NATIONAL BUREAU OF STANDARDS REPORT

8019

HORIZON-SKY BRIGHTNESSES
PRODUCED BY AIRFIELD LIGHTING

By
J. W. Simeroth

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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By
J. W. Simeroth
Visual Landing Aids Field Laboratory
Photometry and Colorimetry Section
Metrology Division

Prepared For
Bureau of Naval Weapons
Department of the Navy
Washington 25, D. C.

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Foreword

"Horizon-Sky Brightnesses Produced by Airfield Lighting" was presented at the May 1961 meeting of the Aviation Committee of the Illuminating Engineering Society and was published in the Proceedings of that meeting. It is now being issued as a National Bureau of Standards Report so that the data contained therein will be more readily available to those concerned with the design of approach and runway lighting systems.

HORIZON-SKY BRIGHTNESSES PRODUCED BY AIRFIELD LIGHTING

J. W. Simeroth

This paper presents the results of measurements of the photometric brightness (luminance) of the sky near the horizon from environmental lights and from high-intensity runway and approach lights. Values of horizon-sky brightness from environmental lights of 0.0005 to 0.2 foot-lamberts were measured. The high-intensity lights increased the brightness of the sky near the horizon by as much as 0.5, 5, and 50 foot-lamberts, respectively, for type M-2 runway lights, slopeline approach lights, and centerrow approach lights. The effects of these brightnesses on the minimum illumination required for detection of point sources are discussed.

1. Introduction

In recent years in airfield lighting there has been much discussion about the "black hole" and the problems it causes for pilots during landing operations at night. Obviously this area over the runway is not truly black but it may appear very dark when contrasted with the brightness of the approach zone, especially to a pilot who has just passed over the approach lights. If the pilot's eyes had had an opportunity to adjust to the brightness level, this area would appear to be fairly well illuminated. To determine properly the visual range of a given light or system of lights and to aid in the design of airfield lighting for maximum effectiveness, knowledge of the photometric brightness of the sky near the horizon at airports, especially when the sky is viewed from positions on the runway and in the approach zone, is needed. This brightness, hereafter referred to as horizon-sky brightness, may be considered as composed of environmental sky brightness, resulting from general lights on and in the vicinity of the airport and from the moon and sky, and incremental sky brightness, resulting from the use of the runway and approach lights. The environmental brightness at night depends upon the phase and direction of the moon, the location and intensity of surrounding lights, and the cloud cover and transmittance of the atmosphere. From the factors involved in producing the environmental brightnesses we should expect the brightness to change with time and location. The incremental brightness produced by the runway and approach lights depends upon the location of the observer, the direction of view, the configuration of the lighting installation, the light beam distribution, the intensity of the lights, the atmospheric transmittance, and the ceiling conditions involved.

2. Installations and Lighting Systems

To determine the environmental brightness for a given airfield, measurements at that field would be required, but by making measurements from locations which have horizon brightnesses near the extremes likely to be encountered, the range and variation of environmental brightnesses can be estimated. The Arcata Airport at Arcata, California, is located in an area representative of airports with scheduled airline operations which have low environmental brightnesses. This airport is well away from any sizable town with only a few scattered homes along the approach path and with the ocean off a bluff at the far end of the instrument runway. The National Bureau of Standards at Washington, D. C. is located in an area representative of metropolitan areas. A limited number of environmental brightness measurements made at Washington National Airport agreed very well with values obtained at NBS, Washington, which indicates that the environmental brightnesses at NBS are similar to those at major airports near large cities.

Three types of high-intensity lighting installations at the Arcata Airport were evaluated for their effect on horizon brightness. These were a type M-2 high-intensity runway edge-light system, a slopeline approach-light system, and a Configuration A centerrow approach-light system. Diagrams of these installations are given in figures 1a, 1b, and 1c, respectively. The type M-2 lights are located along runway 31. Runway 31 is 6000 feet long and 150 feet wide with a surface of asphaltic concrete. The lights are located at 200-foot intervals along each side of the runway and the beams are toed in about four degrees. Each of these lights uses a 200-watt, 6.6-ampere lamp. These lights have a bidirectional beam. Each beam has an intensity exceeding 20,000 candles over 10 degrees horizontally and 8 degrees vertically. The peak intensity is approximately 45,000 candles.

The slopeline approach lights were formerly installed on the approach to runway 31. This system was comprised of two rows of bars of lights, one row on each side of the runway axis, beginning 3000 feet from the runway threshold and ending 100 feet from the threshold. The point of convergence of the rows of bars was located 1250 feet down the runway from the threshold on the centerline. The individual bars were spaced at 100-foot intervals and were mounted in vertical planes perpendicular to the runway axis with the major axes of the bars sloping toward the ideal glidepath at a 45-degree angle with respect to the horizontal plane. The transverse location of the individual bars was determined by the local terrain and the 45-degree angle in the vertical plane from the ideal glidepath. Each bar was composed of ten 250-watt, 12.5-volt, PAR-56 lamps. Each of these lamps had an intensity exceeding 20,000 candles over 30 degrees horizontally and 6

degrees vertically. The peak intensity was approximately 80,000 candles. This system also had a pair of transverse bars of 17 lamps with green filters at the runway threshold and another pair of transverse bars with 22 lamps at 1000 feet from the threshold.

The centerrow approach-light system was the standard Configuration A approach-light system without the flashing lights.* This system is installed on the approach to runway 31. It consists of five-lamp barrettes spaced at 100-foot intervals along the runway axis beginning 3000 feet from the runway threshold and ending at 300 feet from the threshold. The 1000-foot bar has 16 additional lamps, the pair of threshold bars has 18 lamps with green filters, and the wing bars and termination bar contain 26 lamps with red filters. The incandescent lamps used in the centerrow system are 300-watt, 20-ampere, PAR-56 lamps. These lamps have an intensity exceeding 20,000 candles over 30 degrees horizontally and 12 degrees vertically. The peak intensity is approximately 30,000 candles.

