NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT | **NBS REPORT**

0201-20-2327 | November 1957 | 5644

The Determination of the Effective Intensity of Composite Light Units in Restricted Visibility

By

Visual Landing Aids Field Laboratory
Photometry and Colorimetry Section
Optics and Metrology Division

Project No. TED NBS AE-10011
of the
Ship Installations Division
Bureau of Aeronautics
Department of the Navy
Washington 25, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

The Determination of the Effective Intensity of Composite Light Units in Restricted Visibility

Abstract

This report gives the results of measurements made in fog of the effective intensity of 6- and 10-lamp composite light units. The effective intensity of the lights was determined by finding the intensity of a single light which had the same visual range as the test unit. The observation distances extended over a range of 700 to 6300 feet for both daytime and nighttime conditions. The observations indicate that the "shape" factor developed by de Boer is generally applicable to the computation of effective intensity of composite light units, but at short visual ranges the effective intensity may be higher than that computed from this "shape" factor.

1. INTRODUCTION

One of the standard configurations used in airfield approach-lighting systems is a group of sealed-reflector lamps arranged in a line to form a bar-type unit. The slopeline and Navy composite systems used both 6 and 10 lamps to form the units. In these systems the units are mounted at a 45° angle to the horizontal and perpendicular to the extended axis of the runway. Other systems (for example, the ALPA system) use 5-lamp units mounted horizontally.

In order to determine the guidance to be expected from a lighting unit of this type in restricted visibility conditions, information concerning the visual effectiveness of the light is desirable. It is well known that, when observed at sufficiently great distances, a light unit of this type may be considered as a point source with the intensity being the sum of the intensities in the direction of view of all of the lamps of the light. When a light of this type is observed at sufficiently short distances, the effective intensity of the unit will be approximately that of a single lamp of the unit. Either of these extreme distances may be outside the range for which the approach-light system is most useful.

The importance of considering such factors as the size and shape of the light source when computing its visual range has been demonstrated by Keyern [1] and has been studied in the laboratory by de Boer.[2]

Measurements of the effective intensity of composite units in the region between these limits are therefore important. The cumulative effect of the several lamps will vary with the angular separation of the individual lights and hence with the number of lamps in a unit, and with the distance from which the light is observed; the background brightness; and possibly the scattering

coefficient of the fog. Because of the possible importance of the effect on the effective intensity of the unit of the glow produced by scattered light from the light under test, field measurements 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 analagous 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

A composite bar-type unit consisting of 10 sealed-reflector lamps spaced 18 inches apart was constructed and mounted perpendicular to the direction of observation and at an angle of 45° to the horizontal. The lamps used in the unit were type 400PAR approach-light lamps. These lamps are PAR-56 sealed-reflector lamps with horizontal-spread covers and 400-watt, 115-volt, 100-hour-life filaments. Figure 1 is an isocandle diagram of a lamp of this type.

A 6-lamp bar unit was obtained by energizing six of the lamps of the 10-lamp unit. The spacing between the lamps was then 36 inches, except for the two uppermost lamps which were only 18 inches apart.

The intensity of the 10-lamp unit, as determined with a photoelectric photometer from points along the line of observation, was 500 kilocandles and that of the 6-lamp unit was 340 kilocandles. The average intensity of the lamps in the direction of view was approximately 50 kilocandles and not 70 kilocandles as indicated by figure 1.

4. TEST INSTALLATION AND PROCEDURE

4.1 Visibility Test Site

A visibility test site was established approximately 500 feet from the northern end of the taxiway paralleling runway 31-13 (figure 2). 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 3 is a photograph of the equipment at the test site. Four transmissometers were installed at intervals along the test range to provide recorded measurements of transmission from which the indicated visibility was computed.

Three comparison lights 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 lights were as follows:

1) a projector with a 14-inch aperture, 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-light lamp (Type 4569); and

3) a PAR-46 flashing signal lamp (Type 4521).

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

The composite unit was mounted at the right of the visibility mark. This unit was energized directly from the power line.

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 test unit was just visible. With the test light still burning, 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 it, too, was just visible. The current through the comparison light and the voltage applied to the test light were recorded. The intensity corresponding to the comparison-light current was obtained later from the current-intensity curve for the light. No corrections were made for the effects of changes in the voltage applied to the test light since these effects were small in comparison to the spread of the effective intensity observations. If the atmospheric conditions were sufficiently stable, a number of observations were made and the average current was determined. The 14-inch comparison light was used for nearly all intensity comparisons.

The observer used an automobile to provide sufficient mobility to keep him at the visual range of the test unit as the fog density varied. A minimum of lights was used on the vehicle during nighttime tests in order to maintain the dark adaptation of the observer. A mobile radio set mounted in the vehicle was used to communicate with the test site. 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 high-intensity lamps is less than 6000 feet, the moment-to-moment and point-to-point changes in the fog density are generally large. These variations generally restrict the number of observations 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 was observed periodically during the tests and atmospheric transmittance was measured with the four transmissometers installed along the test range.

4.3.2 Effects of Glow

During daylight conditions the visual range of the lights was relatively easy to determine because glow was not apparent. During night conditions the glow from these lights could generally be detected, by most observers, at distances considerably greater than the distances at which the regularly transmitted light could be seen. The distance the 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 direction toward the observer, 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 observer. If it were possible to block off the line of sight between the observer and the lights 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 test unit. The test range was divided into 12 intervals by a geometric series, the limits of which are given in table 1. The average effective intensity and visual range for each observer for each interval was then obtained. The effective intensity as

a function of visual range is given in figures 4, 5, 6, and 7. The number of observations used in obtaining each point is indicated. The curves shown in the figures were obtained by fitting by eye a curve through the arithmetic averages of all the effective intensity - visual range observations in each test distance interval. The curves were drawn so that for a test distance of 100 feet the effective intensity would approach that of a single lamp (50 kilocandles) and for a test distance of 100,000 feet the effective intensity would approach the sum of the intensities of all lamps in the unit. The extrapolated sections of the curves are indicated by broken lines. Note that the results for individual observers differ considerably from the average results. In some cases effective intensities were obtained that are considerably below the intensity of a single lamp of the type used in the units. The low-intensity results were investigated but the reason for these low values could not be determined.

The comparison lights can not be considered as point sources when observed from distances used in this study. Therefore, the effective intensities obtained are somewhat a function of the angular size of the comparison light. In order to obtain a measure of the effective intensity of the composite unit which is independent of the angular size of the comparison light, it is necessary to reduce the effective intensities to the equivalent point-source intensities, that is, the intensity of a point source having the same visual range.

Kevern(1) and de Boer (2) have computed size factors for lights of circular cross section, using the Tiffany Foundation data reported by Blackwell(3). In computing this size factor, de Boer presumably used the data of Part I of Blackwell's paper.

The size factors given by de Boer were used to compute the equivalent point-source intensity of the 14-inch comparison light for background brightnesses of 0.001 and 550 footlamberts, which are the brightnesses representative of the nighttime and daylight conditions. The computed size factors as functions of the visual range of the 14-inch comparison lights are shown in figure 8a. Size factors for this light computed from the data given in Part III of Blackwell's paper are shown in figure 8b.

The computed equivalent point-source intensities as a function of visual range are shown in figure 9. The equivalent point-source intensities for the figure were obtained by applying both sets of size factors from figure 8 to effective intensities read from the curves of figures 4 to 7 and fitting curves to the points so obtained by eye. The data obtained from the extrapolations are indicated by broken lines.

Knowledge of the visual range and effective intensity of the test lights as a function of visibility is often useful. Visibility observations were made periodically throughout the tests, but sampling errors, especially those created by the bluff near the visibility marks, made these results questionable. Since the visual range of the composite unit is generally more than twice the visibility, a small localized area of non-representative fog near the visibility test site had a significantly greater effect on the visibility than on the visual range of the light under test. Therefore the indicated visibility for each observation was determined from the transmissometer readings.

