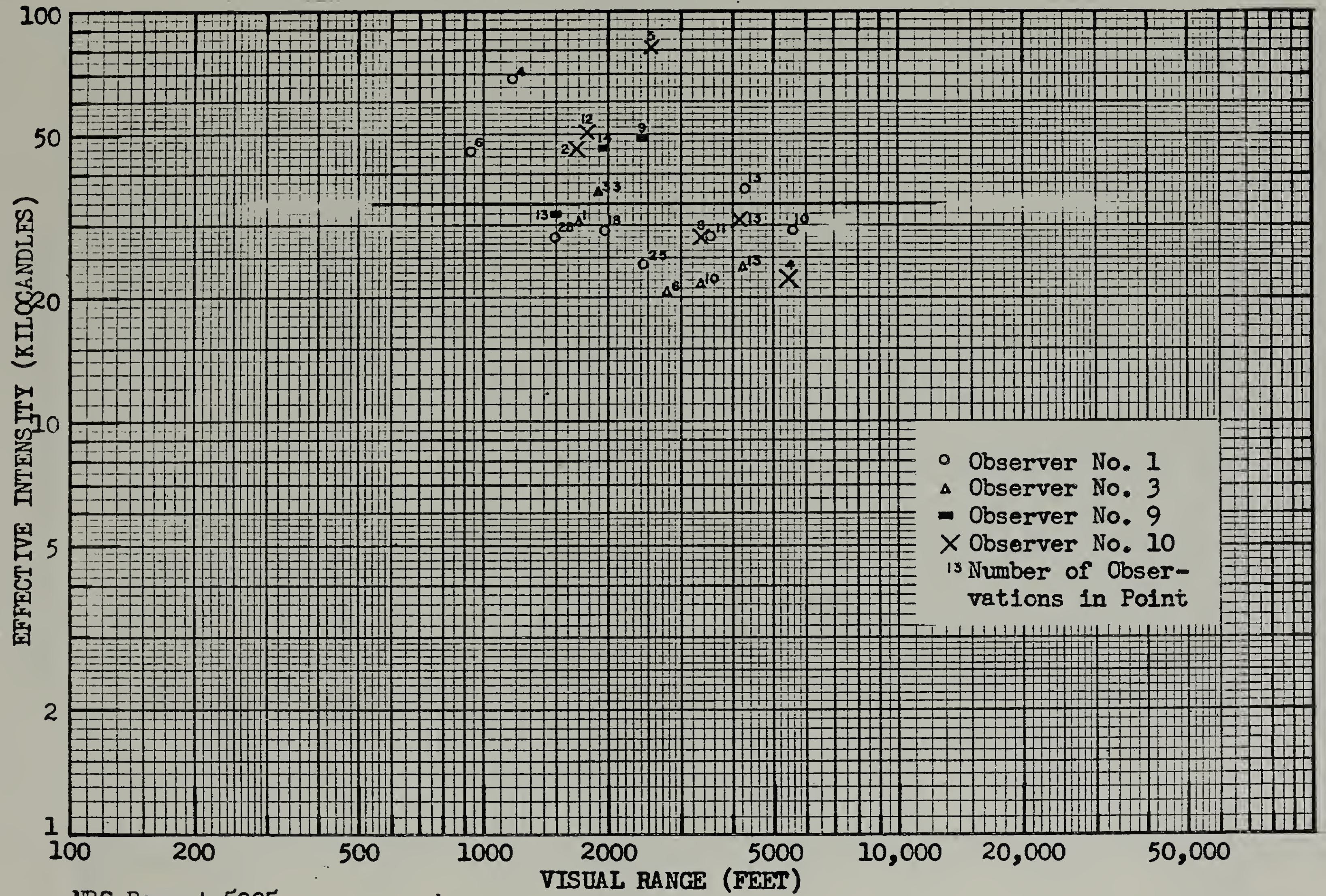

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Figure 9

EFFECTIVE INTENSITY OF LIGHT WITH 200-MICROSECOND FLASH DURATION
DAYTIME