3. Method of Making Measurements

Most of the brightness values were obtained by an observer measuring the luminance of the sky, using a Luckiesh-Taylor brightness meter. For the very low levels, a Macbeth illuminometer was used. Both of these instruments vary the luminance of the comparison field to match that of the test field. These instruments have arrangements for inserting neutral filters between the comparison light sources and the comparison fields to extend the ranges of the instruments for measuring test fields of low luminance levels. All readings were corrected for the transmittances of the filters involved.

The data for the environmental brightnesses at NBS, Washington, were obtained by making measurements in several directions from the Bureau, especially in directions of areas of minimum and maximum brightnesses. The brightnesses were measured at approximately two to five degrees above the highest terrain in the direction being checked. The visibilities were estimated by the observer.

The brightness data at the Arcata Airport were obtained by measuring the luminance of an area above the axis of runway 31, a northwesterly direction, at between one and three degrees above the horizon. The environmental brightness was obtained by measuring the luminance of this area when the runway and approach lights were not operating. The incremental brightness was obtained by measuring the luminance of this area when the lighting system was operating and subtracting the corresponding

* Flashing lights have since been installed.

environmental brightness from this value. The incremental brightness is this difference. The environmental brightnesses and incremental brightnesses of the runway lights were measured from a position on the runway centerline in the touchdown area 1000 feet from the runway threshold. The environmental brightnesses and incremental brightnesses of the slopeline and centerrow approach lights were measured from a tower in the approach zone that was located on the axis of the runway 2300 feet from the runway threshold. This tower was 50 feet high and placed the observer on a level almost up to the elevation of the runway threshold. This height was about 30 feet above the slopeline lights and 20 feet directly above the centerrow lights. This tower was about 150 feet laterally from the slopeline light bars. The incremental brightnesses from the centerrow approach lights were also obtained from a position 150 feet right of the runway axis at 2000 feet from runway threshold at approximately the same elevation as the lights.

The incremental brightnesses produced by back-scattered light from the runway lights and from the centerrow approach lights were obtained at a position on the runway threshold. The back-scatter incremental brightness was obtained by measuring the luminance of an area of the sky in a manner similar to that of the other measurements, but in this case the observer was looking into the approach zone instead of in the landing direction. This position had all the runway lights behind the observer and all the approach lights in front of the observer; the observer was not looking toward the emitted light of either system.

The illumination on a horizontal surface, horizontal illuminance, was also measured for most of the test conditions at the observer's position on the runway, on the tower in the approach zone, and at the runway threshold. The values of horizontal illuminance were obtained by measuring the luminance of a blotter on a horizontal surface at the elevation where the observer was standing and correcting the measured value for the reflectance of the blotter.

The visibilities for the Arcata Airport data were obtained by converting the transmittance recorded at the time of each observation to equivalent visibility. The transmittance values in the touchdown area at the time of the luminance measurements were obtained from a transmissometer located 350 feet right of the runway centerline between points 700 and 1450 feet down the runway from the threshold. The transmittance values in the approach zone at the time of the luminance measurements there were obtained from a transmissometer located 350 feet right of the axis of the runway between points 700 and 1200 feet before reaching the runway threshold.

Since both the environmental brightnesses and the incremental brightnesses produced by the runway and approach lights are a function of atmospheric transmittance or visibility, a series of visibility intervals was used as the abscissa for presenting the results. The series of visibility intervals used was as follows: below 1/8 mile, 1/8 to 3/16 mile, 3/16 to 1/4 mile, 1/4 to 1/2 mile, 1/2 to 1 mile, 1 to 2 miles, 2 to 5 miles, and over 5 miles. The visibilities were obtained from the transmissometer readings. The results of environmental brightness, incremental brightness, and incremental horizontal illuminance measurements are presented as smooth curves which were fitted visually through the values averaged for each visibility interval. When the lights were operated at intensity settings of less than 100 percent intensity, the values of incremental luminance and incremental illuminance obtained from each intensity setting were adjusted to equivalent 100 percent intensity values. The nominal factors used for adjusting the values to equivalent 100 percent intensity values were 625 for intensity setting step 1, 125 for step 2, 25 for step 3, 5 for step 4, and 1 for step 5. As would be expected, the increases in luminance and illuminance were proportional to the intensity of the lights for any given atmospheric condition.

4. Results of Measurements

The results of the measurements of environmental brightness are given in figure 2. The Arcata environmental brightness measurements made looking along the axis of the runway to the northwest from the runway touchdown area and those made from the approach zone are given as separate curves. The lights on the airport and in the vicinity cause the environmental brightness from the approach zone to be approximately three times as great as that from the touchdown area, looking along the same bearing. The curve of the NBS Washington data was obtained as the mean values between areas of maximum brightness and areas of minimum brightness in any direction from the Bureau for the time of the observation.

The incremental brightnesses produced by the lighting installations at Arcata are given in figure 3. The brightnesses produced by the centerrow approach lights viewed from the position at one side of the axis are given in figure 3 also.

The increases in the illuminance on a horizontal surface at the position of the observer produced by each of the three lighting installations are given in figure 4.

The increases in horizon-sky brightness produced by back-scatter of light from the runway lights and from the centerrow approach lights are given in table 1.

Table 1.