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 obtained from this average transmission from the usual transmission-visibility conversion curves. The visual range of the composite lights as a function of the indicated visibility is shown in figure 10. The effective intensity as a function of indicated visibility is given in figure 11.

6. ANALYSIS OF RESULTS

As indicated by figure 10, there is very little difference between the visual range of the 6- and the 10-lamp units at night for a given visibility and at the lower ranges for daylight conditions the difference is small. When the visual range is sufficiently short, the effective intensity of both the 6- and 10-lamp units is expected to approach the intensity of a single lamp. Under these conditions little, if any, difference in visual range would be expected by day or by night. At night, when the visual range of the test units is less than 6000 feet, the atmospheric transmittance is so low that a change in the intensity of either unit by a factor of two would produce a change in the visual range of less than 5%. Hence the expected difference in the visual range of the two units is less than the experimental error in the visual range determinations and the difference in the visual ranges of the units is not measurable (although the difference in effective intensity is measurable). Since the brightness of the glow surrounding the 10-lamp unit was higher than that surrounding the 6-lamp unit, the threshold of the observer viewing the 10-lamp unit could be higher than that of the observer viewing the 6-lamp unit. This would decrease the difference in the visual ranges.

In daylight the visual range of the 10-lamp unit was about 10% greater than that of the 6-lamp unit when the visibility was 2500 feet and the difference increased as the visibility increased. In daylight the atmospheric transmittance corresponding to a given visual range is considerably higher than at night, and a given change in intensity will produce a greater change in visual range. Hence, as indicated by figure 10, the visual range

for a given visibility of the 10-lamp unit was measurably greater than that of the 6-lamp unit when the visual range was greater than about 1500 feet.

De Boer(2) studied in the laboratory the effects of the size and shape of lights of essentially uniform brightness on the equivalent point-source intensity and the effects of the spacing of the lamps in composite sources, similar to the composite unit. From these studies de Boer developed "size", "shape", and "row" factors for obtaining the equivalent point-source intensity. He found that with background brightnesses of 10 and 300 candles per square meter (3 and 90 footlamberts) the eye illumination required to perceive a rectangular composite source with a distance between lamp centers less than twice the diameter of the lamps was substantially equal to that required for a rectangle of uniform brightness and of the same over-all dimensions producing the same illumination. The "shape" factor for a composite source having closely spaced lamps is, therefore, a function only of the angular dimensions of this source and the background brightness. The equivalent point-source intensities of rectangular sources of uniform brightness which have the dimensions of and which provide the same illuminations as do the 6- and 10-lamp composite lights were computed from de Boer's "shape" factor for several visual ranges assuming a background brightness of 300 candles per square meter (90 footlamberts). The results of these computations are shown as the individual points on figure 9.

At visual ranges of 5000 feet or more, the equivalent point-source intensities as determined by de Boer's "shape" factor are in good agreement with test results. The agreement is better when the "size" factors used for correcting for the size of the comparison lamp are computed from Part III of Blackwell's paper instead of the factors obtained from de Boer's paper. For visual ranges less than 2000 feet the agreement of the equivalent point-source intensities computed from de Boer's "shape" factor and the test results are less satisfactory. The equivalent point-source intensities obtained by applying "size" factors computed from Part III of Blackwell's paper to the daylight observations are in fair agreement with the equivalent point-source intensities determined from de Boer's "shape" factor.

De Boer presumably obtained his size factors from Part I of Blackwell's paper. A six-second exposure was used to obtain the threshold data reported in this section of the paper. Blackwell found that an exposure of this length was too short to obtain minimal thresholds. The observational procedure used in obtaining the thresholds reported in Section III was such that the thresholds obtained were minimal and thus represent very long exposure times. Apparently the latter data are more representative of field conditions and should be used in computing the equivalent point-source intensities of lights which are not point sources. Note that these remarks apply to daylight conditions only. The differences between the two sets of size factors for nighttime conditions are not significant unless the angular size of the light is more than one degree.

De Boer developed a "row" factor, which is a measure of the "mutual assistance" of the lights in the row, to apply to composite sources in which the distance between lamps is so great that the light cannot be considered as a simple rectangular unit of uniform brightness. If the composite unit is considered as a group of individual sources, each assisted by the adjacent lamps, the effective intensity of the unit will then be the intensity of a single lamp plus the "assistance" of the adjacent lamps and may be computed by means of de Boer's "row" factor. The equivalent point-source intensities for daylight conditions were computed from this "row" factor by applying his "size" factor correction to the PAR-56 lamps. The intensities are 56,000 candles for the 10-lamp unit and 38,000 candles for the 6-lamp unit when the visual range of the units is 500 feet and 125,000 candles and 80,000 candles for the 10- and 6-lamp units, respectively, when the visual range of the units is 1500 feet. If the "size" factors given by the daytime curve of figure 8b had been used, the equivalent point-source intensities as shown on figure 9b would have been greater than those given above.

These intensities are considerably greater than those obtained experimentally (see figure 9). This difference in intensities may be caused in part by the difference in the length of the sources. De Boer used a row subtending an angle of 10° while the angle subtended by the composite unit was 97 minutes when observed at a distance of 500 feet and 36 minutes when observed at a distance of 1500 feet. However, the differences in intensities appear to be too great to be only the result of differences in length of source. De Boer's data indicates that if a row of PAR-56 lamps is observed at a distance of 500 feet, the spacing between the lamp centers must be 39 feet before the "mutual assistance" between the lamps stops. "Mutual assistance" when the separation is this large seems unlikely.

7. CONCLUSIONS

As was expected, the effective intensity of a composite light source increased as the visual range of the unit increased, and this increase was more rapid for nighttime than for daytime. When the visual range of the composite unit was about 2500 feet, the ratio of the effective intensity of the light to the intensity of a single lamp in the unit was approximately 2.2 for the 10-lamp unit in daytime conditions, 1.2 for the 6-lamp unit in daytime conditions, 1.9 for the 10-lamp unit in nighttime conditions, and 1.1 for the 6-lamp unit in nighttime conditions; but at about 6000 feet the ratios were respectively, 2.7, 1.4, 2.7 and 1.4.

When the visual range of the composite unit was within the region of the visual ranges representative of service conditions, the ratio of the effective intensities of the 10-lamp unit to the 6-lamp unit was approximately equal to the ratio of the number of lamps in the units. For lamp spacings that are

typical of those used in service, the effective intensity of a composite unit may be considered proportional to the number of lamps in the unit.

In daytime the visual range of the 10-lamp unit was approximately three times object visibility when the visibility was in the range of 300 to 2000 feet. The visual range of the 6-lamp unit decreased from approximately 3 to 2.6 times object visibility as this visibility increased from 300 to 2000 feet.

At night the visual range of both lights was approximately twice the visibility of 25-candle lights when visibility was in the range of 500 to 2000 feet.

For daylight conditions the "shape" factor developed by de Boer provides a satisfactory means of determining the equivalent point-source intensity of composite light units. The equivalent point-source intensities provide a more accurate measure of the performance of composite units than the intensity of a single lamp of the unit or the sum of the intensities of all lamps of the unit provide. An extension of de Boer's shape-factor data to lower levels of background brightness is very desirable.