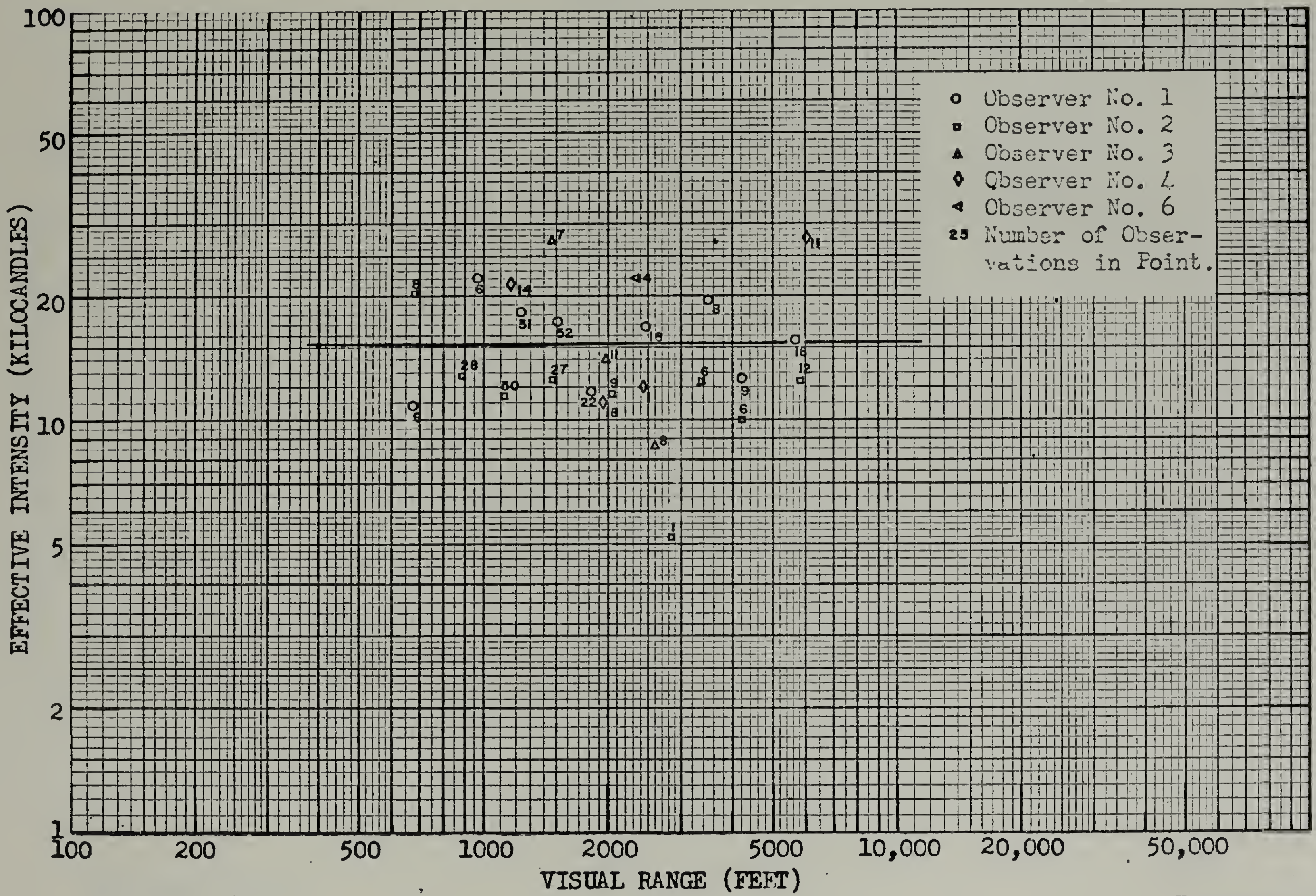

Figure 10

EFFECTIVE INTENSITY OF LIGHT WITH 200-MICROSECOND FLASH DURATION
NIGHTTIME

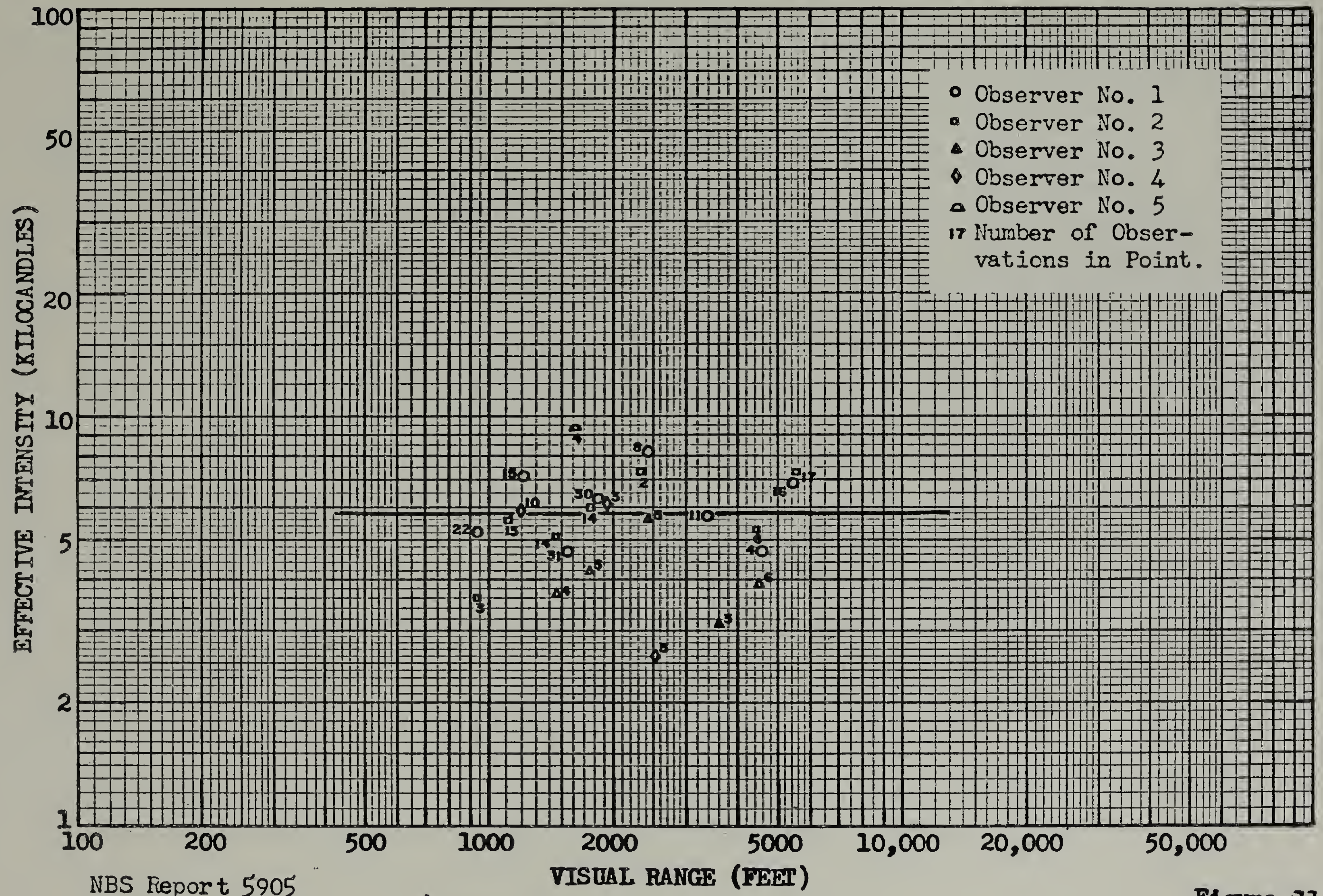

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Figure 11

