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RECOMMENDATIONS ON THE DETERMINATION OF THE LUMINOUS INTENSITY OF A MARINE AID TO NAVIGATION LIGHT

The attached *recommendations on the determination of the luminous intensity of a marine aid to navigation light have been approved by the International Association of Lighthouse Authorities (IALA) and are brought to the attention of Member Governments.

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* Owing to the limited number of copies, distribution is restricted.

RECOMMANDATIONS POUR LA DÉTERMINATION DE L'INTENSITÉ LUMINEUSE D'UN FEU DE SIGNALISATION MARITIME

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Décembre 1977

Extrait du BULLETIN de l'AISM, n° 75 - 1978-3

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RECOMMENDATIONS ON THE DETERMINATION OF THE LUMINOUS INTENSITY OF A MARINE AID-TO-NAVIGATION LIGHT

December 1977

Extract from the IALA BULLETIN, n° 75 - 1978-3

ASSOCIATION INTERNATIONALE DE SIGNALISATION MARITIME
INTERNATIONAL ASSOCIATION OF LIGHTHOUSE AUTHORITIES
43, Avenue du Président-Wilson, 75116 Paris

Recommendations on the determination of the luminous intensity of a marine aid-to-navigation light

December 1977

These Recommendations and the following Technical Note were prepared by the I.A.L.A. Technical Committee on Calculation of Intensity of Lights (Chairman: L. G. REYNOLDS) and approved by the Executive Committee of I.A.L.A. in December 1977

The International Association of Lighthouse Authorities makes the following recommendations:

(a) DEFINITION OF THE LUMINOUS INTENSITY* [1]

The quoted luminous intensity of a marine aid-to-navigation light shall be taken as that obtained, within defined limits of tolerance of luminous intensity, within the zone of utilization of the light.

Unless otherwise specified, the zone of utilization is defined as the ensemble of all directions from the light, within which it is intended to be seen from a vessel.

(b) DETERMINATION OF THE LUMINOUS INTENSITY BY MEASUREMENT

Before bringing into service a new type of aid-to-navigation light, at least one equipment of that type shall be subjected to appropriate photometric measurements. The measurements shall provide information on the luminous intensity of the light for substantially all directions within its zone of utilization. Measurements on flashing lights* shall provide information on the variations of luminous intensity wi h time. In each country, the competent technical authority shall determine the appropriate measurements to be made for each type of aid-to-navigation light. Photometric methods shall be determined by the laboratory to which the task is assigned, but, as an indication of the general principles to be followed and of the problems involved, reference should be made to Section A of the Technical Note.

(1) The terms marked with an asterisk are defined in Chapter 2 of the IALA "International Dictionary of Aids to Marine Navigation". An alphabetical list of these terms with reference numbers is given in Appendix II to the Technical Note, p. 43.

(c) CALCULATION OF EFFECTIVE INTENSITY* OF FLASHING LIGHTS

For flashing lights an "effective" intensity shall be determined from the photometric data, by the application of one or other of the methods given in Section B. 3 of the Technical Note. In each country, the responsible authority should make a choice of method and apply this consistently. The method used should be stated.

If it is desired to determine the effective intensity of trains of rapidly-repeated flashes, then Method II should be used.

In applying these methods, the value of the time-constant of vision shall be taken equal to 0.2 second for night-time observation. For day-time observation at all levels of background luminance* of 100 candelas per square metre* or above, the value of the time-constant shall be taken equal to 0.1 second.

(d) "IN SITU" TESTING AND TYPE-TESTING

If possible, the photometric measurements should be made on a complete aid-to-navigation light as installed, including protective housing enclosing the optical system. To this end, measurements "in situ" may be desirable (See Technical Note, Section A. 3).

Measurements may also be made at suitable test sites, on a complete equipment, or on a source-optic combination without protective housing, and possibly also without colour filters* intended for use in service. Such measurements, after correction for the effects of protective housing and of colour filters (where used), shall be applied to the actual equipment intended for subsequent installation, or to a light consisting of an identical source and optical system and operated under identical conditions to those of the aid-to-navigation light in question. The deduced effective intensity and luminous range* may be taken as those of the installed aid.

(e) FACTORS FOR LOSSES DUE TO PROTECTIVE HOUSING, TO THE USE OF COLOUR FILTERS, AND TO SERVICE CONDITIONS

Factors shall be applied to luminous intensities obtained by measurements as in (d) above, where these are necessary to allow for losses due to protective housing and the inclusion of colour filters. For the former a factor of 0.85 is to be applied (See Technical Note, Section A. 4). For the latter, separate measurements of transmission factors* of colour filters are to be made and these are to be applied as reduction factors (See Technical Note, Section A.2.4).

Responsible authorities may, at their discretion, apply a further factor of 0.75 for the effects of service conditions (See Technical Note, Section A.5). If so, this should be stated.

(f) USE OF RATIO-ING TECHNIQUES

For existing aid-to-navigation lights for which both "in situ" measurement and type-testing are impossible (e.g. in the case of unique older optics in inaccessible tower locations), every attempt shall be made to obtain an approximate effective intensity by comparison with known measured data for a similar optical system with a different source or for a similar source with a different optical system. These techniques are discussed in Section D of the Technical Note.

(g) QUOTATION OF LUMINOUS INTENSITY

The effective luminous intensity over the zone of utilization shall be determined from the measured values, with limits of tolerance based on the variation of effective intensity within the zone. The tolerance on the published value of a luminous intensity shall, unless otherwise stated, correspond to the last significant figure of the published value.