References

1. G. M. Kevern, Effect of Source Size Upon Approach Light Performance, Ill. Eng. 45, 96 (1950).

2. J. B. de Boer, Visibility of Approach and Runway Lights, Philips Research Report 6 (1951).

3. H. R. Blackwell, Contrast Threshold of the Human Eye, JOSA 36, 11 (1946).

Table I

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

Interval No.	Interval Limits (Feet)	Interval No.	Interval Limits (Feet)
1	700 - 849	7	2100 - 2499
2	850 - 999	8	2500 - 2999
3	1000 - 1199	9	3000 - 3599
4	1200 - 1449	10	3600 - 4349
5	1450 - 1749	11	4350 - 5199
6	1750 - 2099	12	5200 - 6300

CANDLEPOWER DISTRIBUTION
400PAR APPROACH-LIGHT LAMP

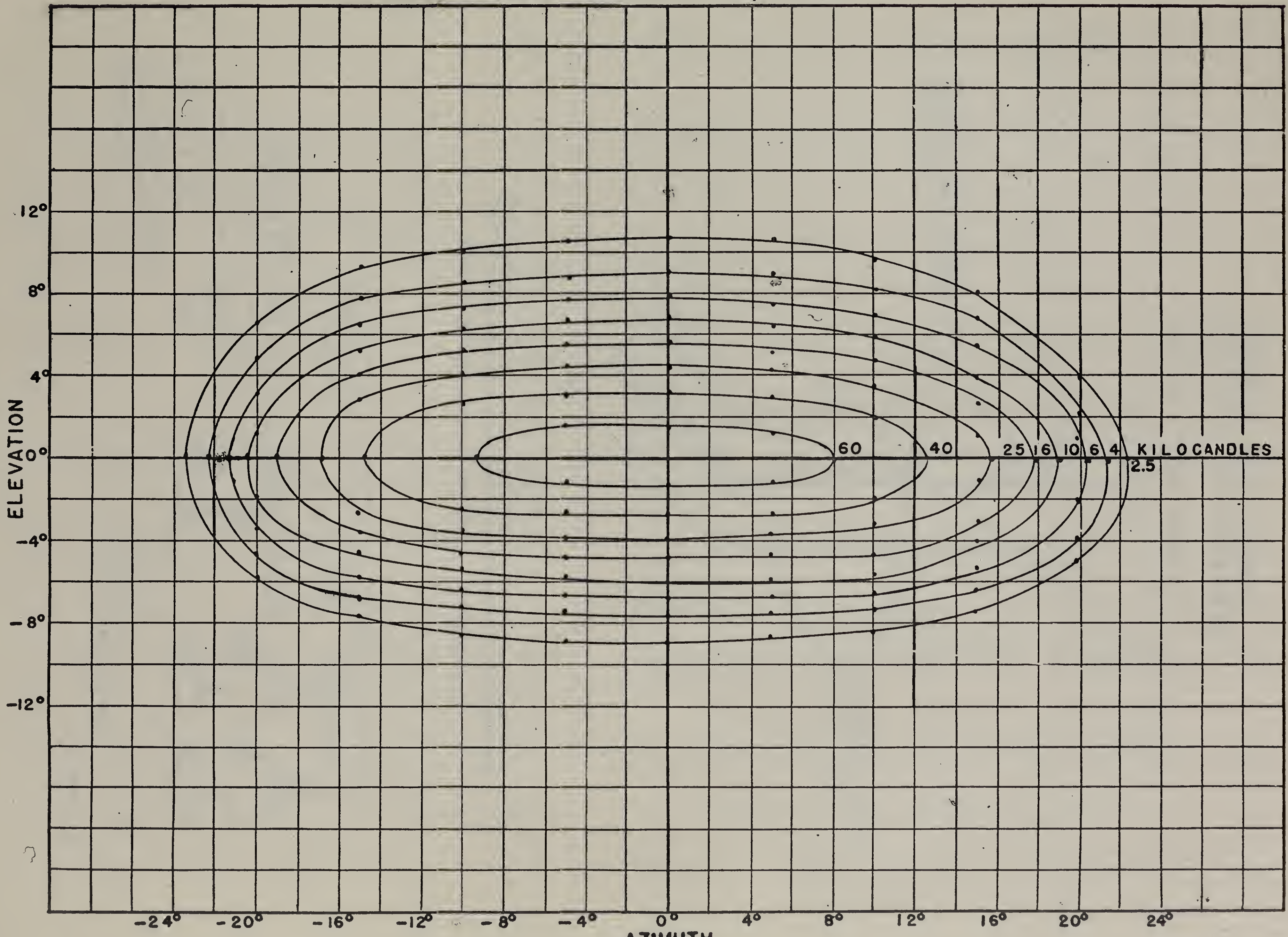


Figure 1

VISUAL TEST RANGE
SCHEMATIC ARRANGEMENT

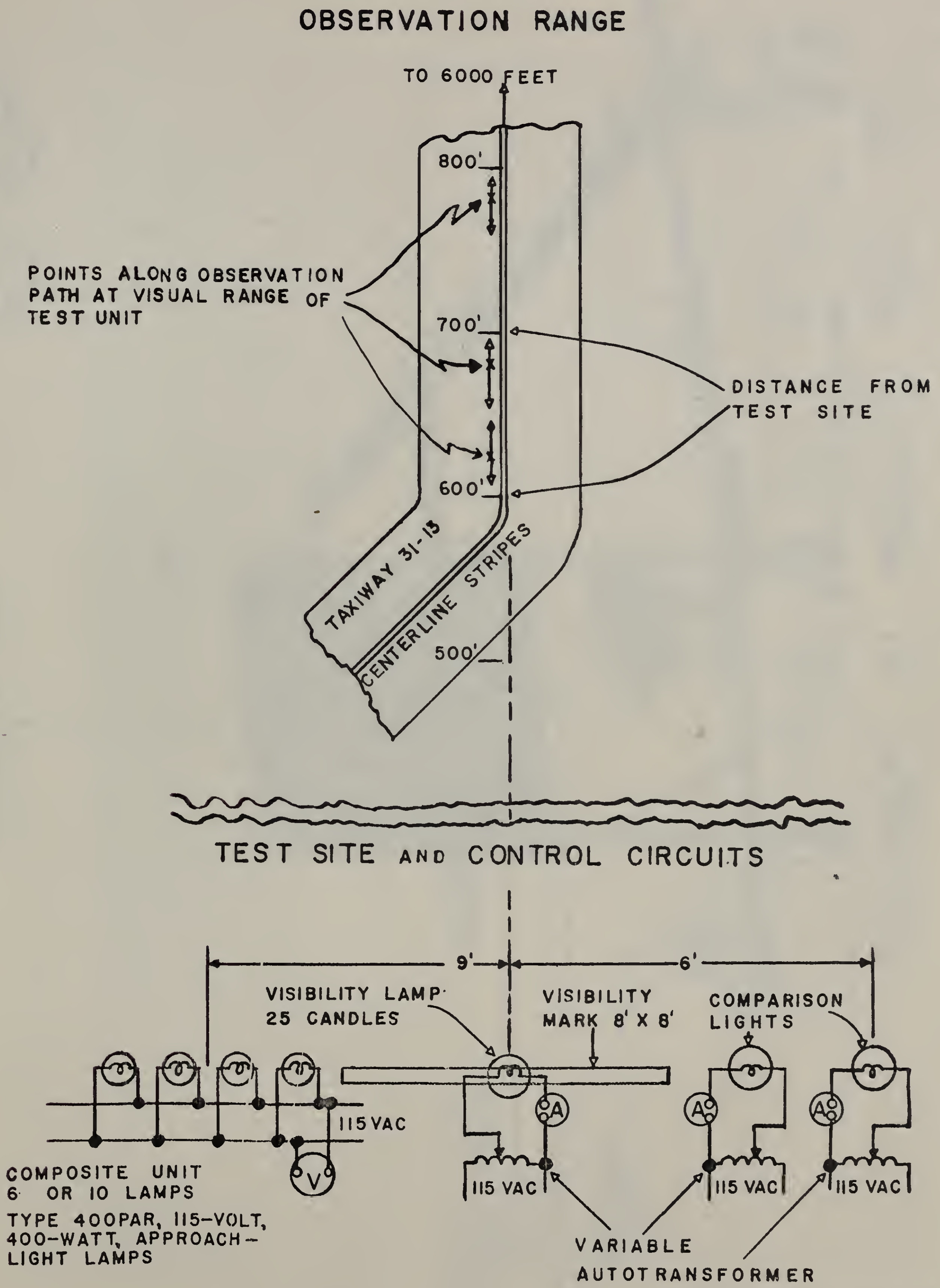
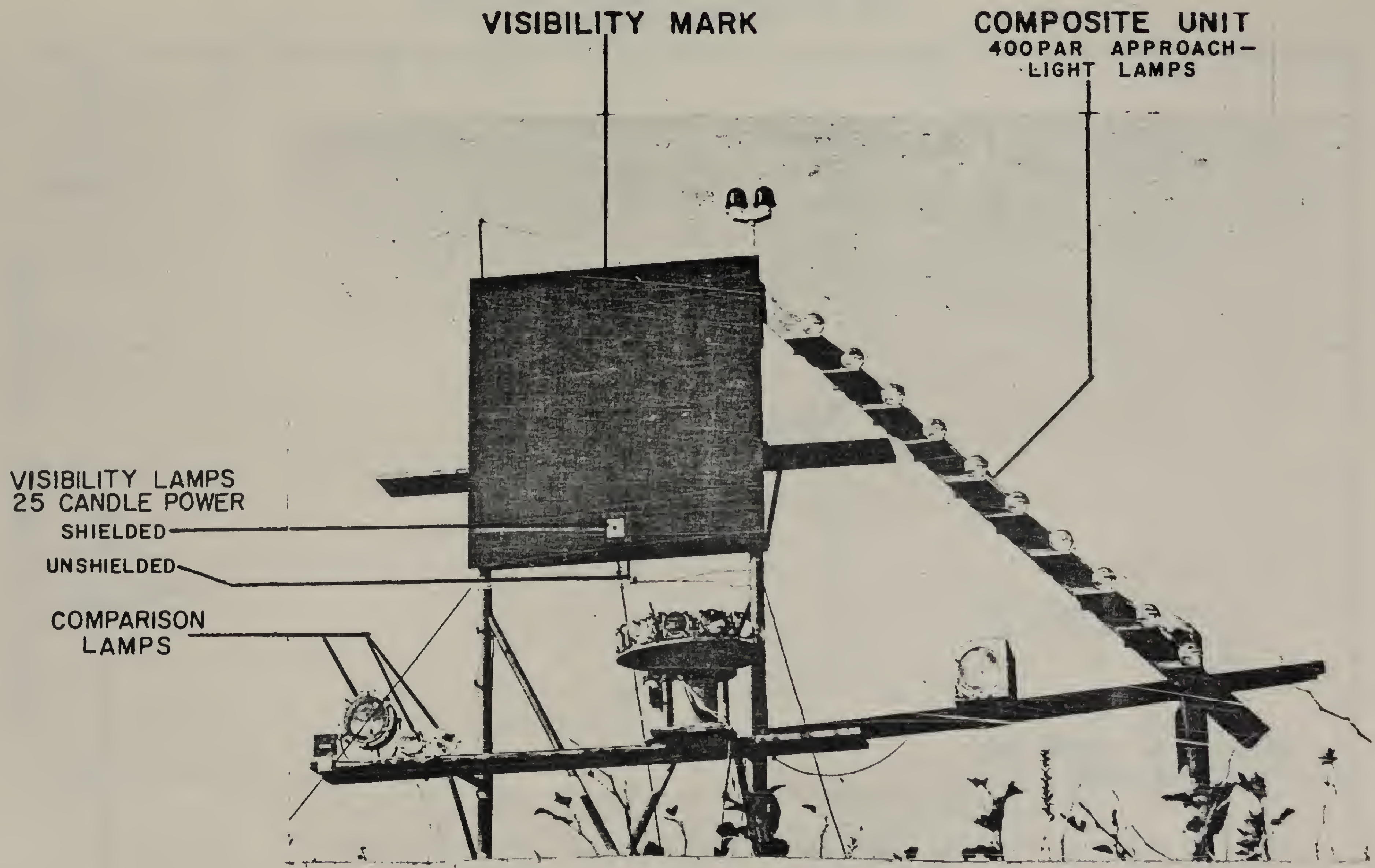