Incremental Brightnesses Produced by Back-Scatter from Lights

Visibility Interval	---Centerrow Approach Lights--- No. of Observations	Average Visibility	Back-Scatter Luminance	----Type M-2 Runway Lights---- No. of Observations	Average Visibility	Back-Scatter Luminance
(miles)		(miles)	(fL)		(miles)	(fL)
Over 5	3	5.3	0.21	1	6.1	0.0057
2 - 5	12	3.4	0.55	8	3.7	0.017
1 - 2	3	1.6	0.53	0	-	-
1/2- 1	3	0.53	0.83	4	0.85	0.011
1/4- 1/2	12	0.33	1.1	8	0.39	0.032
3/16-1/4	6	0.22	0.57	6	0.21	0.012
1/8 -3/16	8	0.15	1.5	7	0.15	0.014
Below 1/8	0	-	-	0	-	-

5. Discussion of Results

5.1. Environmental Sky Brightness.

The environmental brightness near the horizon at night for different airports with scheduled airline operations may differ by a factor of about 100, with values ranging from about 0.003 to about 0.4 foot-lambert. The brightness is affected by the position of the observer on the airport, the direction of view, and the atmospheric conditions, as well as the location of the airport. From two positions on the Arcata Airport, one in the approach zone and one in the touchdown area, separated by 3300 feet, looking along a common bearing, the environmental brightness differed by a factor of approximately three for any given atmospheric condition. Measurements at NBS, Washington, showed that sky brightness near the horizon in different directions usually varied by a factor of five and in some cases by a factor of ten. A few measurements at Washington National Airport were similar but values averaged slightly higher than the NBS, Washington, values. As the visibility decreased from good visibility to dense fog, the environmental brightness increased gradually, reaching a maximum value for visibilities of 0.5 to 1 mile and remained approximately constant at this level for still lower visibilities.

5.2. Factors Affecting Incremental Sky Brightness.

The incremental brightnesses produced by the runway and approach lights are determined primarily by the lumen output of the lights, but they are also affected by the configuration of the system, the observer's position, and the atmospheric conditions. For a given system and viewing condition, the incremental luminance was found, as expected, to be directly proportional to the intensity at which the lights were operated.

An examination of the incremental brightnesses produced by the three different lighting installations shows some effects caused by the configurations of the systems. The runway lights and the slopeline lights differed in the arrangement of the light sources and in the lumen output and beamspreads of the lights, but each configuration can be considered as two effectively parallel rows with the observer between them. The curves of the increase in sky brightness are similar in shape and have a ratio of 10 to 1, which is the same as the ratio of the power used by the two installations. The curve of the incremental brightness from the centerrow lights is appreciably different in shape from the curves of the other two systems. Also, the values of incremental brightness were greater for this system than for either of the other two systems, although the lumen output was less than that of the slopeline system. The higher values of incremental brightness resulted from the observer being nearer the line of lights and more nearly in the peak of the beams. As an example of how the direction of view may affect the incremental brightness from the centerrow approach lights, the brightness was approximately twice as much when measured just above the lights as when measured at one to three degrees above the lights. The curve of the incremental brightness as observed from the side of the light lane shows the effect of the observer's position. This incremental brightness curve is similar in shape to that of the curve of observations from the centerline of the same system. Since the values of incremental brightness from off to one side of the centerrow system were of the same order of magnitude as those of the slopeline lights, although the total lumen output of the system was much less and the lateral distance of the observer from the row of bars of lights was approximately the same, the greater vertical width of the beams and different aiming of the centerrow lights must affect the incremental brightness.

The atmospheric conditions have an appreciable effect on the incremental brightness just as they do on environmental brightness. As the visibility decreases, the value of incremental brightness increases reaching a maximum value in the visibility range from 2.5 to 0.5 miles, which is also the range at which environmental brightness levels off, but the incremental brightness decreases as the visibility continues to decrease below 0.5 mile. This decrease in incremental brightness is primarily caused by the reduced effect of the more distant lights as the visual range becomes equal to or less than the distance to these lights.

5.3. The Effect of Sky Brightness on Visual Range of Lights.

To use the data in determining the effectiveness of the lights in a system[1/] or in properly designing a light, consideration must be given to the illuminance at the observer's eye necessary for detection of a given light source against a given background brightness condition. The illuminance necessary for detection is called threshold illuminance. The values of threshold illuminance for 50 percent probability of detection are given in figure 5, and are based on Blackwell's Tiffany Foundation data[2/]. The discontinuity in the curve is the result of the eye changing from cone to rod vision. These values of threshold illuminance are applicable for a stationary observer whose eyes are adapted to the background brightness level. If the observer's eyes are not completely dark adapted, as is usually the case for a pilot on an approach, his threshold-illuminance level will remain approximately constant for background brightnesses below 10^{-2} foot-lambert as is indicated by the broken line in figure 5.

For brightnesses above 10^{-2} foot-lambert the threshold illuminance increases with increases of background brightness.

For lights to be detectable against environmental brightnesses measured at Arcata or at NBS Washington, illuminance levels would not have to be much above the minimum threshold values for foveal vision. When the background brightness is increased by the effect of the high-intensity runway and approach lights, the illuminance must be increased in order for a given source to be detectable. Since the brighter areas produced by a given lighting system will not cover the entire field of view, there is some question of the brightness level to which the eye will adjust itself. Knoll, Tousey, and Hulburt[3/] have found that the threshold illuminance level is governed only by the brightness within the immediate area of the source, within 0.4 degree, if this is the brightest area in the field of view. Thus, using the luminances of figure 3 at a visibility of one-half mile and the threshold illuminance values of figure 5, the threshold illuminance is increased above the minimum value for foveal vision by factors of 4, 30, and 250, respectively, for runway, slopeline, and centerrow lights.

The increase in threshold-illuminance level caused by the environmental and incremental brightnesses of the airfield reduces the effectiveness of increasing the light output of high-intensity systems. The effect of the increased threshold illuminance level is shown in table 2 for visibilities of 0.5 and 2 miles when environmental brightnesses are similar to those obtained at Arcata and Washington. The incremental luminances from the lighting systems at 100-percent intensity were obtained from figure 3. The incremental luminances are proportional to the relative intensities of the lights and the factors used were 0.0016, 0.008, 0.04, 0.2, and 1 for intensity settings steps 1, 2, 3, 4, and 5, respectively. The environmental luminances were obtained from figure 2. The horizon-sky luminances, the sums of the incremental and environmental luminances, were used in figure 5 to determine the threshold illuminance values. The relative effectiveness per candle output at a given intensity setting is the ratio of the threshold illuminance for environmental brightness only as compared to the threshold illuminance for the total horizon-sky brightness at the intensity setting.