The angular limits of the zone of utilization shall be stated in bearing and in elevation.

For lights on floating supports, the zone of utilization is defined with respect to a reference position; unless otherwise stated, this is to be taken as the position of the floating support in the absence of current, wind and swell.

Tolerances may be indicated for the limits of zones of utilization, or otherwise should correspond to the last significant figure quoted.

(h) CALCULATION OF LUMINOUS INTENSITY WHEN MEASUREMENT IS IMPOSSIBLE

If — and only if — none of the foregoing methods can be applied, the effective luminous intensity shall be calculated, using the methods of Section C and Section B of the Technical Note.

In these circumstances, the figure of intensity shall not be published but shall be applied to the table of Appendix IV of the I.A.L.A. publication "Recommendation for the notation of the luminous intensity and range of lights". The nearest rounded-off value of the "nominal range"* corresponding to the entered value of intensity shall be published as the nominal night-time range of the light.

If a nominal day-time range is also required, the table of Appendix IV of the IALA publication "Recommendation for a definition of the nominal day-time range of maritime signal lights intended for the guidance of shipping by day" may be used in a similar way.

Technical Note on the determination of the luminous intensity of a marine aid-to-navigation light

CONTENTS

INTRODUCTION

The usefulness of a marine aid-to-navigation light depends greatly on the proportion of time for which it may be seen at any required distance. In enclosed waters the maximum distance at which it is required to be seen may be limited, but it is of interest to guarantee this range in as poor a visibility as it is economical to provide for. For major lights used as landfall* aids it is necessary to ensure that the limit of range determined by the luminous intensity of the light (i.e. the luminous range) should be at least as great as the limit of range determined by the curvature of the earth (i.e. the geographical range*) for all but the poorest conditions of visibility. The relationship between luminous range and luminous intensity may be derived from Allard's Law* and Koschmieder's Law, and requires knowledge of the meteorological visibility* characterizing the transparency of the atmosphere (1). A knowledge of the effective luminous intensity of the light throughout its zone of utilization is therefore necessary in order to permit calculation of the limiting range at which the light may just be seen by the mariner for a given meteorological visibility. A meaningful figure or figures characterizing the performance of the light is also required for publication in the Lists of Lights published in many countries.

The purpose of the present Technical Note is to describe how to measure or to calculate one or more figures of luminous intensity to provide meaningful descriptors of the performance of a light when it is used at an installation. It will rarely be possible to make the necessary measurements on the installed light in situ, but for the majority of lights it should be possible to measure the spatial distribution of luminous intensity of the beam or beams* of light emitted, e.g. by a fixed lens* or by a number of prismatic lens* panels, either on the actual equipment to be installed or on an exactly similar one. The measurements will usually be made at a photometric test site set up for this purpose. As far as possible, the equipment measured at the site should be identical in all particulars with that of the installation, including both colour filters and lantern glazing* where applicable. In cases where these cannot be included in the measuring set-up, corrections for colour filter transmission factors may be derived from separate measurements and allowance for losses in lantern glazing may be made as indicated in Section A.4. For flashing lights exhibiting flashes* of short duration, an effective luminous intensity, less than the maximum of measured intensity during the flash, is to be derived, using knowledge of the response of the human eye to short flashes. This effective intensity is to be used in the calculation of luminous range.

The Technical Note is divided into four Sections A, B, C and D. The recommended way of determining the intensity of the beam is by direct photometric measurement on a suitable measuring range.

Section A discusses in detail the problems of the photometry of projection apparatus and may be used as a guide to the most suitable method to be used in any given circumstances. It must be recognised that a single figure for the peak luminous intensity on the axis of a projection system is usually an inadequate descriptor of the performance of the system. The extent to which other data are necessary, and the methods of obtaining such data, are discussed in Section A.

Section B deals with methods of calculating the "effective intensity" of a light from data on the variation of instantaneous luminous intensity with time, as measured by the method of Section A.

Section C gives details of a method for the approximate calculation of the peak luminous intensity of a beam from an aid-to-navigation light, i.e. the intensity at a maximum of its distribution in space, usually in the direction of the optical axis* of the beam projection system. The approximate derivation of effective intensity is also included. This type of calculation is intended for use when direct photometric measurement is impossible and when the data required for the methods of Section D are not available.

Section D describes methods by which it is possible to obtain better estimates of luminous intensity and effective intensity, for a given source-optic combination, than those obtainable by the methods of Section C, provided that measured data are available for an identical optic with other sources or for an identical source with other optics. This type of calculation is preferred to that of Section C, where possible.

(1) For further information on the relationship between luminous intensity and luminous range, see the IALA "Recommendation for the notation of luminous intensity and range of lights" [1], which is applicable to lights seen by night, and the IALA "Recommendation for a definition of the nominal daytime range of maritime signal lights intended for the guidance of shipping by day" [2].