EFFECTIVE INTENSITY OF LIGHT WITH 0.3-SECOND FLASH DURATION
DAYTIME

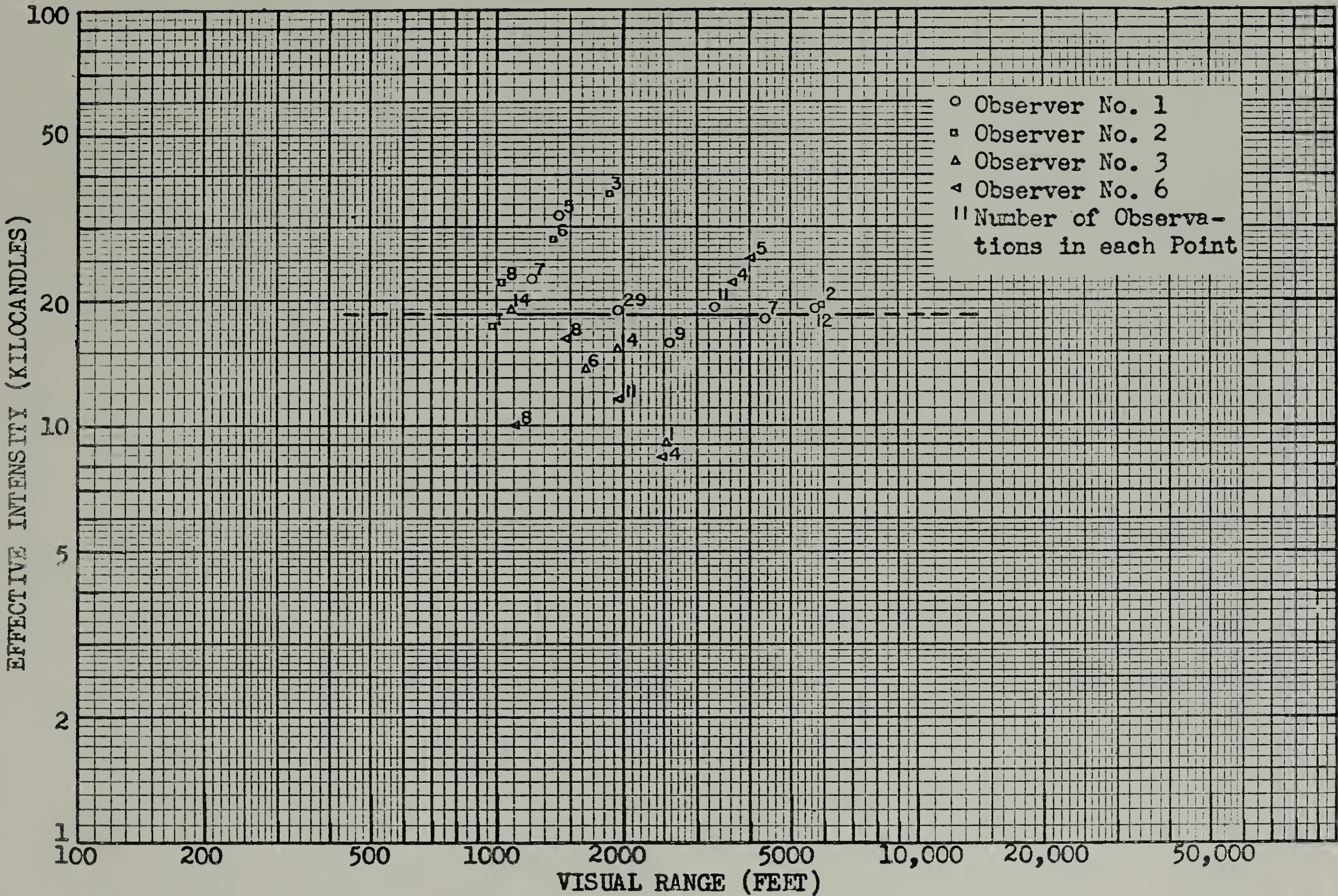

Figure 12

EFFECTIVE INTENSITY OF LIGHT WITH 0.3-SECOND FLASH DURATION