Thus:

$$K_R = E_o/E$$

Where K_R is the relative effectiveness per candle output for a given intensity setting,

E_o is the threshold illuminance when the observer is adapted to a background brightness equal to the environmental brightness, and

E is the threshold illuminance when the observer is adapted to a background brightness equal to the incremental brightness plus the environmental brightness.

The relative system effectiveness, the effectiveness of the system at this intensity setting as compared to the effectiveness at step 1, is the relative effectiveness per candle output of a given intensity setting multiplied by the ratio of the intensity at the given intensity setting to the intensity at step 1.

Table 2

Effect of Sky Brightness Increases on Usefulness of Lights

--Intensity--		----------Runway Lights ---------				---------- Slopeline Lights ----------				---------- Centerrow Lights ----------			
Step No.	Factor	Incre-mental Lumi-nance	E	K_R	K_S	Incre-mental Lumi-nance	E	K_R	K_S	Incre-mental Lumi-nance	E	K_R	K_S
	%	(fL)	(mile-candle)			(fL)	(mile-candle)			(fL)	(mile-candle)		
Arcata Airport - visibility 0.5 mile; environmental luminance: 0.0015 fL., runway; 0.004 fL., approach zone													
1	0.16	0.0006	0.08	1.0	1.0	0.006	0.09	0.9	1.0	0.08	0.17	0.5	1.0
2	0.8	0.003	0.08	1.0	5.	0.03	0.12	0.7	4.	0.4	0.4	0.2	2.
3	4.	0.015	0.10	0.8	20.	0.15	0.2	0.3	9.	2.	1.3	0.06	3.
4	20.	0.08	0.17	0.5	60.	0.8	0.7	0.13	18.	10.	5.	0.016	4.
5	100.	0.40	0.4	0.19	120.	4.	2.	0.03	20.	50.	20.	0.004	5.
Arcata Airport - visibility 2 miles; environmental luminance: 0.0013 fL., runway; 0.004 fL., approach zone													
1	0.16	0.0008	0.08	1.0	1.0	0.008	0.09	0.9	1.0	0.03	0.12	0.6	1.0
2	0.8	0.004	0.08	1.0	5.	0.04	0.13	0.6	3.	0.15	0.2	0.3	3.
[illegible]	4.	0.02	0.11	0.7	19.	0.2	0.3	0.3	8.	0.8	0.7	0.12	5.
[illegible]	20.	0.10	0.19	0.4	50.	1.0	0.8	0.10	14.	4.	2.	0.03	6.
[illegible]	100.	0.5	0.5	0.16	100.	5.	3.	0.03	19.	19.	9.	0.009	9.
NBS, Washington - visibility 0.5 mile; environmental luminance, 0.04 foot-lambert													
1	0.16	0.0006	0.13	1.0	1.0	0.006	0.13	1.0	1.0	0.08	0.2	0.6	1.0
2	0.8	0.003	0.13	1.0	5.	0.03	0.16	0.8	4.	0.4	0.4	0.3	3.
3	4.	0.015	0.15	0.9	20.	0.15	0.3	0.5	13.	2.	1.3	0.10	4.
4	20.	0.08	0.2	0.6	80.	0.8	0.7	0.19	30.	10.	5.	0.03	5.
5	100.	0.4	0.4	0.3	190.	4.	2.	0.06	40.	50.	20.	0.006	6.
NBS, Washington - visibility 2 miles; environmental luminance, 0.03 foot-lambert													
1	0.16	0.0008	0.12	1.0	1.0	0.008	0.13	0.9	1.0	0.03	0.16	0.8	1.0
2	0.8	0.004	0.12	1.0	5.	0.04	0.17	0.7	4.	0.15	0.3	0.5	3.
3	4.	0.02	0.14	0.8	20.	0.2	0.3	0.4	11.	0.8	0.7	0.18	6.
4	20.	0.10	0.2	0.5	70.	1.0	0.8	0.15	20.	4.	2.	0.05	8.
5	100.	0.5	0.5	0.2	150.	5.	3.	0.04	30.	20.	9.	0.013	11.

E = Threshold illuminance for total horizon-sky brightness (incremental and environmental).

K_R = Relative effectiveness per candle output.

K_S = Relative system effectiveness.

Thus:

$$K_S = K_R I_N/I_1$$

Where:

K_S is the relative system effectiveness,
I_N is the intensity at the given setting, and
I_1 is the intensity at setting step 1.

The values given in table 2 show how a given change in intensity may be much more effective for some systems than for others. As the intensity is increased by a factor of 625, the effectiveness of the runway lights is increased 100 to 200 times, but the effectiveness of the centerrow lights is increased only 5 to 10 times. The small increases in effectiveness show why there is little to be gained by using intensity steps 4 and 5 for the centerrow approach lights at night. In the daytime when the background or environmental brightness is high the incremental brightness is small compared to the environmental brightness; consequently, the effectiveness of the lighting system is approximately proportional to the intensity.

5.4. The Effects of Lights on Horizontal Illumination.

As shown in figure 4, the illumination from the lights on a horizontal surface increases as the visibility decreases, reaching a maximum value when visibility is in the range of 0.5 to 0.2 mile, and then slowly decreases as visibility decreases further. The values of horizontal illuminance also depend on the configuration of the system, the intensity of the lights, and the location of the observer. For instrument-approach conditions, visibilities of two miles or less, the runway lights increase the illumination on the centerline of the runway by 0.02 to 0.03 foot-candle and the centerrow approach lights increase the horizontal illumination on the approach-zone centerline by 0.2 to 0.6 foot-candle.