SECTION A

METHODS OF MEASUREMENT OF THE LUMINOUS INTENSITY OF AN AID-TO-NAVIGATION LIGHT

1. INTRODUCTION

In this section guidance is given on the particular problems of photometric measurements on aid-to-navigation lights. Section A.2 deals with measurement of luminous intensity in a photometric laboratory or over an open-air photometric range. Section A.3 considers the problems of measurement on installed lights on site and Sections A.4 and A.5 deal with allowances for loss of luminous intensity due to the housing of the light and to service conditions.
Methods described are currently in use, or have been successfully used in the past, for the measurement of luminous intensity of a projected beam. The appropriate method must be determined in relation to each individual case. No general recommendation of preferred method can be given which would have sufficiently wide validity.
As a general guide, reference may be made to Walsh [3], particularly Chapter XIV, to Reeb [4] and, for the historical background, to Blondel [5]. The special problems of projection photometry are dealt with in documents published by the U.S. National Bureau of Standards [6, 9], by the Illuminating Engineering Society of Great Britain [7], and by the International Association of Lighthouse Authorities [8].

2. MEASUREMENT OF LUMINOUS INTENSITY

In accordance with clause (a) of the Recommendations, luminous intensity is to be measured on an ensemble of directions forming the zone of utilization. In practice the number of directions on which measurement is required may be reduced by judicious assessment of the symmetry of angular distributions of intensity. A minimum requirement for the beam from an optical panel* will be to measure the luminous intensity distribution in the horizontal plane and in the vertical plane through the optical axis of the panel, but for more complete information the intensity distribution has to be measured in the horizontal plane and in a number of cones with axis vertical and vertex at the centre of the optical system. These may be both above and below the horizon plane but interest will generally be limited to those below it.
For flashing lights produced by eclipsing or switching the light source, the distribution of intensity with time for each direction of interest has to be measured directly. For at least the principal directions, effective intensity has to be derived by application of one of the methods given in Section B. For flashing lights produced by rotating optical systems, the same method may be applied; alternatively, measurements of angular distribution of intensity may be made on the optic when not rotating, in cones of various angles as described above. Such distributions may be converted to distributions of intensity with time for specified rotation rates. Effective intensity for each elevation angle is then calculated from the distribution of intensity with time measured in each appropriate cone.
An extreme accuracy in measurements of luminous intensity for lighthouse application is not required, since the luminous range does not change rapidly with intensity except at very good visibilities. Nevertheless, it is necessary to maintain the maximum of reasonable precaution against measurement errors.
The measurement of luminous intensity may be made indoors, but where long distances are essential for accurate measurement open-air photometric ranges will be necessary.
Measurements must be made using a suitable photometer*, which will generally be a physical photometer* using a photoelectric receptor. A photometer bench is commonly used at least for shorter range measurements and a goniometer should be available for measurements of angular distribution of intensity.
Power supplies to light sources and particularly to working standard* sources must be very stable, and precision measuring instruments must be used to read photoreceptor output and to ensure and check stability of the supplies.

2.1. PHOTOELECTRIC RECEPTORS

2.1.1 **General Requirements**

Luminous intensity is usually derived from the illuminance* at a known distance from the test light, measured by a photoelectric receptor.

Requirements of the receptor include:

(a) A spectral sensitivity approximating as close as possible to the spectral luminous efficiency* V (λ) for the C.I.E. standard photometric observer in photopic vision [10].

(b) Adequate absolute sensitivity for operation at any distance of the receptor from the light required in practice.

(c) Short response time in comparison with any significant changes of intensity during measurements. This is of particular importance in the measurement of rhythmic lights.

(d) A linear relation between incident light (whether perpendicularly or obliquely incident) on the receptor surface and the photoelectric current.

(e) As far as possible, freedom from the effects of fatigue and of ambient temperature variations, and from long term deterioration. The influence of temperature should be particularly considered where measurements are to be made in the open air.

The optical system at reception must be arranged so that, as far as possible, the whole of the photosensitive area of the receptor is uniformly illuminated by the light under test. If this is not possible, then the same restricted area of the receptor should be used for both test light and reference light.

Correction of the spectral sensitivity of any given receptor to the C.I.E. V (λ) function requires synthesis of the spectral transmittance* of correction filters. References [11] to [14] indicate methods which have been used for this purpose. Corrected receptors are now commonly available commercially to various degrees of accuracy.

It is possible to make use of uncorrected receptors if these are first calibrated by comparison with a reference receptor, which may be either the human eye or a working standard photoelectric receptor adapted correctly to the V(λ) function.

In the first case, the correction factor for measurement of intensity of light of a given colour may be found by measuring the intensity of a light of that colour in turn by the uncorrected receptor and by heterochromatic photometric matching against a working standard (incandescent) light source, using a visual photometer, for example a flicker photometer*.

In the second case, the correction factor for light of a given colour may be found by measuring the intensity of a light of that colour in turn by the uncorrected receptor and by a receptor correctly adapted to the V (λ) function.

The adequacy of these corrections is dependent on the availability in the laboratory of light sources of colour sufficiently closely approximating that of the light for which the luminous intensity is ultimately measured. The difficulty of colour correction of receptors is increased if it is required to measure the intensity of a coloured light of high purity. This is discussed in more detail in Section A.2.4.

2.1.2 Types of Photoelectric Receptor in Use

2.1.2.1 *Selenium photovoltaic cells* have been used widely as receptors. They provided a well-defined plane of reception and photo-sensitive area, and could give sufficient output without amplification to drive meters for direct observation. They were subject to variations in sensitivity, particularly due to fatigue and to thermal change. They were often available commercially with simple colour correction filters, but these did not give very good adaptation to the V(λ) function. Better adaptation could be obtained by the use of combinations of filters of different colours and dimensions.