NIGHTTIME

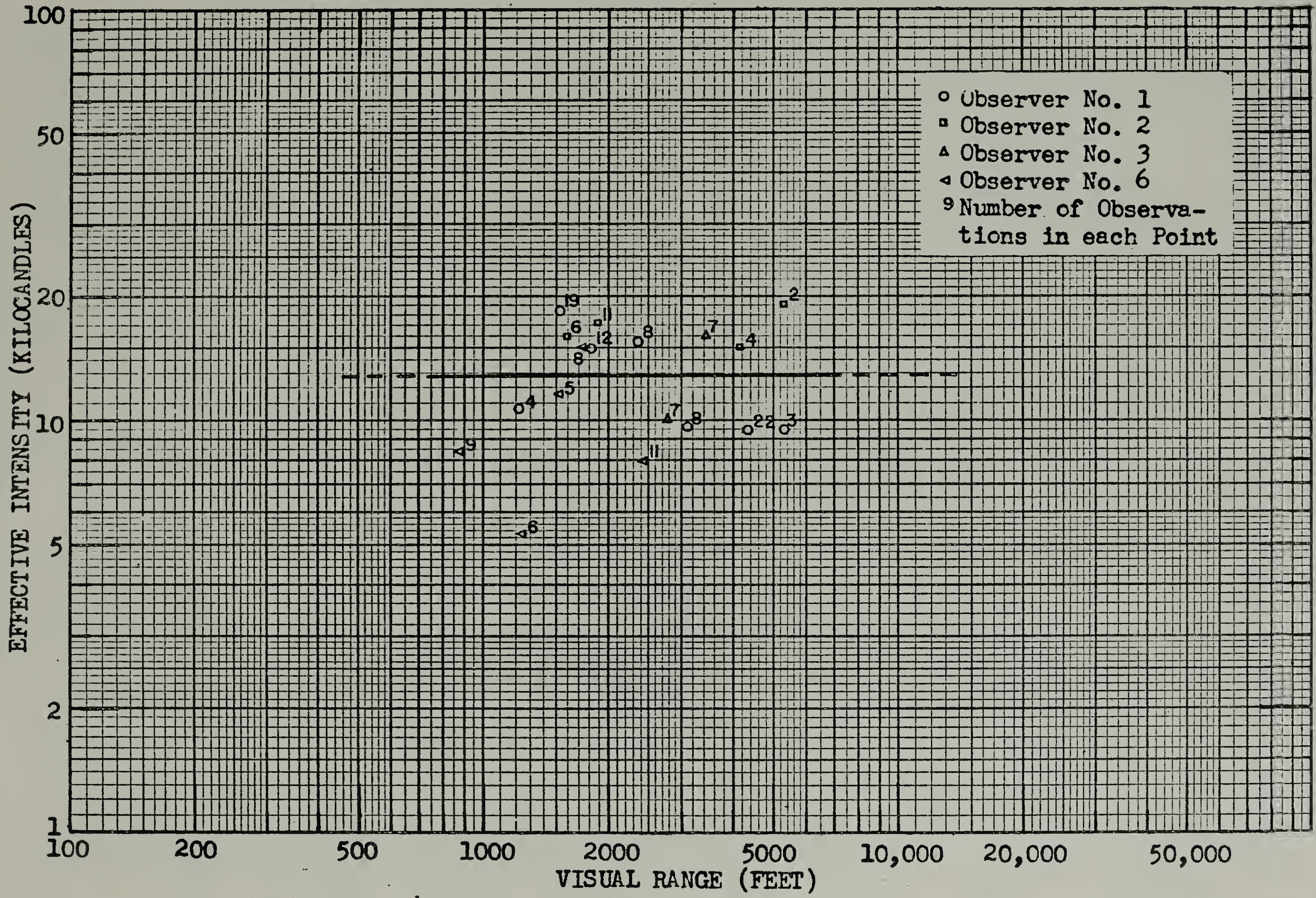

Figure 13

EFFECTIVE INTENSITY OF LIGHT WITH 0.5-SECOND FLASH DURATION
DAYTIME

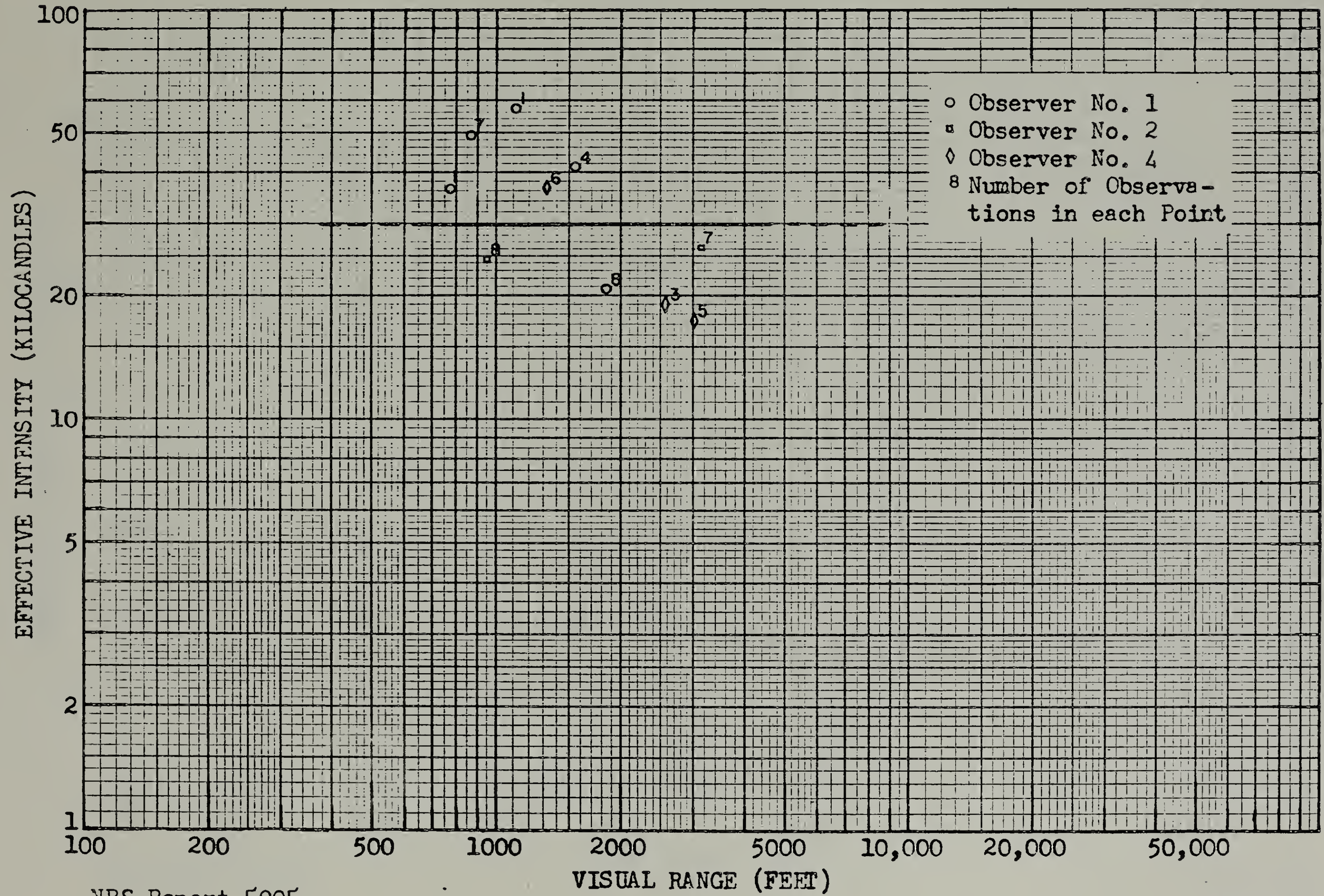

