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ON THE CALCULATION OF EFFECTIVE INTENSITY
A REVISED APPROACH

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ON THE CALCULATION OF EFFECTIVE INTENSITY: A REVISED APPROACH

by

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SUMMARY

The validity of the heretofore generally accepted premise that the "Blondel-Rey Constant" should correspond to the practical eye illumination level used in the calculation of luminous range is questioned. It is suggested that elevations in eye illumination level to account for various marine environment factors that do not exist in the laboratory should in no way influence the calculation of effective intensity. Effective intensity should be calculated only from laboratory data representing central foveal vision and a 99% probability-of-seeing.

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ON THE CALCULATION OF EFFECTIVE INTENSITY: A REVISED APPROACH

For a point source of intensity I, Allard has shown that the illumination, E, at a distance, x, from the source varies as a function of the atmospheric transmission, T, according to the equation

$$E = \frac{I}{x^2} T^x . \qquad (1)$$

For marine signaling the equation assumes the form[1]

$$E = \frac{I}{x^2} (.05)^{x/v} \qquad (2)$$

where v, the meteorological visibility in a homogeneous atmosphere, is the distance at which E is reduced to .05 times the value it would have were the atmosphere perfectly transparent.

The luminous range of a steady-burning light can be determined from Eq. (2) by setting E equal to the minimum eye illumination level required to maintain foveal recognition of the light. Calling that level the luminous range threshold, E_L, the luminous range of the steady light is determined by solving the following modification of Eq. (2) for L:

$$E_L = \frac{I}{L^2} (.05)^{L/v} \qquad (3)$$

If the light is flashing, its effective intensity, I_e, must be used in place of I. Hence, for flashing lights there is the equation

$$E_L = \frac{I_e}{L^2} (.05)^{L/v} . \qquad (4)$$

Eqs. (3) and (4) are herein referred to as the "luminous range equations".

For a given background condition, it is desirable to use a value for E_L that is common to both steady-burning and flashing point sources. At first glance, this might appear to create the requirement that steady-burning and flashing point lights of equal luminous range must have equal apparant intensities at the limit of their luminous range. This may, in fact, be true. But if so, it is incidental. There is nothing in the definition of luminous range requiring the two lights to be equally intense. The requirement is that the two lights be equally "recognizable", foveally, when viewed from their luminous range limit. Hence, the desirability of a common E_L for Eqs. (3) and (4) forces the effective intensity of a flashing light, I_e, to be the intensity of a juxtaposed steady-burning light that is equally recognizable, foveally.

Of obvious significance is the consequent realization that calculation of effective intensity should not be based upon judgments of equal intensity, but rather upon judgments of equal recognizability. Equal recognizability judgments can easily be made using common threshold measurement techniques, if it is accepted that equal recognizability is synonomous with equal "probability-of-seeing". Since the requirement within luminous range is for the mariner to be able to identify the signal light continuously, it would seem logical to adopt a 99% probability-of-seeing level as the minimum recognizability criterion for luminous range. Once this has been established, it is a simple matter to determine the time-intensity profiles satisfying the recognizability criterion by using standard threshold measurement techniqies. From these profiles time-intensity relationships for effective intensity can be developed.

The most significant point to be made in this paper is that these time-intensity relationships for effective intensity apply at all values of eye illumination level for which there is a 99% probability-of-seeing. This means that they apply to laboratory levels for which there is a 99% probability-of-seeing, and they apply to marine environment levels for which there is a 99% probability-of-seeing. More appropriately, they apply for low values of E_L representing laboratory conditions, and they apply for "elevated" values of E_L representing typical marine environmental conditions. In other words, there is no need to adjust effective intensity to reflect marine conditions different from those in the laboratory.

The only adjustment necessary in the transition from laboratory to typical marine application of Eq. (4) is in elevation of E_L. It is in E_L that all environmental factors inhibiting flashing signal visibility (e.g., wind, rain, rolling ship) must be reflected in order to accomplish appropriate reductions in luminous range that guarantee for foveal viewing at least a 99% probability-of-seeing within luminous range. Elevations in E_L are made solely to account for the environmental factors that elevate the minimum eye illumination level at which the mariner will see a signal light 99% of the time when he is looking right at it.