2.1.2.2 *Phototubes* are vacuum electronic tubes with cathodes capable of emitting photoelectrons when exposed to radiation. They have high stability, are linear in response over a wide dynamic range, and have a short response time, well suited to measurements on rhythmic lights*.

They require auxiliary amplifying systems and usually have to be provided with suitable external filters individually designed to adapt the cathode spectral sensitivity to the V (λ) function.

2.1.2.3 *Photomultipliers* are phototubes in which signal amplification is provided by secondary electron emission from intermediate electrodes. Their sensitivity is greater than that of phototubes, but is ultimately limited by the dark current.

Greater care is necessary with photomultipliers to ensure supply stability and to operate only over the linear part of the dynamic response.

Photomultipliers of improved stability and linearity, designed especially for photometric use, are becoming commercially available.

2.1.2.4 *Silicon photodiodes* are semiconductor devices which are now widely used as receptors in commercial photometers because of their stability and convenience. They have a very short response time, of the order of a few nanoseconds, and have a linearity and sensitivity comparable with those of phototubes. They can be made largely independent of temperature extremes. Signal-to-noise ratios are generally lower than for phototubes and photomultipliers.

In recent years very high-grade silicon photodiodes [14], colour-corrected to match the spectral luminous efficiency for the CIE standard photopic observer to very close tolerance, have become commercially available in certain countries.

2.2 TECHNIQUES OF MEASUREMENT

2.2.1 Minimum Photometric Distance

The measurements of luminous intensity must be made at such a distance that the measured results adequately represent the performance of the optical apparatus when observed at the large ranges normal in maritime applications.

If a certain angular resolution is required in the description of performance throughout the zone of utilization, then the measuring distance must be great enough to ensure that the angles subtended by the test optic at the point of reception and by the entrance aperture of the receptor at the point of emission are both insignificant in relation to that resolution.

It is also necessary to measure at such a distance that the illuminance at the receptor varies as the inverse square* of the distance of the receptor from the test optic. This can conveniently be established by plotting the product $E \cdot r^2$ against r, where E is the illuminance and r the distance. The distance at which the curve approaches closely the asymptote $E \cdot r^2 = \text{constant}$ can be taken as a minimum photometric distance.

Various formulae have been given to assist in the estimation of adequate working distances [7, 9]. Typical measuring distances are up to about 50 m for small optical systems, e.g. buoy lanterns, sealed beam lamps* and lighthouse optics of low order*, but may be up to 200 or 300 m for optics of high order.

2.2.2 Indoor (short range) Measurements

If the minimum photometric distance is less than about 50 m, measurements can be effected indoors. The walls of the photometric laboratory must be matt black drapes and baffles must be used to reduce stray light*. It is also useful to place diaphragms between the optic under test and the receptor; they must not screen any part of the optic from the receptor but must as far as possible screen the receptor from all parts of the room other than the position of the optic.

For indoor measurements photometric test benches are commonly used, on which the photometer can be moved over a suitable range of distances from the optic under test, for which the inverse square law can be verified. The receptor is usually calibrated on the test bench by reference to a working standard of luminous intensity, the light from which should have a colour as close as possible to that of the light source in the equipment under test.

2.2.3 Measurements in the Open Air

If the minimum photometric distance is more than about 50 m, it is usually more economical to have most of the test site in the open air. Measurements can be made by day if the luminous intensity of the beam is adequate. A suitable test installation would comprise an enclosure for the optic under test, with an aperture permitting the whole optic to be seen from the position of the receptor, and a separate enclosure to house the photometer and associated equipment. The enclosures should be sufficiently high above ground to eliminate ground reflections and to minimise scintillation [8].

The receptor may be of a telescopic type [6, 7, 8] and should incorporate an iris so that the acceptance angle can be made to fit closely to the size of the optic under test. Means must be provided for controlling and checking alignment of the receptor. In order to reduce the effects of atmospheric scattering, particularly the scattering of daylight into the receptor, all measurements should be carried out in conditions of good visibility ($V > 5$ km if possible). The loss of luminous intensity resulting from atmospheric scattering over the measuring range should be estimated, either directly by measurement over the whole range on a light source of known luminous intensity, or by calculation from the visibility as measured by a local visibility-meter. If the loss is significant, a correction must be made to the measured luminous intensities from the equipment under test.

Other errors due to stray light may be reduced by designing the test enclosure as a light-trap and keeping the test equipment well inside it, by providing diaphragms at intervals along the light-path between the enclosures [6] and by causing light entering the receptor to pass through a long tube. For estimates of the magnitude of the errors involved, see Reference [8].

To deal with the large difference between beam intensity of high order optics and the luminous intensity of working standards, one of the following methods may be used :

(a) Direct comparison of test beam and working standard over the full base-line, using a receptor linear over a very wide dynamic range, such as the Boutry-Gillod phototube [8, 11]. This effectively eliminates effects of loss due to atmospheric scattering.

(b) Use of a working standard at relatively short distance from the receptor to give a range of illuminance at the receptor similar to the values obtained from the test optic over the full base-line.

(c) Attenuation of the light from the test beam to bring it within the optimal measuring range of the photometer. In this case various devices are available by which controlled attenuation of the light may be introduced, either continuously or in discrete steps. Such attenuators must be spectrally non-selective and calibrated to adequate precision. They include neutral density filters* and wedges, polarizers, click-stop irises and rotating sector-discs. The use of sector-discs when measuring intensity of rhythmic lights or of discharge lamps may introduce errors and is therefore not recommended.
Care must be taken when using attenuators that the photosensitive area of the receptor remains fully illuminated under all conditions.