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Figure 14

EFFECTIVE INTENSITY OF LIGHT WITH 0.5-SECOND FLASH DURATION
NIGHTTIME

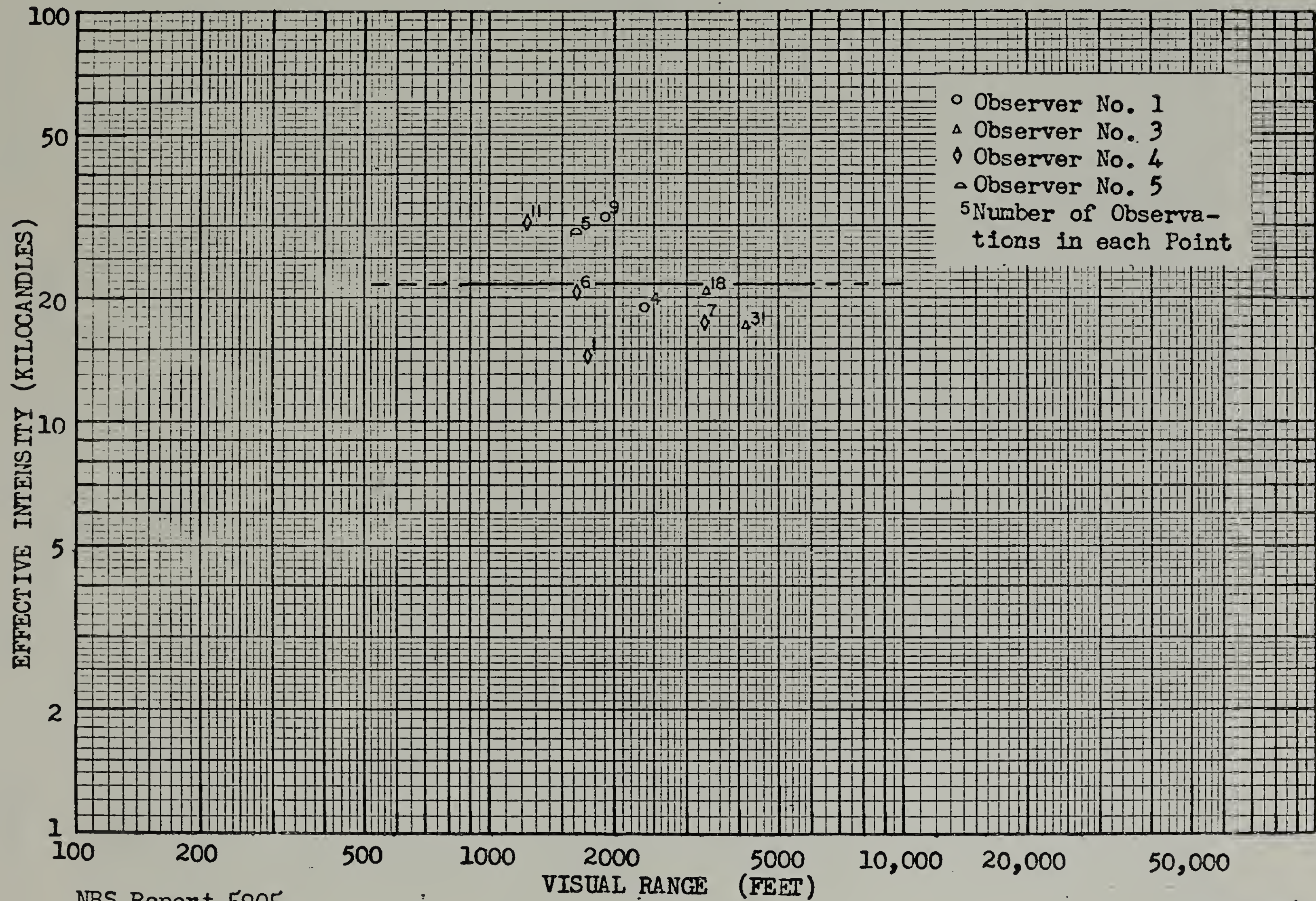

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Figure 15