5.5. Brightnesses from Back-Scatter of Light.

The effects of back-scatter of a bidirectional lighting system can be deduced by comparing the results given in table 1 with those shown in figure 3. The measurements of the back-scatter of the runway lights are indicative of the effects of all lights behind the observer, and the measurements of the back-scatter of the approach lights are indicative of the effects of all the lights ahead of the observer. In fog, the brightness produced by back-scatter from the lights behind the observer (the runway lights) was of the order of 5% of the brightness produced by the forward scatter of these lights, and the brightness produced by the lights ahead of the observer (the approach lights) was of the order of 5% of the brightness produced by the forward scatter of these lights. Hence the back-scatter of a system of bidirectional lights would increase the incremental brightness produced by these lights by about 10%.

6. Conclusions

1. The horizon-sky brightnesses at airports at night, especially the incremental brightnesses from high-intensity airfield lighting, are sufficiently high to have an important effect on the effectiveness of the lights. This should be considered in the operational planning and use of these lights.

2. The intensity, width of beams, and number of lights of an installation should be kept to a minimum consistent with operational requirements in order to keep incremental brightnesses and threshold-illuminance levels as low as possible. This is important in the design of lights and installations as well as in control of intensity.

3. The back-scattered light from bidirectional lights does not significantly affect the detection and usefulness of these lights in the range of present operational atmospheric conditions.

4. The environmental brightnesses at other airfields and the incremental brightnesses from other lighting systems, especially those of narrow-gage and centerline runway lights, should be determined in order to evaluate better the effectiveness of any given lighting system at a given location.

5. The incremental brightness produced by runway and approach lights viewed from the approach glide slope should be determined.

6. The operational threshold-illuminance levels for pilots' eyes under approach and landing conditions for various brightnesses, including limited areas of brightness and changing brightness levels, should be determined.

7. In considering the effectiveness of floodlights for touchdown areas of runways, the illumination on the runway surface produced by the runway lights and the effects of the incremental brightness on the visibility of the runway surface should be considered.

7. References

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3. H. A. Knoll, R. Tousey, and E. O. Hulburt, Visual Threshold of Steady Point Sources of Light in Fields of Brightness from Dark to Daylight, JOSA 36; 480 (1946)

NBS Report 8019
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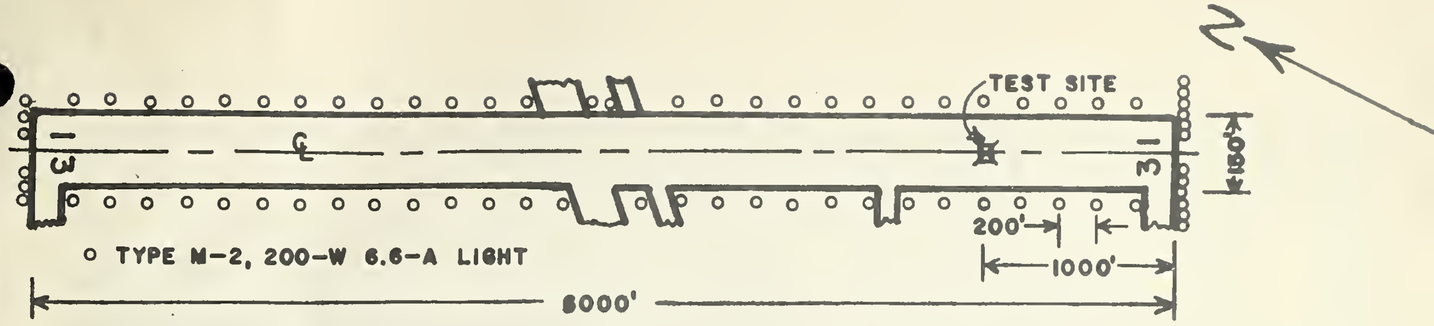

Figure 1a. Type M-2 runway lighting installation.

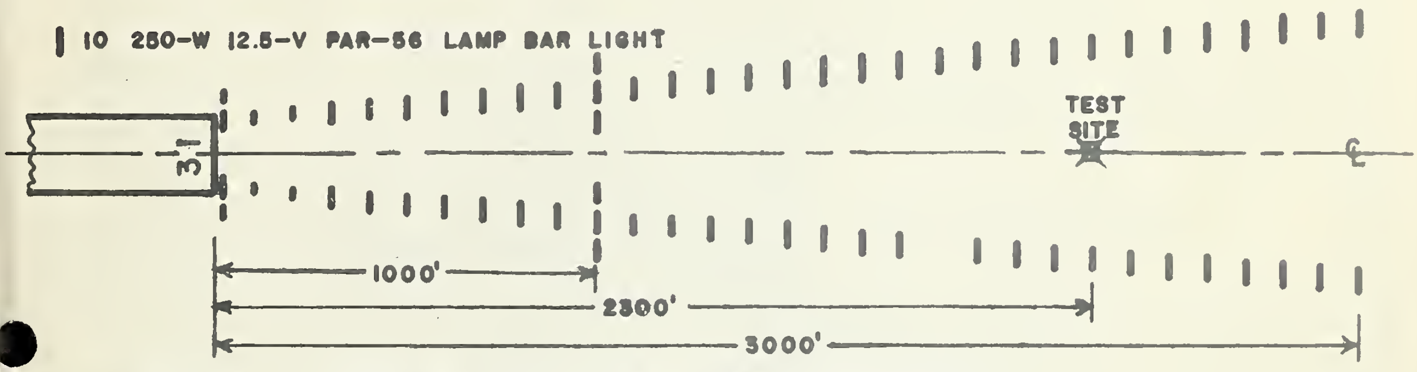

Figure 1b. Slopeline approach lighting installation.