(d) Use of an intermediate standard of luminous intensity between that of the test optic and that of the working standard. This is commonly a standard projector*, of sufficient intensity that, when operated over the whole base-line, the illuminances at the receptor due to both standard and test optic lie within the linear range of receptor response.
The standard projector is calibrated against the working standard under laboratory conditions.
As in (a) above, this method eliminates the loss due to atmospheric scattering.

2.3 FLASHING LIGHTS

In order to obtain the effective intensity of lights which are normally operated in a flashing mode, it is necessary to know the luminous intensity as a function of time for the optic under test. Except in the case of rotating optical systems (see Section A.2), this must be measured directly, using a suitable photo-electric receptor having a sufficiently short response time to give the required resolution of the intensity variations with time. Generally, a phototube or photodiode must be used.

If it is required to find the integral of luminous intensity with respect to time, e.g. if the method of Schmidt-Clausen for calculation of effective intensity is to be used, an intensity-time integrating photometer [15] can be employed.

Care is required in such measurements to ensure that saturation of the receptor does not occur at the higher instantaneous intensities occurring during the flash, as the full value of integrated intensity may thereby not be measured.

The measurement of integrated intensity can also be made by the use of bolometers, which have a slow response imposed by their thermal capacity. The time constant will effect smoothing and will generally be sufficiently long that the receptor will not become saturated when high instantaneous intensities are presented to it.
The measurement of the peak intensity or of the time variation of intensity of very short flashes presents difficult problems. Even if phototubes are used as receptors, there may be serious limitations in accuracy of measurement due to the finite response time of the amplifiers and display systems, and in particular due to the stray capacities of the linking circuits between the receptor proper and its associated amplifier. Great care is also needed to avoid errors which may occur if there are within the flash high peaks of intensity which may exceed the linear dynamic range of the receptor.
Since the time variation of the luminous intensity from a rhythmic light source in a fixed optic is generally unaffected by the optical system, it may be more convenient to deal with temporal variations by measurements on the light source alone.

2.4 COLOURED LIGHTS

Coloured light may be produced directly f om certain luminous sources such as discharge* or fluorescent* lamps, but is usually produced by the combination of a white light source with a colour filter.
When the luminous intensity is required to be known for a light which is coloured when in use, it is recommended that direct measurement be made of the intensity of the coloured beam.
If, however, the coloured beam is produced by the use of a colour filter, it will often be easier to make measurements of the luminous intensity of the light beam in the absence of the filter and to multiply the measured intensity by the transmission factor of the filter for light of the given colour. The transmission factor may be conveniently measured separately using a light source of the same colour in the laboratory. Alternatively, the transmission factor for light of the given colour may be calculated from measurements of spectral transmittance. Absolute spectroradiometric measurements may also be made directly to find the spectral radiant intensity of the coloured light, from which the luminous intensity may be calculated.
If, however, luminous intensity is measured in the conventional way using a photo-receptor, very accurate adaptation of its spectral sensitivity to the V (λ) function is required and small departures from this may give seriously incorrect values for luminous intensity if they occur in a spectral region in which there is a rapid change of radiant intensity with wavelength.
Small departures may also lead to substantial proportional errors when measurements are made on red, blue or violet lights such that only the extremes of the visible spectrum are involved. For these, better accuracy may sometimes be obtained by the use of receptors precisely adapted to that part of the V (λ) function which is of interest, response at other wavelengths being insignificant.
A method of obtaining good adaptation to the entire V (λ) function by the use of a succession of filters, each giving precise adaptation over a part only of the V (λ) function, and by processing the resulting data, has also been described [13].
The measurement of luminous intensity of monochromatic light can be effected by making a measurement of a radiant quantity characterising the output and by using knowledge of the luminous efficiency of the radiation.
If there is significant chromatic aberration in the test optic, special techniques have to be used [16].

2.5 MEASUREMENTS OF SPATIAL ANGULAR DISTRIBUTION OF LUMINOUS INTENSITY

In order to verify performance of an aid-to-navigation light throughout its zone of utilization, measurements of the angular distribution of the luminous intensity must be made at a sufficient number of directions within that zone. To define these directions in an orderly manner, it is necessary to specify them with respect to a reference system of axes related to the optical system. This must comprise a conveniently chosen reference centre (close to, and usually at, the focus* of the optic), through which passes a reference axis (which will coincide with the vertical axis when the light is installed), and a reference meridian plane. The plane normal to the reference axis and containing the reference centre may be referred to as the equatorial plane (Fig. 1).
To effect the necessary rotations for measurement purposes, the optic under test is most conveniently mounted on a goniometer [17, 18, 19]. If the vertical plane beam divergence* is considerable, the goniometer should be of the type which has one fixed horizontal axis, perpendicular to the line joining the optic under test to the receptor, and one axis, perpendicular to the former axis, which can be tilted to various required angles from the vertical.
Rotation may be effected either at suitably chosen discrete intervals of angle or continuously. Backlash in rotation mechanisms may be minimised by good engineering design, by the use of anti-backlash devices and by maintaining rotation in one sense throughout a set of measurements.
If the distribution of luminous intensity is approximately rotationally symmetrical, it may be sufficient to measure the distribution of intensity only in the equatorial plane and in one or two planes through the reference axis.
For a pencil beam* of fixed direction, the reference centre may be chosen at the focus of the optical system or at some convenient point close to it, e.g. the centre of the exit aperture. For practical purposes it will sometimes be sufficient to measure distributions of intensity in the equatorial plane and in a meridian plane containing the maximum of the luminous intensity distribution of the equatorial plane. In general, however, the angular distribution of luminous intensity has to be measured in the equatorial plane and in cones at various angles of elevation with respect to the equatorial plane, comprising all directions of light of interest within the zone of utilization.