SEARCH AND THE EFFECTS OF BACKGROUND BRIGHTNESS

The fundamental intent here is to present an essentially new philosophy for the calculation of effective intensity. It is not to discuss or justify the many details involved in the selection of practical elevations for E_L. In order to justify dissociation of the problems of search acquisition from the procedure for the calculation of effective intensity, however, it is expedient to illustrate one precise method by which elevations of E_L can account for luminous range "ease-of-finding" criteria when the adaptational level is mesopic or photopic.

Under ideal environmental conditions typical of the laboratory, E_L for the dark adapted mariner could logically be assumed to be .05 microlux. Allowing that the mariner's vision is not restricted, that the typical navigational signal light is either steady-burning or regular in its flashing presentation and that the mariner's age is the same as the "normal young laboratory observer", this value can be obtained by interpolation from the resume' of results in Table 1. Because parafoveal sensitivity is greater than foveal sensitivity in scotopic vision, the mariner under ideal environmental viewing conditions can be expected to experience no difficulty in finding and then holding a flashing signal light which provides this level of "effective illumination" (i.e., the level of illumination from a juxtaposed steady-burning light source that corresponds to a foveal 99% probability-of-seeing for the particular environmental conditions that exist).

When background brightness levels are high enough to stimulate mesopic or photopic adaptation levels, the situation changes as shown in Figure 1. For the purposes of this discussion, the curve is called "The Laboratory Effective Illumination Curve". Adapted from the "unlimited search time" data of Blackwell's Tiffany work[2], it shows how the 99% probability-of-seeing threshold illumination level increases from the scotopic value of .05 microlux to values over one thousand times greater in the photopic region. The locus sensitivity inserts show corresponding locus retinal sensitivity changes with increasing background brightness. It can be seen that parafoveal sensitivity exceeds foveal sensitivity on dark nights, but after the background brightness has increased beyond .003 Nits, the start of the mesopic region, foveal sensitivity becomes greater than parafoveal sensitivity[3]. It increases steadily in relative magnitude throughout the mesopic region until the photopic region, where retinal locus relative sensitivity is constant throughout.

Contrary to the dark adaptation situation, therefore, it is very difficult for the observer under ideal environmental conditions to find and hold his eye on a signal light that presents only laboratory effective illumination when the background brightness is high enough to cause mesopic or photopic light adaptation. He must know exactly where to look before he can see and identify the signal light.

Such a condition is obviously unsatisfactory. The definition of luminous range must incorporate a requirement concerning "ease-of-finding" as well as foveal probability-of-seeing. Assuming that the mariner should know at least approximately (e.g., within 20^{o}) where to look for the light, it would seem reasonable to require a 99% probability-of-seeing whenever the observer's point of central fixation is within 2.5^{o} of the signal light. Thus, the mariner who knows within 20^{o} of horizontal visual arc where to look needs only to divide the arc into four 5^{o} segments to find the light. This makes the light "moderately easy"[4] to find.

The means by which this or any other adopted ease-of-finding criterion is achieved in the calculation of luminous range is, of course, through elevation of E_L. It is not necessary to adjust I_e. The right-hand insert in Fig. 1 shows that E_L should be elevated by a factor of three to meet the 5^{o} ease-of-finding criterion for photopic background conditions. In the scotopic region it requires no elevation. In the mesopic region its elevation increases from zero to three as background brightness increases. Therefore, E_L, when corrected for ideal environmental conditions to meet the ease-of-finding criterion, should vary as a function of background brightness in a manner such as that shown in Fig. 2. This curve is entitled the "Uncorrected Luminous Range Threshold Curve".

A "Corrected Luminous Range Threshold Curve" for uniform backgrounds and practical marine conditions is the logical successor to the uncorrected curve. It's derivation demands considerations much too detailed for presentation here, however. Included within the derivation of this curve should be a re-evaluation of the adequacy of the 0.2 microlux "International Marine Threshold". If this threshold is judged adequate for nighttime viewing conditions, a decision must be made concerning the maximum background brightness for which it applies. Because lighted background levels are typically in the mesopic region but extend into the photopic region, other levels, either discrete or continuous, will have to be adopted for use in the luminous range equations when the background brightness exceeds the levels to which the International Marine Threshold applies.