Figure 2



EQUIPMENT AT VISIBILITY TEST SITE

Figure 3

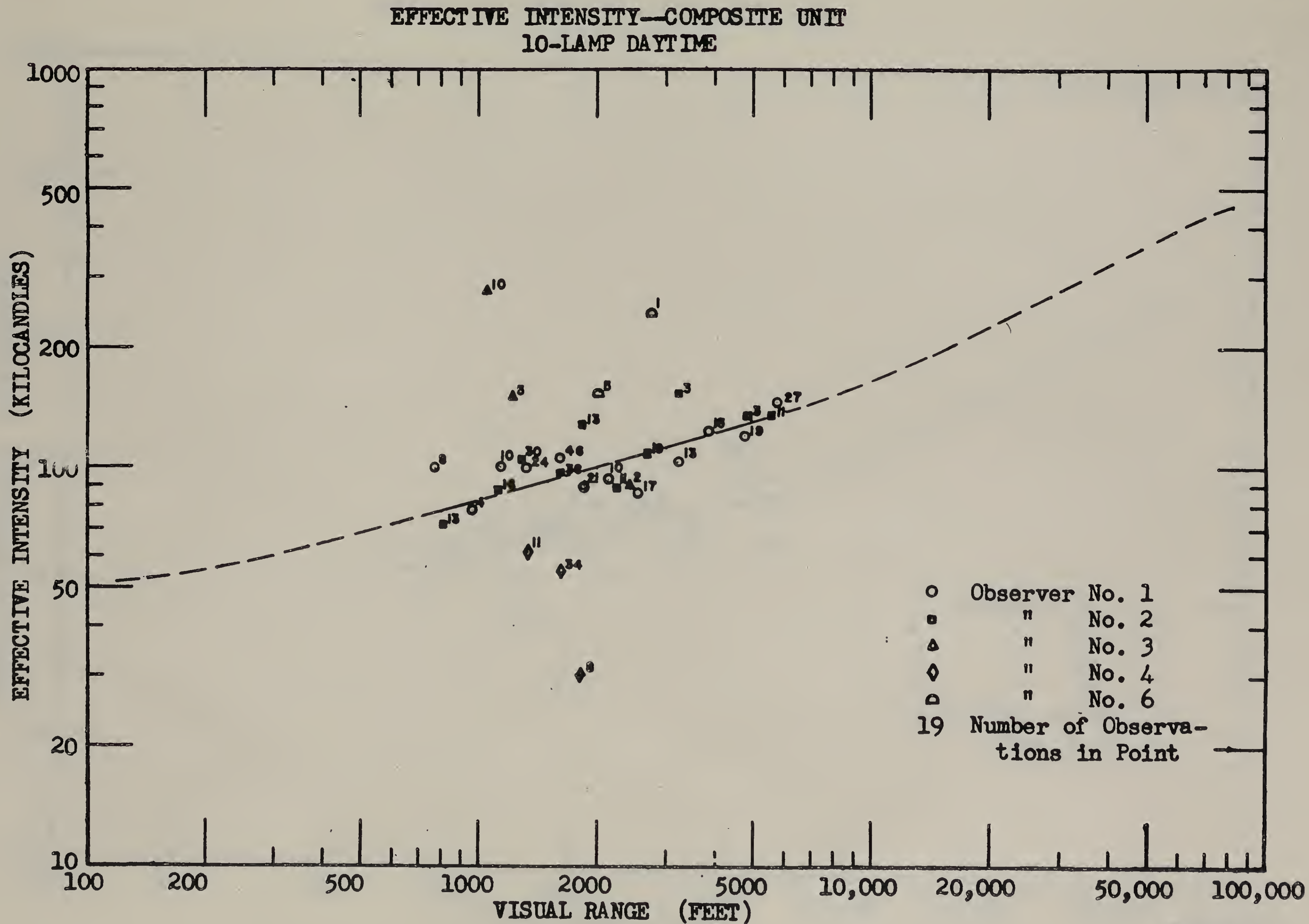

EFFECTIVE INTENSITY—COMPOSITE UNIT
10-LAMP DAYTIME
EFFECTIVE INTENSITY (KILOCANDLES)
VISUAL RANGE (FEET)
1000
500
200
100
50
20
10
100
200
500
1000
2000
5000
10,000
20,000
50,000
100,000
Observer No. 1
" No. 2
" No. 3
" No. 4
" No. 6
19 Number of Observations in Point