For a rotating optical system, the reference axis is the axis of rotation and a reference meridian plane for the optic is usually chosen to contain the optical axis of one of the panels. Measurements of luminous intensity as a function of direction may be made exactly as for the fixed direction light. It is, however, often convenient to allow the optical system to rotate at its working speed and to record continuously the variation of illuminance with time at a fixed receptor in the horizontal plane through the reference centre. The axis of rotation of the optic must be the secondary axis of the goniometer which can itself be rotated about the primary horizontal axis to selected discrete angles. Each such angle corresponds to a different elevation angle with respect to the final installed system, and each continuous record gives the intensity-time distribution corresponding to that elevation angle. If the light source is not rotationally symmetrical and remains fixed while the optical system rotates, it will be necessary to examine the luminous intensity distribution for at least two different orientations of the receptor with respect to the source.
The minimum distance between the test apparatus and the measuring receptor required for accurate measurement of angular distributions of luminous intensity is in general likely to be greater than that required for the measurement of luminous intensity on the axis of the projection system, perhaps by a factor of between 3 and 10 times [6, 8]. An estimate may be made if the angle of beam divergence* is known approximately. The angular resolution required determines the required ratio of optic aperture radius to measuring distance.

3. MEASUREMENTS "IN SITU" [20]

It is sometimes necessary to make measurements of luminous intensity on an installed aid-to-navigation light, particularly if it is required to assess the loss of light caused by lantern glazing, deterioration and dirt.
The principal difficulty is generally that of finding a convenient fixed location for the measuring equipment. Measurements have to be made at night and should be confined to periods of very good visibility ($V > 10$ nautical miles). To minimise the effects of atmospheric scattering, it is necessary to use a standard projector (see Section A.2.2.3). Difficulties may arise from scintillations caused by air turbulence; this effect is reduced if measurements are made toward the end of the night.
Very accurate results cannot be expected from "in situ" measurements.

4. INTENSITY LOSSES THROUGH GLAZING

Some types of light require protective housing. If they are minor lights it is possible to measure the luminous intensity on the complete installation and no correction for losses is required. However, most major lights will require the installation of the lighting apparatus within a protective housing or lantern*, comprising e.g. lantern glazing, supporting members, or astragals*. It will then generally be necessary to correct the measured intensities by a factor which comprises the losses resulting from obstruction by astragals and the reflection and transmission losses at the lantern glazing. *It is recommended that the factor should be taken as 0.85 for a system in clean condition.*

5. SERVICE CONDITIONS FACTOR

In practical installations, reduction of luminous intensity is likely to occur under service conditions. A distinction may be made between the effects of meteorological conditions (which may be only temporary), the effects of dirt and salt deposition (which can be minimised by an efficient regular programme of cleaning of the optical system and housing) and effects due to deterioration of the light source and optical system which are progressive throughout service life.
It is clearly impossible to represent such a complex of factors in any simple way, and a proper assessment of the various effects could only be made by measurements on site at regular intervals. However, in order to give a more realistic figure for average performance under service conditions than is given by the luminous intensity measured in a laboratory or on a photometric range, certain countries apply a further factor to the measured intensity.
It is recommended that this factor be taken as 0.75.

SECTION B

THE EFFECTIVE INTENSITY OF A RHYTHMIC LIGHT

1. INTRODUCTION

The range at which an observer may just see a light flash may be described in terms of a single parameter which is called the "effective intensity" of the flash. The eye does not analyse the variations of the luminous flux incident upon it during the course of a brief flash but reacts to the total visual impression in assessing the apparent luminosity* of the light. In particular, when the flash can just be seen it is possible to obtain a quantitative measure of the effectiveness of its light by comparing it with a steady light which is also just seen under the same conditions at the same range and by the same observer. Sufficient consistency is obtained in such observations to permit the evaluation of effective intensity of the flash as the intensity of the fixed light which is its equivalent for detection at threshold*. In the present Section, methods of evaluating the effective intensity for various flash forms (distributions of luminous intensity with time) will be considered. The effective intensity is defined by the equivalence of fixed and flashing lights at threshold levels, and levels above threshold are not considered. Unless otherwise stated, the evaluations are for single flashes, i.e. the interval between successive flashes is assumed to be at least a few seconds.

To permit the use of methods of evaluation which shall be simple, universally applicable and of sufficient accuracy for practical purposes of lighthouse engineering, the other conditions of observation have been restricted to certain standard reference values, which have been chosen to represent typical average conditions for marine observation of lights:

(a) Young observer with normal vision.

(b) The light seen in foveal vision and at chromatic threshold.

(c) Subtense angle of light source at the eye of the observer $\leqslant 1'$.

(d) Colour of light: White.

For observation by night, the level of background luminance has been assumed not to exceed 10^{-2} cd/m². For observation by day, the level of background luminance is dependent on diurnal and seasonal effects and on weather conditions. For the effect of such variations on the threshold of illuminance for vision of steady lights, see Ref. [2].