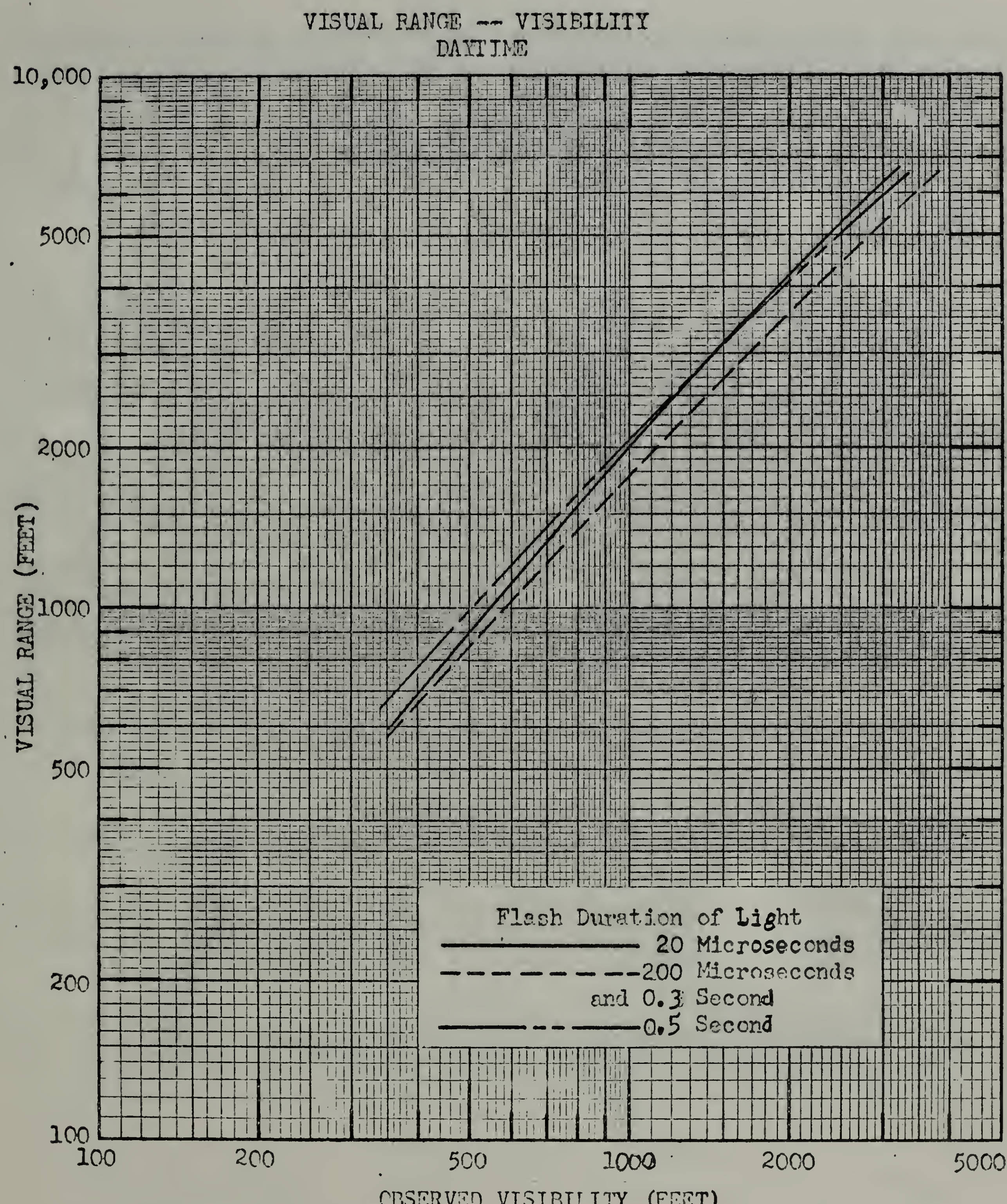

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Figure 16

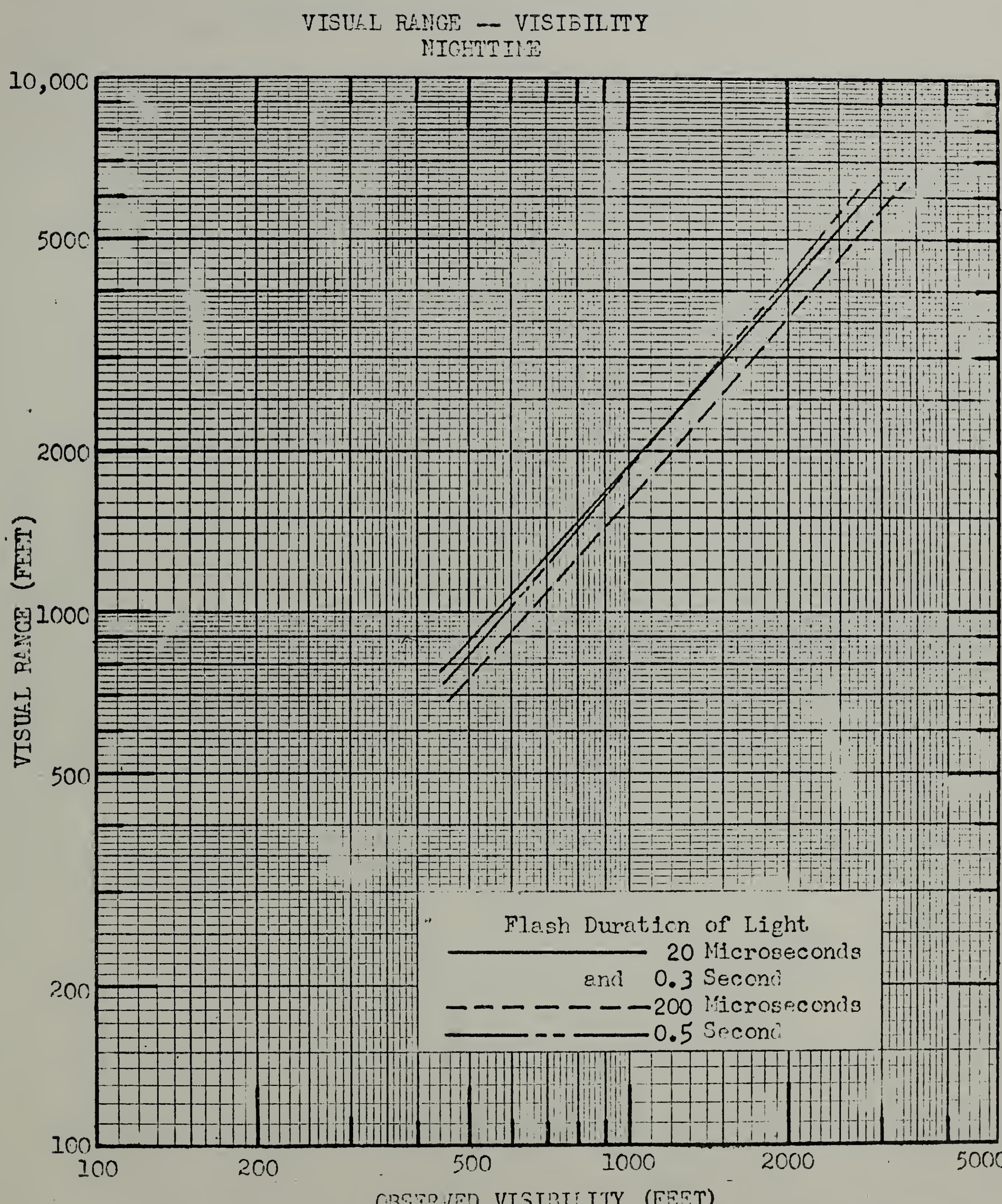
VISUAL RANGE -- VISIBILITY
NIGHTTIME
VISUAL RANGE (FEET)
OBSERVED VISIBILITY (FEET)
10,000
5000
2000
1000
500
200
100
100
200
500
1000
2000
5000
Flash Duration of Light
20 Microseconds
and 0.3 Second
200 Microseconds
0.5 Second