Figure 4

EFFECTIVE INTENSITY--COMPOSITE UNIT
6-LAMP DAYTIME

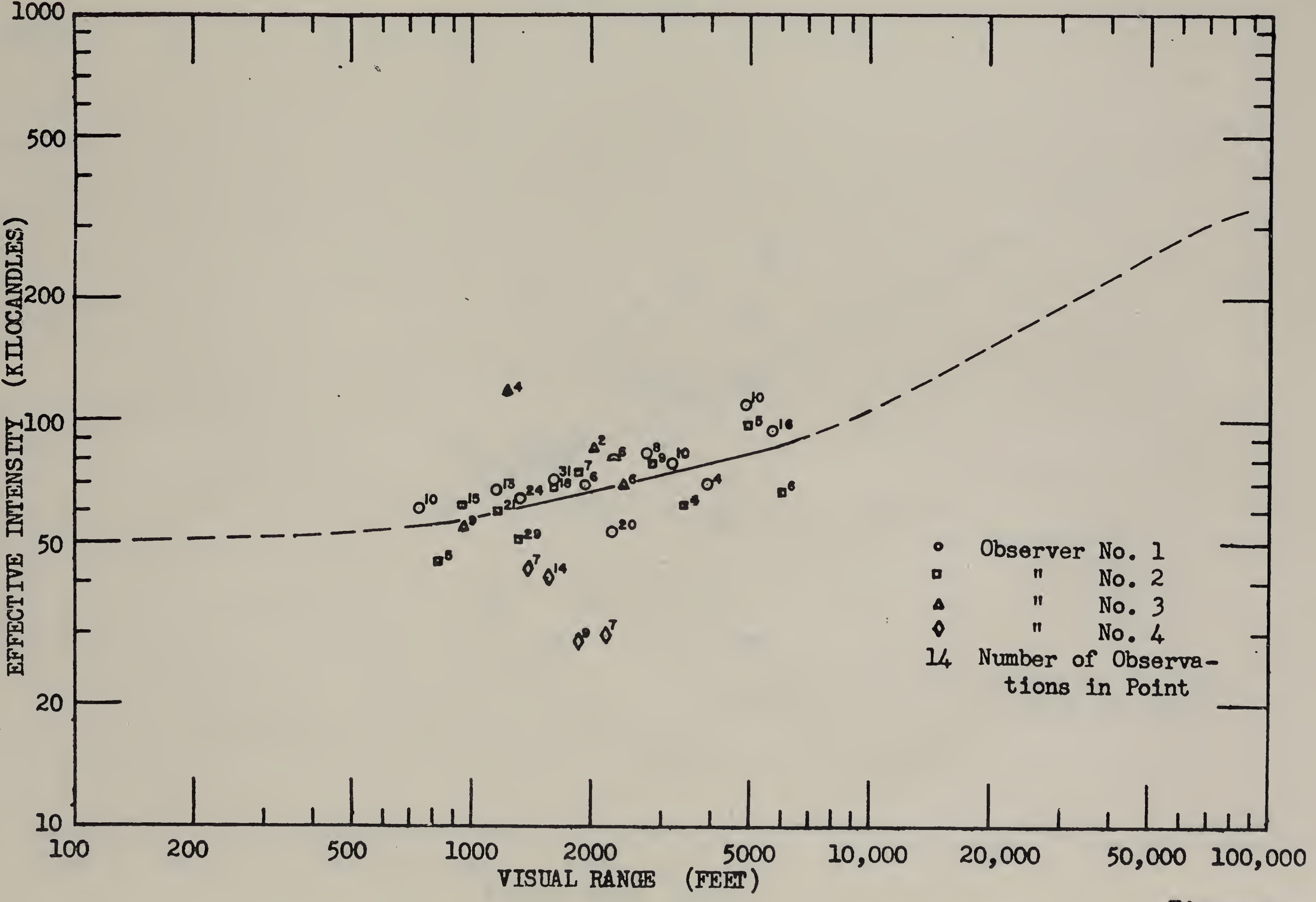


Figure 5

EFFECTIVE INTENSITY--COMPOSITE UNIT
10-LAMP NIGHTTIME

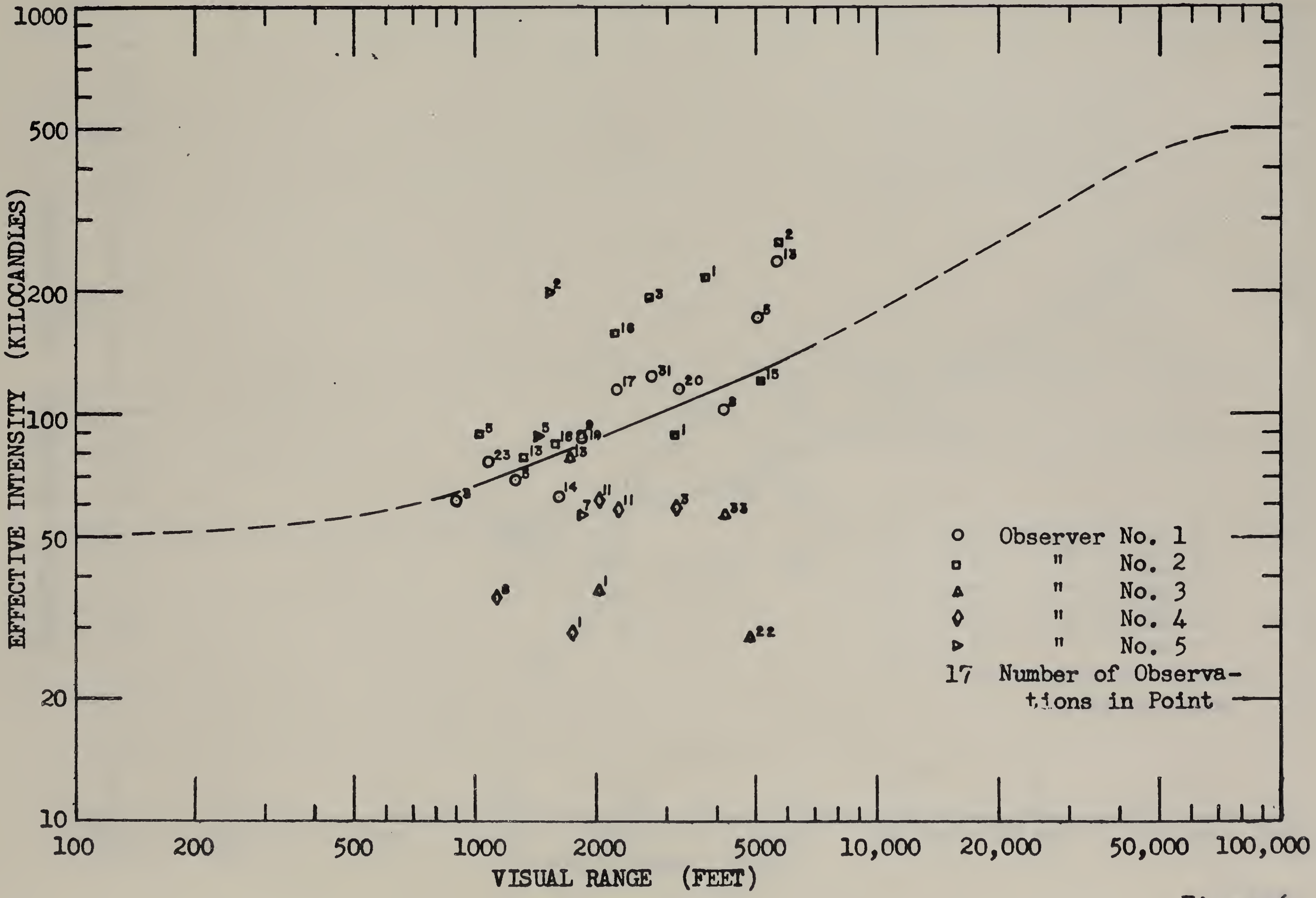


Figure 6

EFFECTIVE INTENSITY--COMPOSITE UNIT