The effective intensity deduced may be applied to determine the luminous range of the light, using the methods laid down in Ref. [1], and in particular may be used to determine the nominal range of the light for publication in Lists of Lights. The methods of evaluation given make use of time constants of the visual system denoted by C in the Method I, by A in the Method II and by *a* in the Method III. (It should be noted that, in the Method I, the time-constant is really C/F, where F is a "form-factor", less than unity for all non-rectangular flashes; the time-constant is only equal to C in the case of rectangular flashes). These constants are closely related to the more familiar time-constant *a* of the Blondel-Rey expression [21] for the effective intensity I_e of flashes of rectangular form, viz. $\frac{I_e}{I_0} = \frac{\tau}{a + \tau}$ where I_0 is the intensity of the flash at maximum and τ is the duration of the flash. In general these time-constants are dependent on the colour of the light exhibited, on the level of background luminance against which the light is seen, and on the angular subtense of the light source at the eye of the observer. *Under the reference conditions stated above, for night-time observation it is recommended that the values of C, A and "a" be taken equal to 0.2 second.* It is not considered necessary, for the purpose of calculation of effective intensity for practical marine applications, to take into account differences in the value of the time constant for different colours of lights. *For day-time observation at all levels of background luminance of 100 cd/m² or more, it is recommended that the values of C, A and "a" be taken equal to 0.1 second.*

2. THE CONCEPT OF EFFECTIVE INTENSITY OF A FLASH

In the case of a fixed light*, the measurements of Section A can supply all the information required for the prediction of performance. If, however, the light source is flashing or occulting*, or if the beam projection apparatus rotates, then for an observer at a given location there is a variation of luminous intensity from instant to instant of time. Usually this variation goes from zero or near-zero through a series of finite values falling again to zero. There is thus an "appearance of light"* of roughly definable duration. If the duration of light is clearly less than that of the neighbouring durations of darkness, we speak of a "flash". If the total duration is not more than about 0.3 second, the human eye responds to the totality of visual experiences within the flash; the total effect, whether expressed in terms of the apparent luminosity of the flash when easily seen, or of the intensity of the flash when just seen, is a function of the instantaneous intensities within the flash. If a flash is found to be just seen in conditions in which a steady light of intensity I_e is also just seen at the same distance and in the same atmospheric conditions, the flash is said to have an effective intensity I_e. It is this effective intensity which must be used when calculating the range of the light in any given atmospheric conditions.

3. THE EVALUATION OF EFFECTIVE INTENSITY

The determination of effective intensity for any given flash proceeds from knowledge of the variation of the instantaneous luminous intensity with time. It is usually desirable both to determine the form of this variation and to scale the curve so that the ordinates are the values of luminous intensity at each instant. Photometric measurements of luminous intensity and of the distribution of luminous intensity with time have been described in Section A, and the difficulties and limitations inherent in them have been discussed.

The classic work on evaluation of effective intensity was that of Blondel and Rey [21]. The formula based on their experimental observations was limited in its application to flashes of rectangular or quasi-rectangular form. They indicated a possible formula which might be applicable to flashes of non-rectangular form, and this was later elaborated by Douglas [22] into the Method III described below. The Blondel-Rey-Douglas formula has been widely used and has given satisfactory results in practice.

In Ref. [23] it is shown that results obtained by the three methods given below differ to some extent, but that the effect of these differences on the derived luminous range of the light is not significant in most practical applications. The differences may be more significant when a regulation requires that a light provide a specified luminous range; the values of luminous intensity calculated to meet the requirement may differ substantially according to the method of calculation selected. ***It is recommended that*** *national authorities should determine which of the methods they will apply; that each should apply only one method consistently; and that the method applied should be clearly stated.*

The differences of result by the three methods, for certain specific flash forms approximating forms commonly encountered in practice, can be seen in Tables 1 and 2 (pages 46-48). Rectangles and trapezia approximately represent the flashes from eclipsed lights; sine-squared and Gaussian curves approximately represent the flashes from rotating beams; the curves of Table 2 approximately represent the flashes from switched electric lights or from mantle burners*. For further tables extending to other flash forms, as well as for tables of explicit solutions for effective intensity for simple flash forms, see Ref [23].

Method I can also be applied when very short flashes are measured by comparison with standards of integrated intensity using time-integration photometers. It is not necessary to measure the complete flash form, but it is necessary to find also the maximum instantaneous intensity during the course of the flash (the so-called "peak intensity", I_0). Accurate measurements of I_0 for flashes of about one millisecond or less in duration present problems, as discussed in Section A.

3.1. METHOD I — THE METHOD OF SCHMIDT-CLAUSEN [24, 25, 26]

The variation of instantaneous luminous intensity I with time t during a flash is described by the function I (t). This has a maximum value I_0, the peak intensity of the flash. The integrated intensity of the flash, viz. the integral of instantaneous intensity with respect to time taken over the whole of the flash, is denoted by

$$J = \int_{\text{Flash}} I \cdot dt$$

According to Schmidt-Clausen, the effective intensity I_e of the flash is given by

$$I_e = \frac{J}{C + \dfrac{J}{I_0}} \qquad (1)$$

where C is a visual time constant *to be taken as 0.2 second for night-time observation and 0.1 second for day-time observation.*

In this form the method is convenient for use in evaluation of the effective intensity of short flashes produced by electronic flash tubes*, for which J can be measured directly. It is to be noted, however, that the peak intensity during the flash, I_0, has also to be measured.