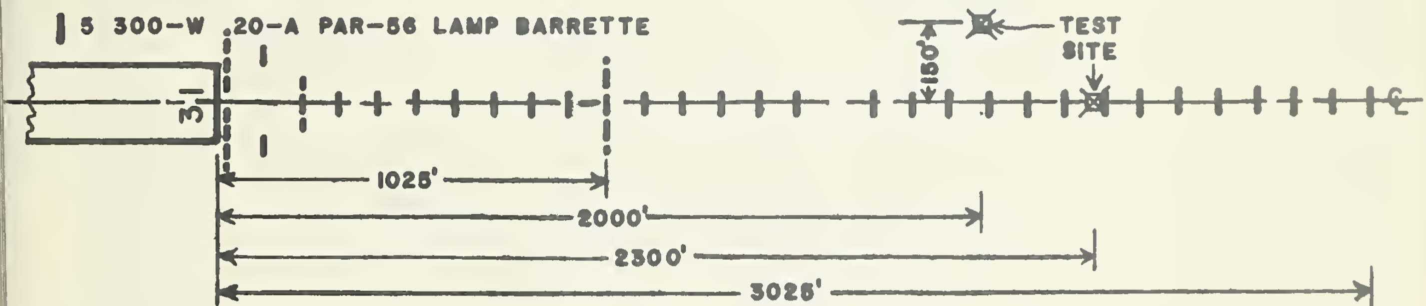

Figure 1c. Centerrow Configuration A approach lighting installation.