CONCLUSIONS

The validity of the heretofore generally accepted premise that effective intensity relationships should be determined from judgments of "equivalent fixed intensity" at adopted practical eye illumination levels is questioned. Contrary to the recommendations resulting from the laboratory investigations of Toulmin-Smith and Green[5] and the subsequent paper of Hampton[6], it is suggested that elevations in eye illumination level to account for various marine environmental factors that do not exist in the laboratory should in no way influence the calculation of effective intensity. Additionally, effective intensity calculations should be based upon threshold measurements of "equivalent ease-of-seeing", not upon judgments of equal intensity as previously advocated.

It is suggested that the term "effective illumination", which is used for flashing lights in the computation of luminous range, be defined as the illumination from a juxtaposed steady-burning source that corresponds to a foveal 99% probability-of-seeing. In marine application, elevations of its value over and above its laboratory value are necessary to account for environmental factors which tend to reduce ease-of-seeing. Similarly, it must be adjusted in order to meet the luminous range "ease-of-finding" criterion in cases where the level of adaptation is mesopic or photopic. This latter adjustment is incorporated into a recommended "Uncorrected Luminous Range Threshold Curve", which is shown in Fig. 2.

This revised approach to the calculation of effective intensity has two important advantages over the method requiring adjustment of effective intensity as a function of observer eye illumination level: (1) it is simpler, (2) it is more accurate. Removal of the requirement to make difficult apparant intensity judgments in the laboratory experiments from which effective intensity relations are developed is a big advantage on both accounts. Although there are no known published references stating the fact, it is generally acknowledged among reliable authorities in visual aids to navigation that no one except Green himself (at age 75) has been able to duplicate the results reported in the Toulmin-Smith and Green paper. Without even questioning the validity of the method, this certainly points up the difficulty and inaccuracy inherent in its execution.

Common threshold techniques offer much more accuracy and are much simpler to perform. Schmidt Clausen[7] finds a 99% probability-of-seeing found "only when three successively determined values showed no deviations from each other" to be very satisfactory. Kishto[8] prefers a method whereby "the observer adjusts the magnitude of the stimulus until he can just detect it against the background", which, he says, gives thresholds that "correspond to a 75-80% probability of perception". Blackwell prefers to determine thresholds for a 50% probability-of-seeing and to convert these results to a 99% probability-of-seeing by multiplying by a factor of two in accordance with his "normal ogive"[9]. The inaccuracies in the Blackwell normal ogive method as noted by Kishto[10] (due to differences among observers and variations of conditions of observation) are most certainly not of sufficient magnitude to increase significantly the overall error already inherent in the luminous range equations (e.g., in the selection of meteorological visibility, v). At the least, it, the Schmidt-Clausen and the Kishto techniques are repeatable to much greater accuracies than have heretofore been experienced with near-threshold intensity matches such as those performed by Toulmin-Smith and Green, a factor which in itself is suitable justification for adoption of this revised philosophy concerning the laboratory measurement and the practical marine use of effective intensity.

TABLE I

INVESTIGATOR	Dark Adapted 99% Prob. of Seeing Foveal Threshold	REMARKS
Reynaud (1859)	.1 ulx.	Measured in open air
Gehlhoff and Schering[11] (1919)	.14	Mean for two observers. Steady light
Lohle[12] (1929)	.15	Monocular - one observer
	.11	Binocular - another observer
Green[13] (1935)	.06	Steady light; 3 observers
Stiles and Crawford[14] (1937)	.04	Monocular; two observers
	.06	.75 sec flash every 3 seconds
Hill[15] (1946)	.2	Monocular; average age 32; 2.5 second observation time; 90% value converted to 99% value
Tousey and Hulbert[16] (1948)	.04	Value at transition from foveal to parafoveal vision -10^{-2} nits
Blackwell and McCready[17] (1952)	.1	1 sec flash; irregular presentation
Meulders[18] (1958)	.03	1° Parafoveal
Luizov and Bulanova[19] (1960)	.03	5 observers "foveal vision"; "point source at infinite duration"; corrected from reported .02 value for 80% probability
Schmidt Clausen[20] (1968)	.04	14' Parafoveal, 3 sec flash, regular, dark intervals >5 secs.