6-LAMP NIGHTTIME

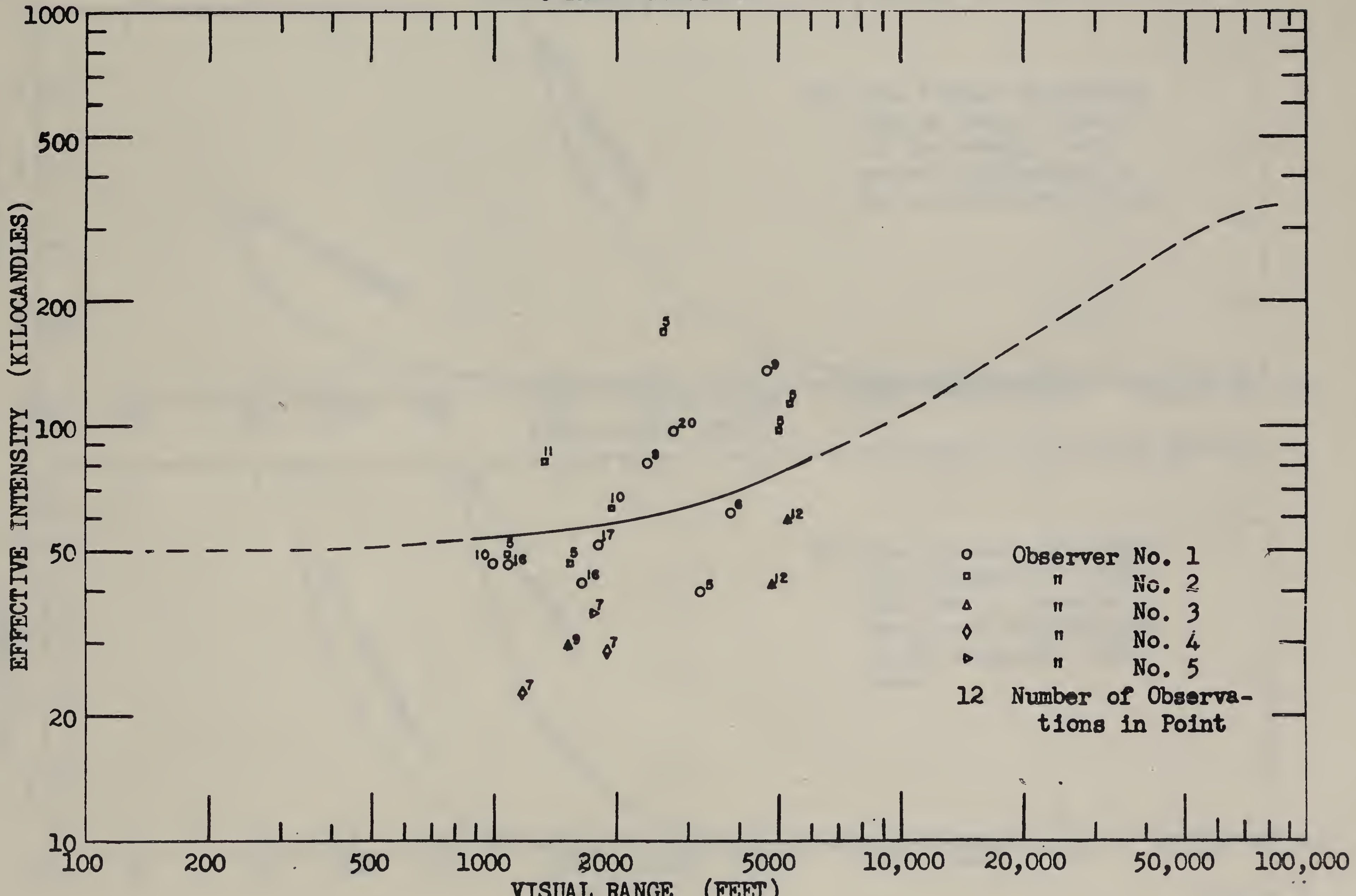


Figure 7

SIZE FACTORS FOR COMPARISON LAMP
(14-INCH COURSE LIGHT)

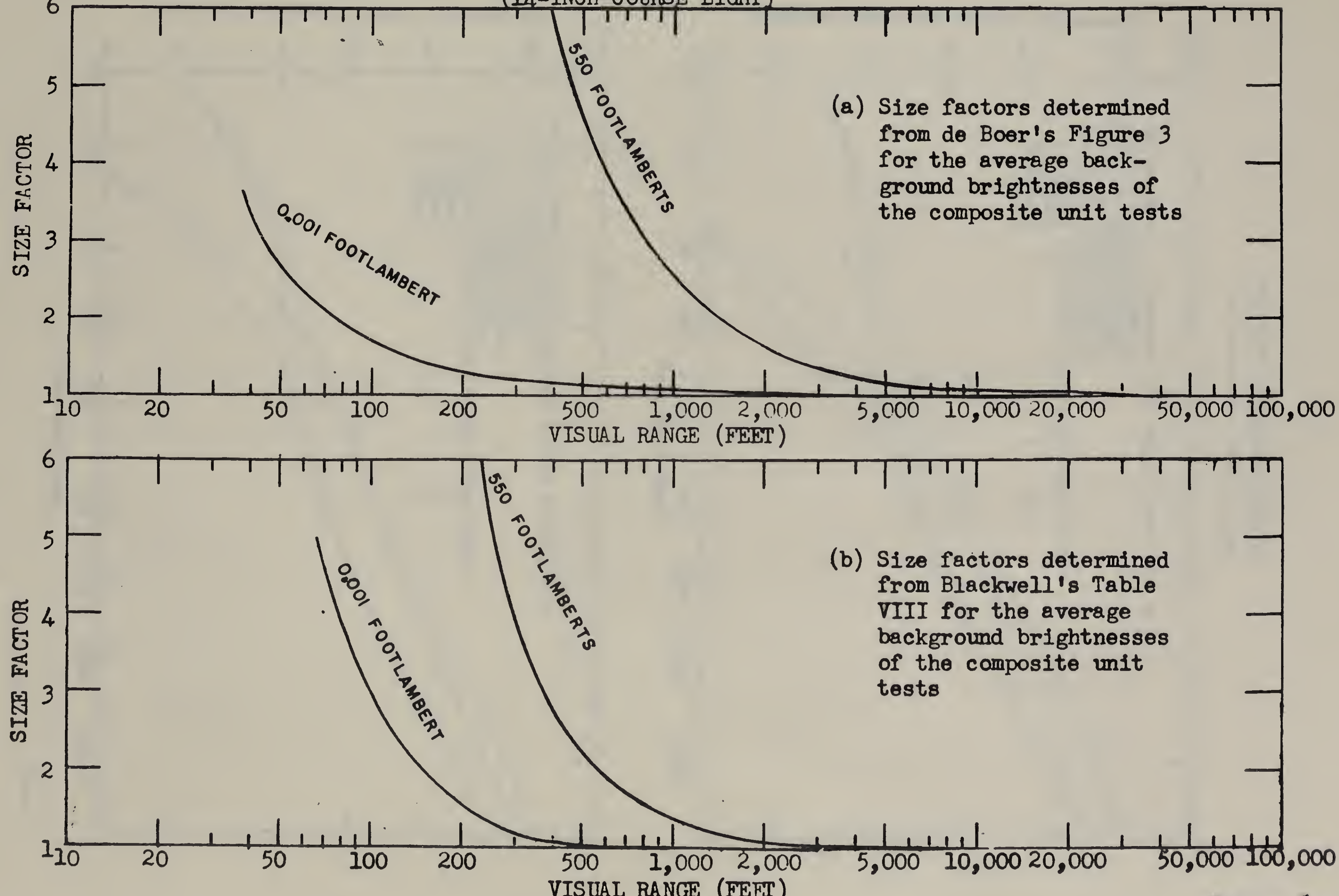


Figure 8

EQUIVALENT POINT-SOURCE INTENSITY

(10- AND 6-LAMP COMPOSITE UNITS)