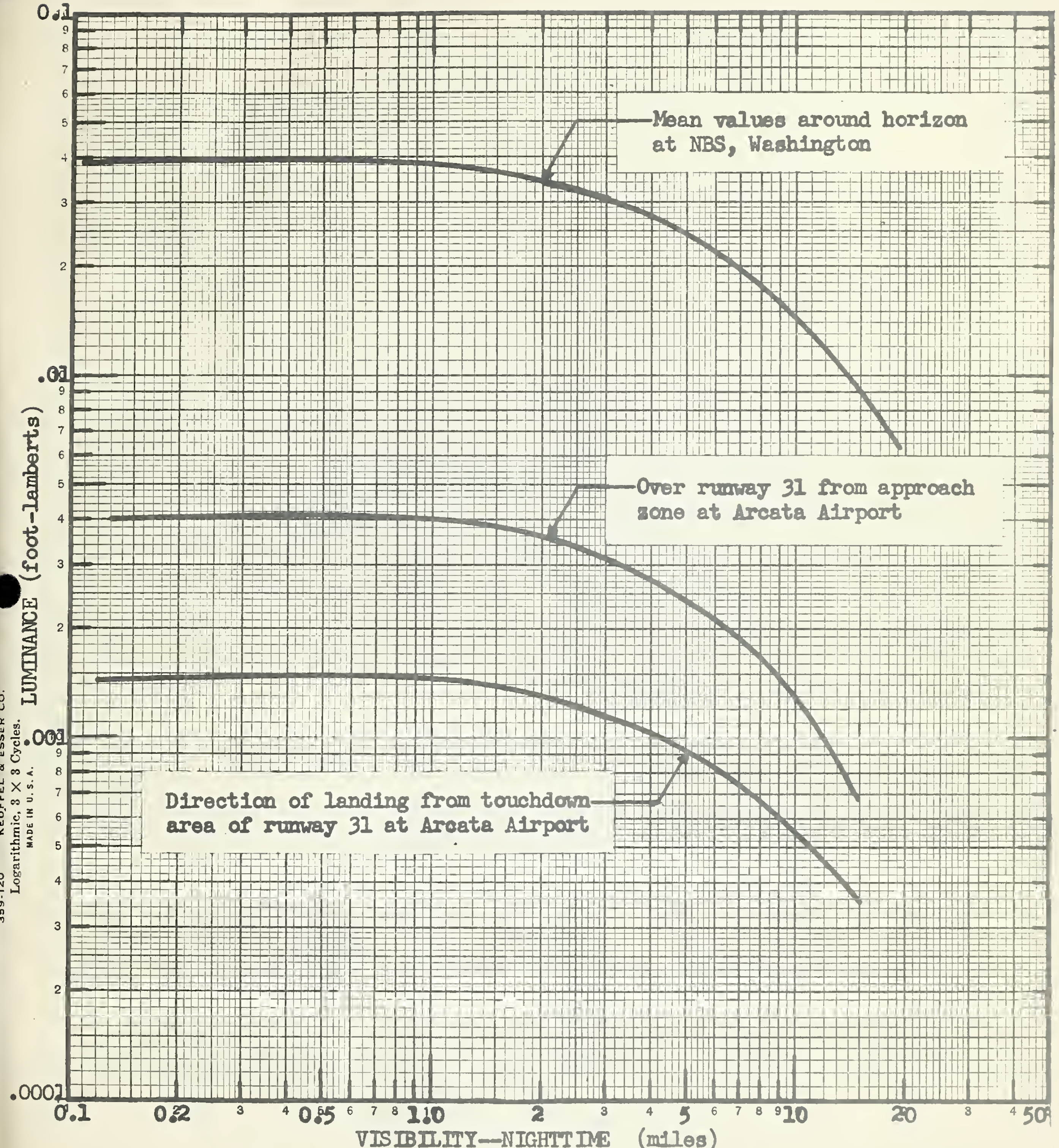

Figure 2. Environmental sky brightnesses at Arcata and Washington

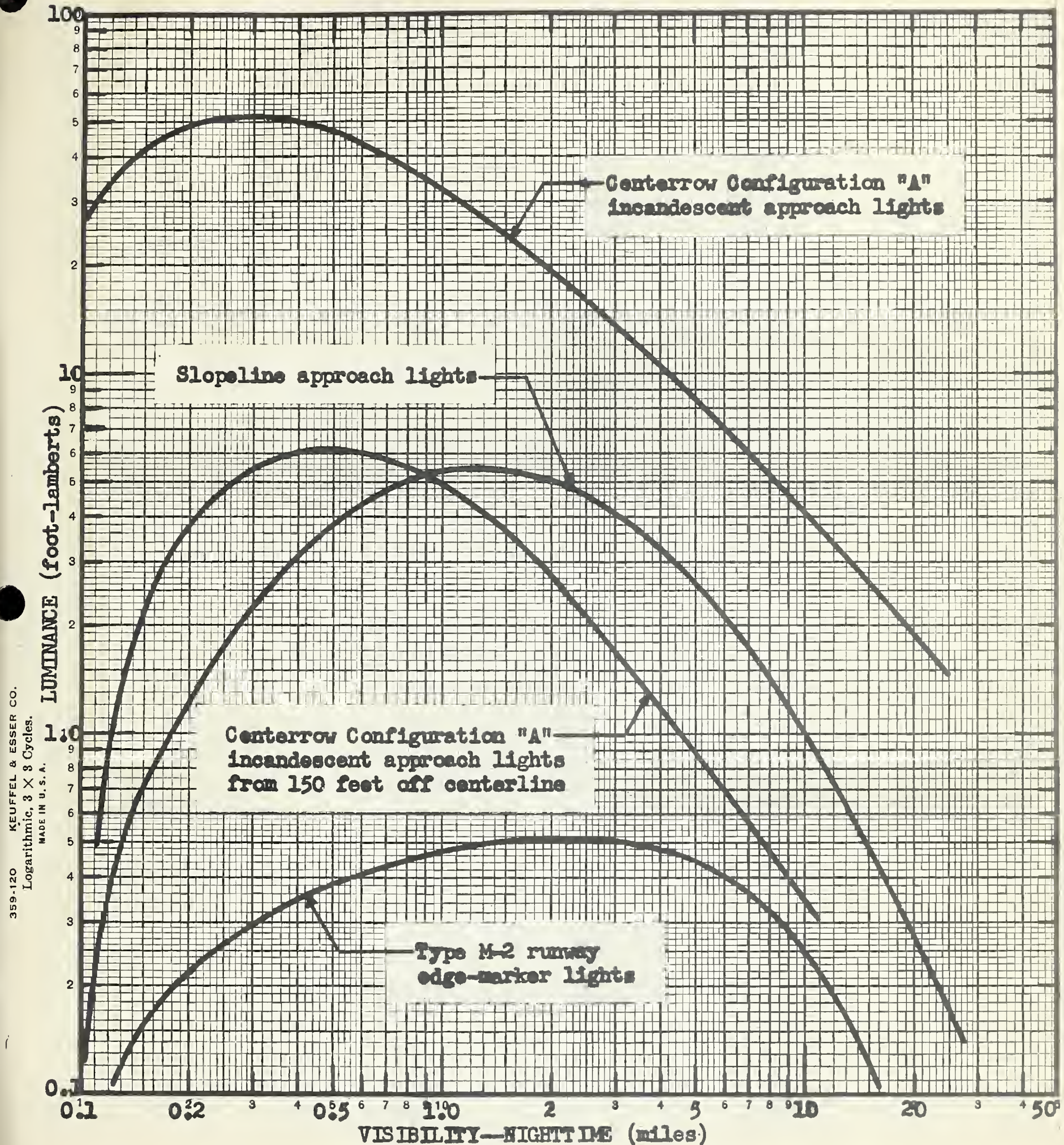

Figure 3. Incremental sky brightnesses produced by runway and approach lights

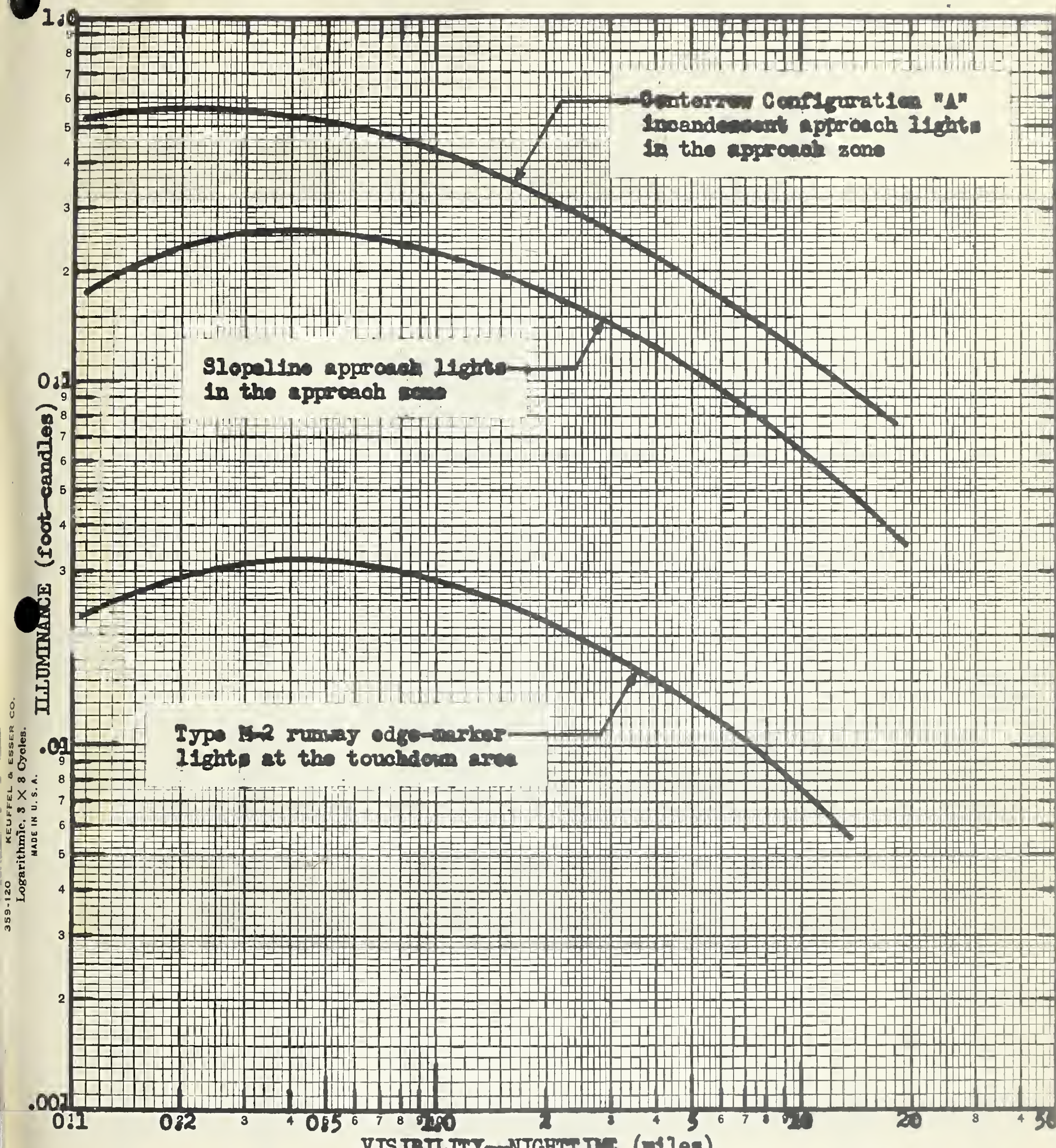

Figure 4. Illumination on a horizontal surface produced by airfield lights