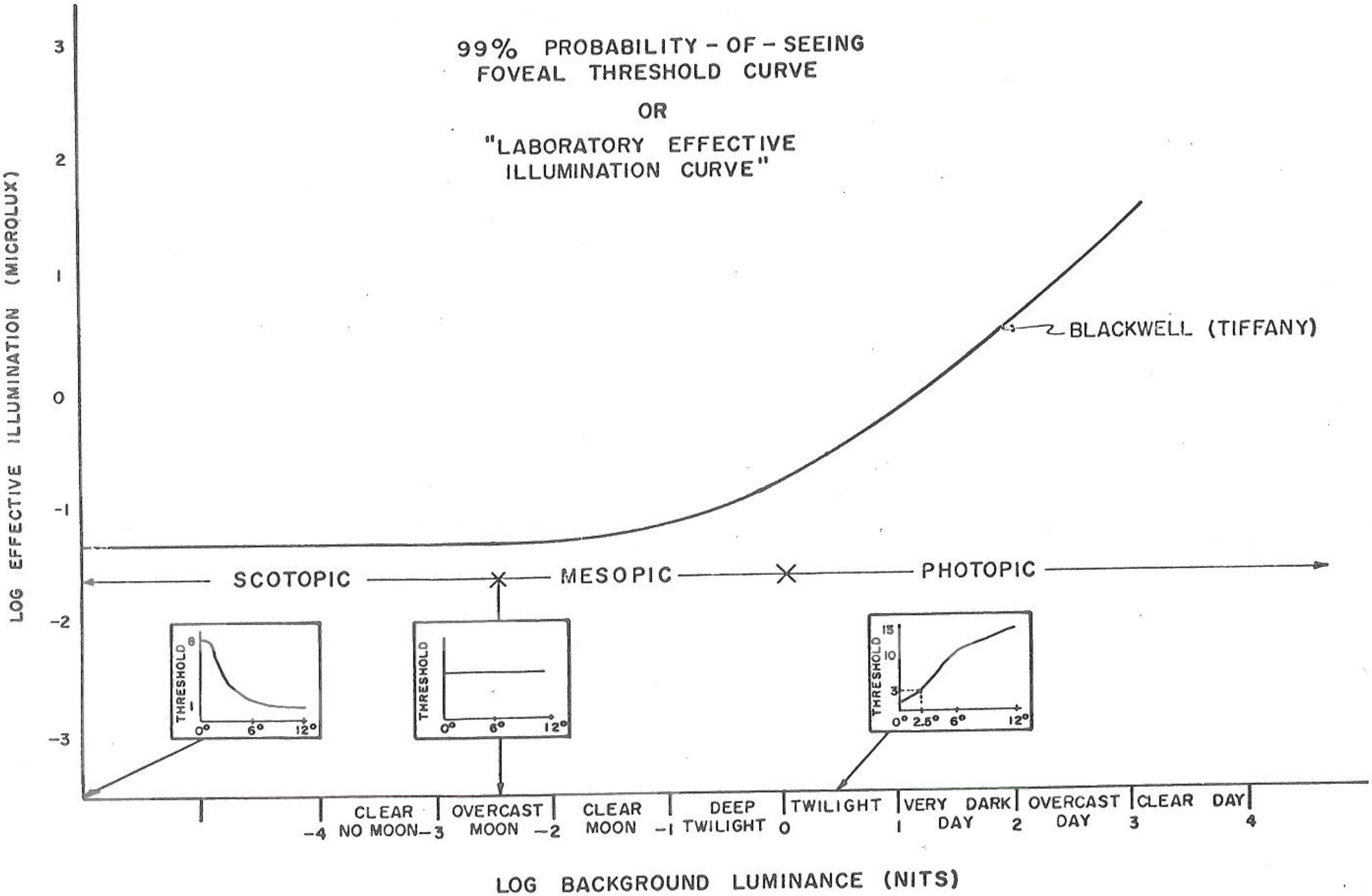
99% PROBABILITY - OF - SEEING
FOVEAL THRESHOLD CURVE
OR
"LABORATORY EFFECTIVE
ILLUMINATION CURVE"
BLACKWELL (TIFFANY)
LOG EFFECTIVE ILLUMINATION (MICROLUX)
SCOTOPIC
MESOPIC
PHOTOPIC
THRESHOLD
CLEAR NO MOON
OVERCAST MOON
CLEAR MOON
DEEP TWILIGHT
TWILIGHT
VERY DARK DAY
OVERCAST DAY
CLEAR DAY
LOG BACKGROUND LUMINANCE (NITS)