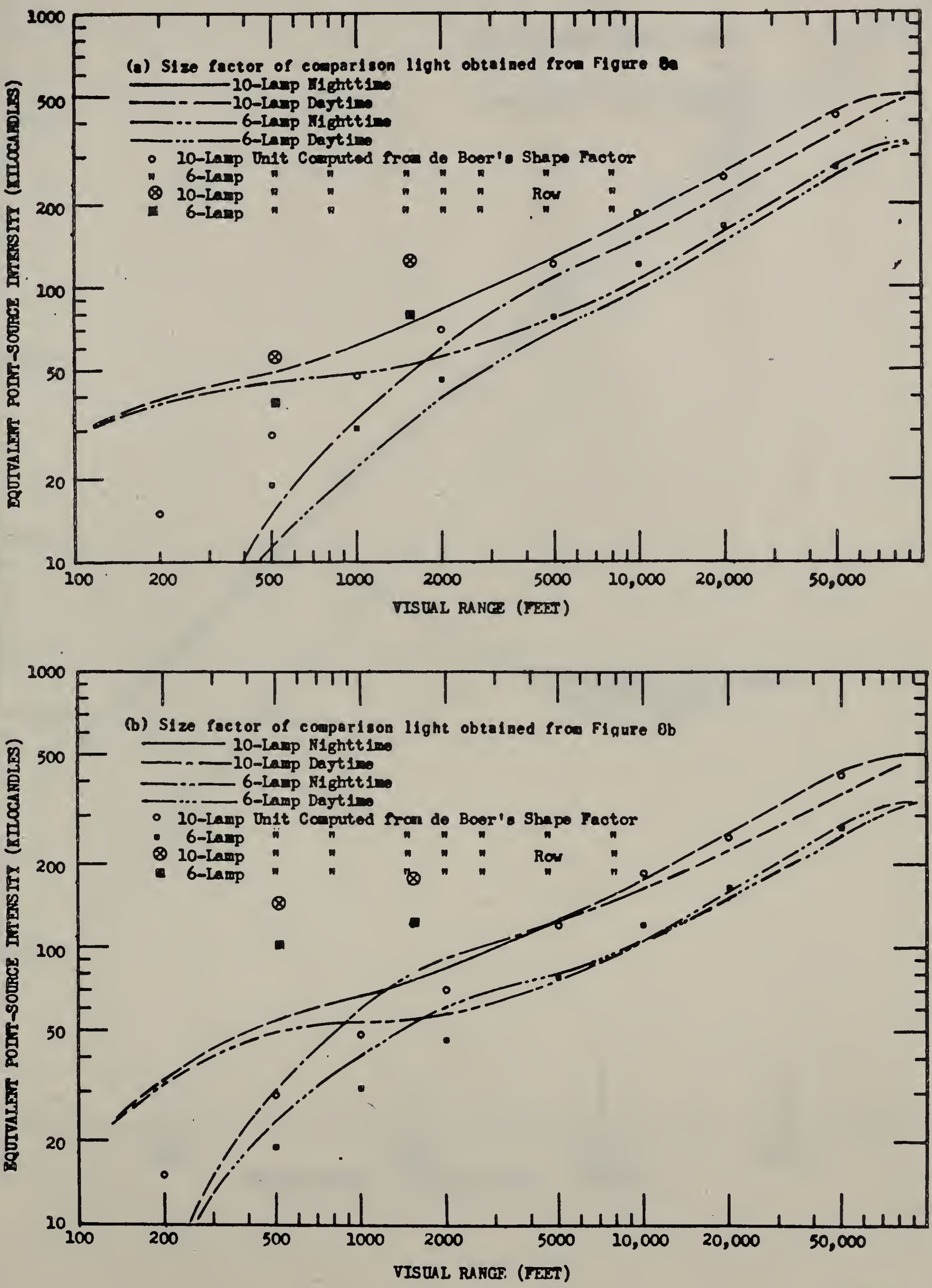


Figure 9

VISIBILITY-VISUAL RANGE
CHARACTERISTICS

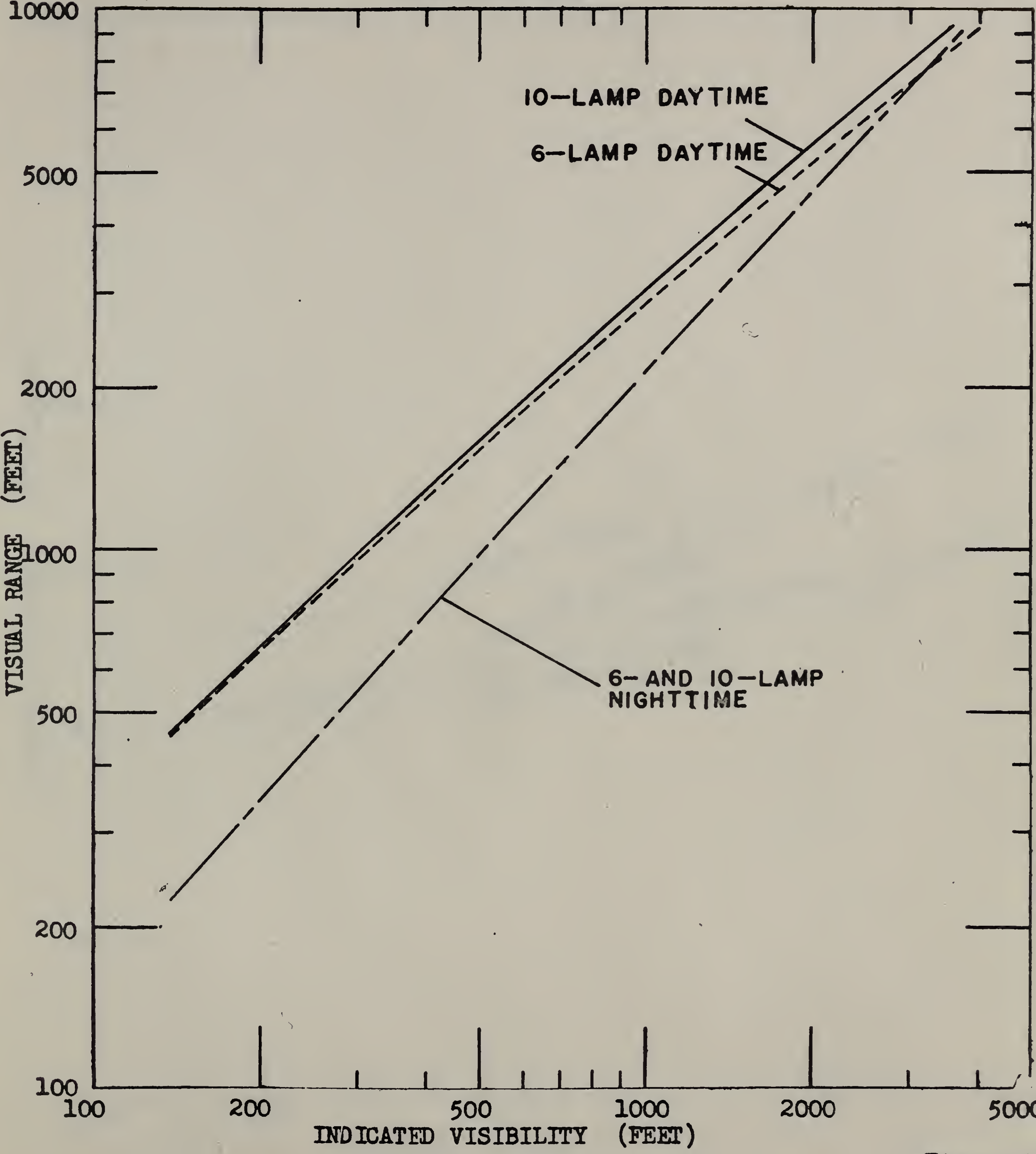
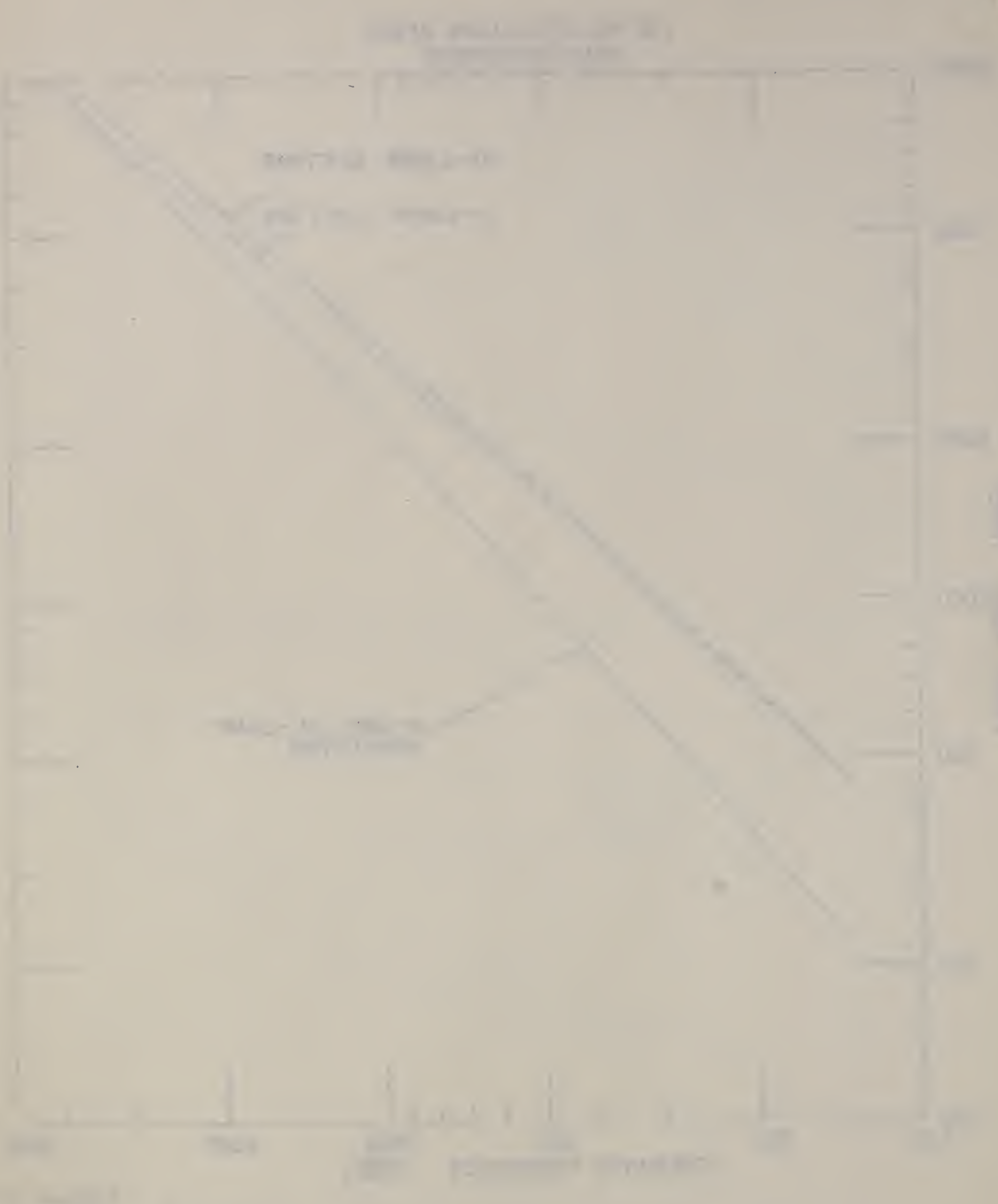
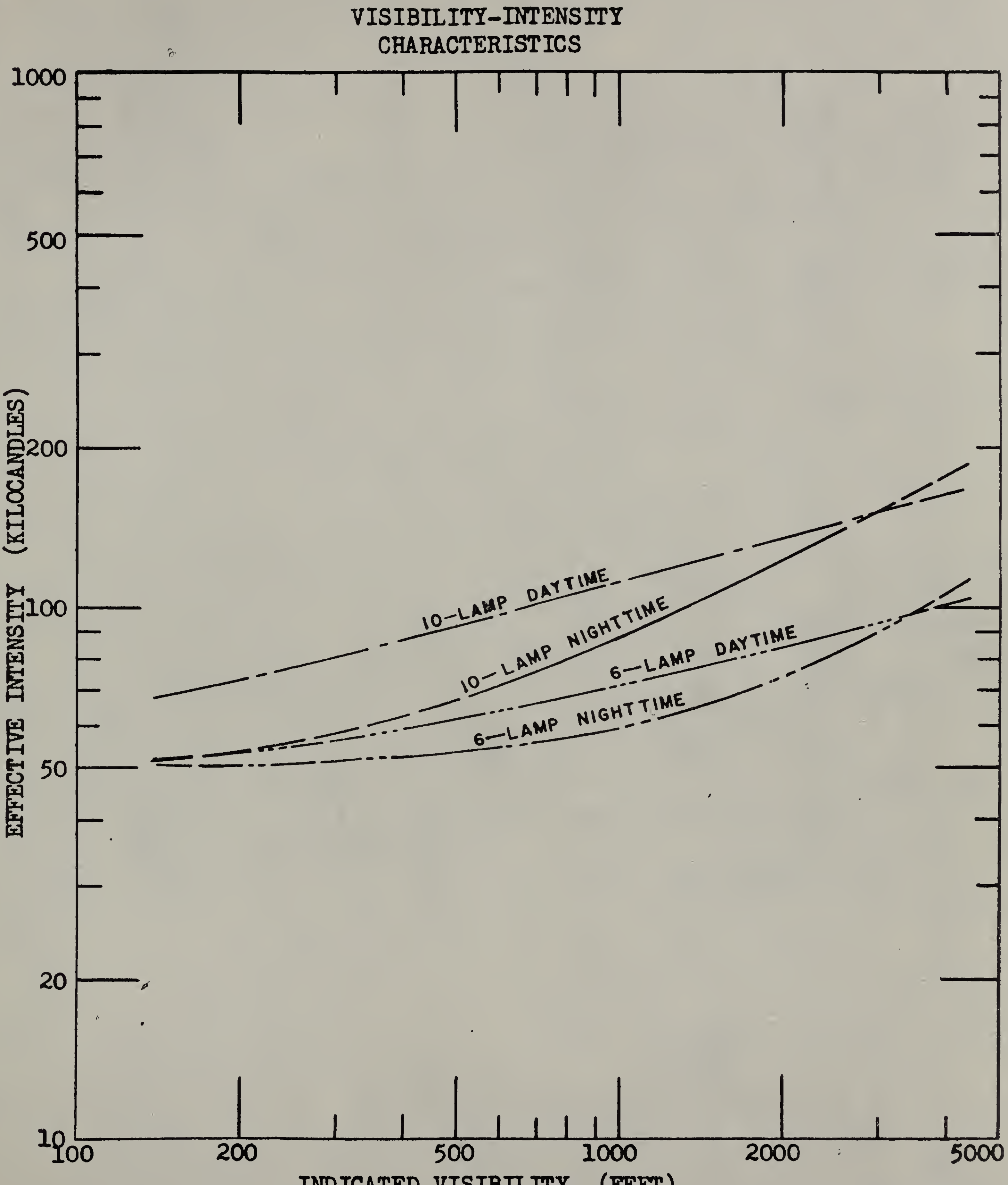


Figure 10





VISIBILITY-INTENSITY
CHARACTERISTICS
EFFECTIVE INTENSITY (KILOCANDLES)
1000
500
200
100
50
20
10
100
200
500
1000
2000
5000
INDICATED VISIBILITY (FEET)
10-LAMP DAYTIME
10-LAMP NIGHTTIME
6-LAMP DAYTIME
6-LAMP NIGHTTIME

Figure 11