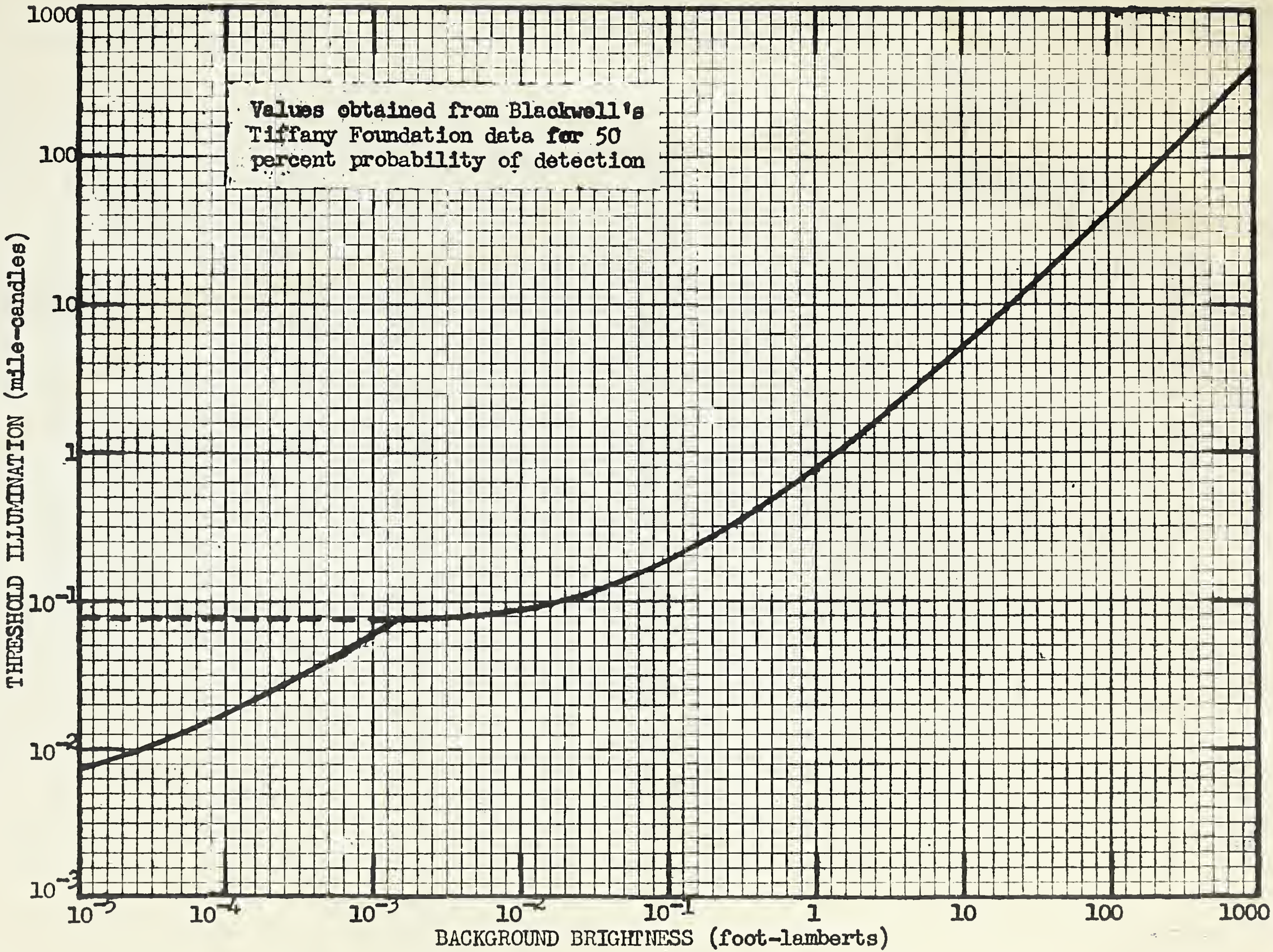

Figure 5. Threshold illumination required for detection of point sources of light

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

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

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