FIGURE 1

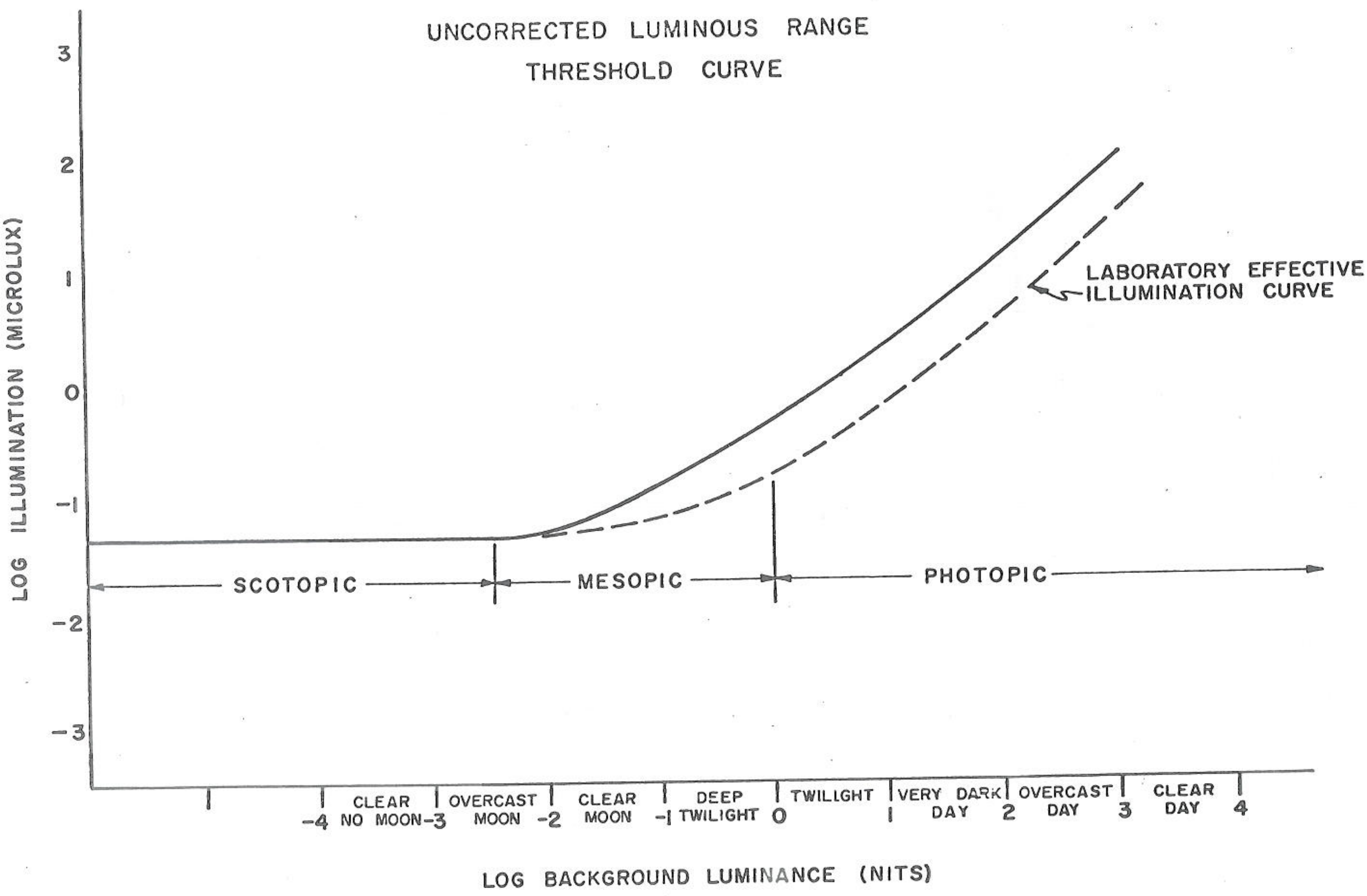
UNCORRECTED LUMINOUS RANGE
THRESHOLD CURVE
LOG ILLUMINATION (MICROLUX)
3
2
1
0
-1
-2
-3
LABORATORY EFFECTIVE
ILLUMINATION CURVE
SCOTOPIC
MESOPIC
PHOTOPIC
-4
CLEAR NO MOON
-3
OVERCAST MOON
-2
CLEAR MOON
-1
DEEP TWILIGHT
0
TWILIGHT
1
VERY DARK DAY
2
OVERCAST DAY
3
CLEAR DAY
4
LOG BACKGROUND LUMINANCE (NITS)

FIGURE 2

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