Figure 17

VISUAL RANGE -- INDICATED VISIBILITY
DAYTIME

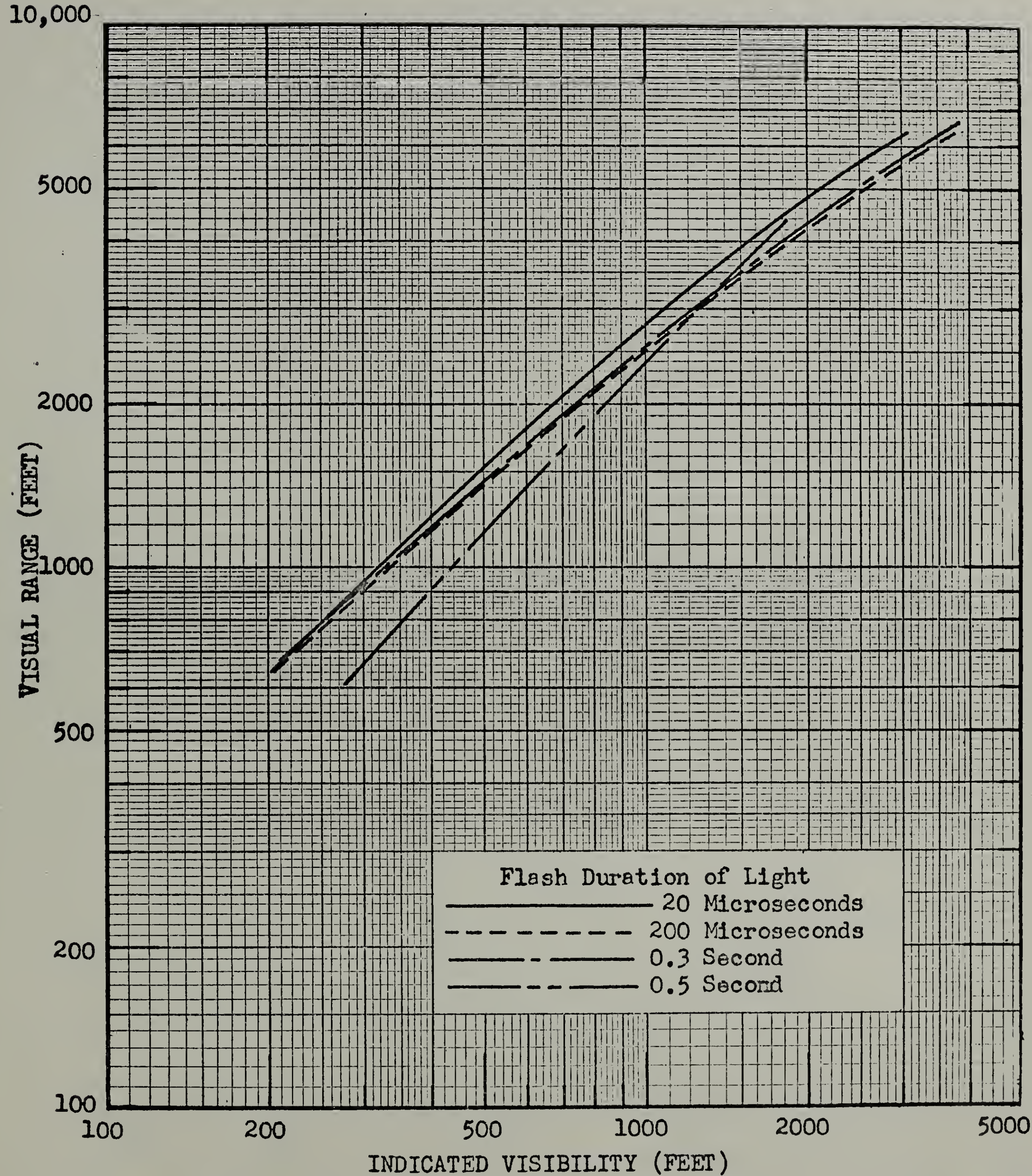

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Figure 18

VISUAL RANGE — INDICATED VISIBILITY
NIGHTTIME

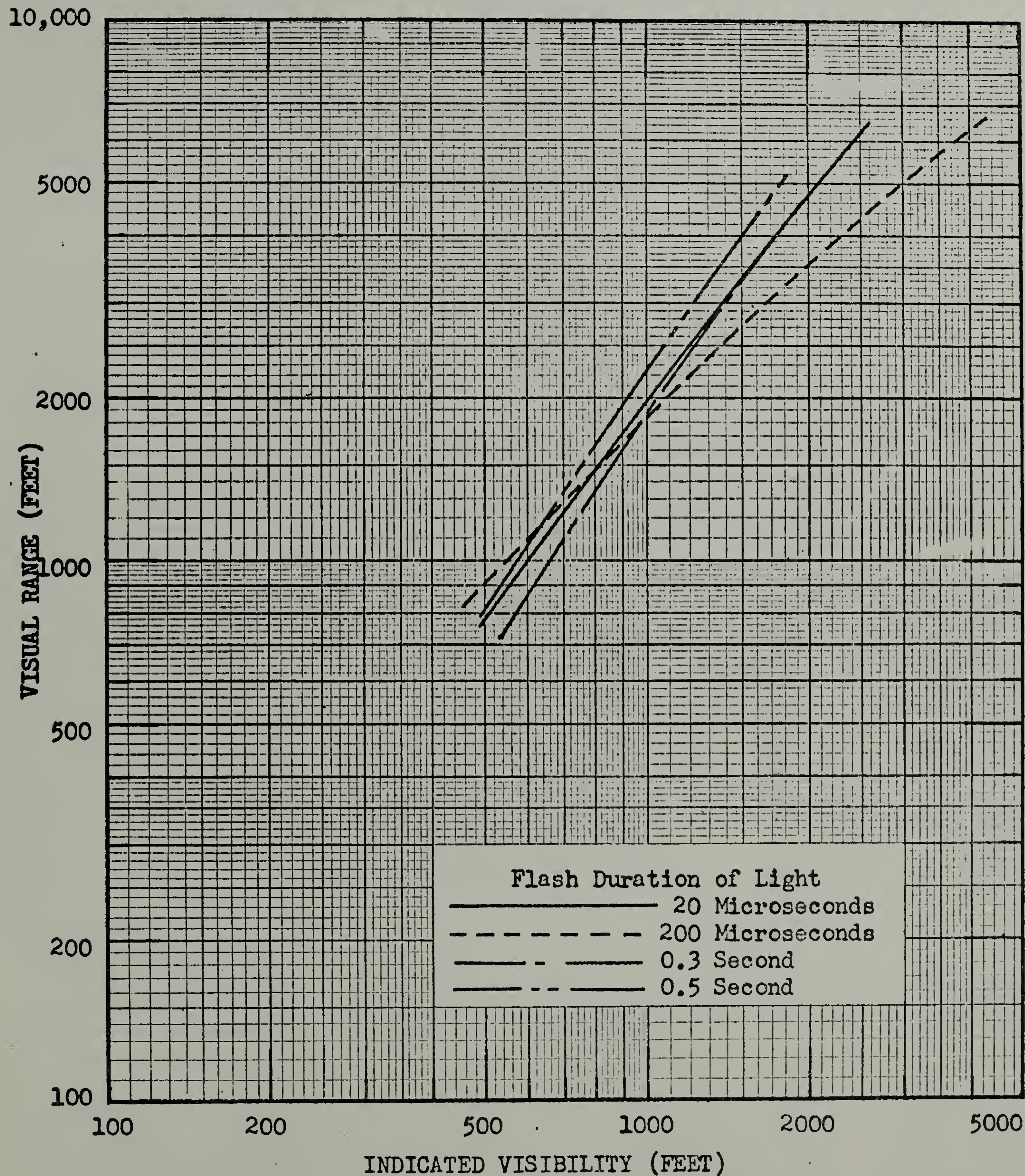

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Figure 19

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

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

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major laboratories in Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside front cover.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.
Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.
Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.
Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment.
Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.
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. 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. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.
Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.
Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog 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. VHF Research.
Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio Meteorology.
Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

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