For longer flashes, such as those produced by revolving beams, it may be more convenient to express effective intensity in the following form:

$$I_e = \frac{I_0 \tau}{\dfrac{C}{F} + \tau} \qquad (2)$$

where τ = total duration of the flash

F = the Schmidt-Clausen form-factor defined by

$$F = \frac{\int_{t_1}^{t_2} I(t) \cdot dt}{t_2 - t_1} \qquad (3)$$

where t_1 = time of commencement of the flash

t_2 = time of cessation of the flash

so that

$$\tau = t_2 - t_1$$

If a graph is drawn of the form of the flash, and a rectangle is drawn enclosing this, so that the rectangle is of length $t_2 - t_1$ and of height equal to the maximum of intensity of the flash, then the form-factor is the ratio of the area under the graph to the area of the rectangle (Fig. 2).

The precise choice of limits t_1 and t_2 is unimportant, provided that they correspond to instants of zero intensity preceding and following the flash, respectively. Where no such instants exist, as may be the case for flashes produced by revolving beams, the intensity of which may never fall completely to zero, it will generally be sufficient to choose instants at which the instantaneous intensity is at a sufficiently low value (for example, 5% of the peak luminous intensity of the flash). This is equivalent to calculating the effective intensity of the flash which is considered as being superimposed over a steady luminous intensity equal to that at the chosen instants t_1 and t_2.

For extremely short flashes, τ becomes negligible in comparison with C/F and equation (1) becomes

$$I_e = \frac{J}{C} \qquad (4)$$

Taking C = 0.2, this equation may be used for flashes shorter than 0.05 s. For these the effective intensity is five times the integrated intensity (when the unit of time is the second).

The expression (2) above can be readily represented by a simple electrical resistance circuit analogue. Certain countries have found it useful to develop additional circuit elements so that effective intensity may be derived for a wide range of values of background luminance and regular size of light source [27]. The variations of these parameters are outside the scope of the present document.

Specially-constructed "slide-rules" have also been developed for these calculations.

The use of a digital computer makes the calculations very simple. Generally it is convenient to evaluate J from the measured values of I (t), using any convenient standard integration programme. I_e is then calculated from equation (1) above.

3.2. METHOD II — THE METHOD OF ALLARD [28]

This method also proceeds from the variation of instantaneous luminous intensity I as a function of time t, described by the function I (t). The corresponding instantaneous effective intensity is defined by a function i(t).

According to the theory of Allard these functions are related by the differential equation

$$\frac{di}{dt} = \frac{I(t) - i(t)}{A} \qquad (5)$$

where A is the time-constant for visual response. In this case, A is associated with the time required for the eye to respond to a light stimulus, and is a measure of the so-called "inertia of vision".

For practical calculations under the reference conditions of night-time observation, A is to be taken as 0.2 second.

Solutions of equation (5) yield values of i (t) at each instant during and after the course of a flash (see Fig. 3). If it is assumed that the visual impression is proportional to the light stimulus, and in particular the assumption is made that the observer's eye remains in a constant state of adaptation during the variations of intensity within the flash, then equation (5) relates the instantaneous intensity I (t) during the flash to the luminous intensity i (t) of a fixed light which would result in the same visual response as that occurring in the eye at that instant. The assumption of constant adaptation is reasonable under the conditions of observation in which lights are seen at threshold levels by an observer adapted to surrounding light on the bridge of a vessel.

The effective intensity I_e is the maximum value of i (t) during the duration of the flash.

An explicit solution of equation (5) may be obtained in integral form (1). From this it may be seen that, for flashes of very short duration, the effective intensity becomes.

$$I_e = \frac{J}{A}$$

where J = integrated intensity, as defined in Section B.3.1. If the visual constant A be taken identical with C in Method I, it may be seen that the two methods give identical effective intensity for very short flashes.

It is generally more convenient to obtain solutions of equation (5) directly by computers rather than to use the explicit solution. The equation is identical with that for an electrical circuit consisting of a capacitor charged through a resistor from a time-varying voltage source. It is not considered, however, that an analogue circuit of this type can be readily constructed in practice to give results of sufficient accuracy. The use of a digital computer is therefore recommended. The problem is then one of finding the function i (t) as a solution of the differential equation given as equation (5) above, for any programmed or entered values of the function I (t). Any standard computer programme for the solution of first-order linear differential equations may be used. Ordinary difference methods are generally sufficient for this purpose. The effective intensity I_e is the maximum value of the solution i (t).

The Allard method can be readily applied to trains of rectangular flashes [23]. Results thus obtained are given in Table 3 for trains of 1 to 10 flashes, for two ratios of flash duration to period. The limiting values for infinite trains of pulses are also indicated. For rapidly repeating pulses these agree closely with Talbot's Law.

3.3 METHOD III — THE METHOD OF BLONDEL-REY-DOUGLAS

Blondel and Rey indicated that, for non-rectangular flash forms, a likely extension of their simple law [21] would assume the form

$$I_e = \frac{\int_{t_1}^{t_2} I(t)\,.\,dt}{a + t_2 - t_1} \qquad (6)$$

in which

- I (t) describes the variation of instantaneous luminous intensity I with time t
- a is the Blondel-Rey visual time-constant (see Section B.1)
- t_1 and t_2 are the initial and final instants of time, the determination of which remained ambigous.

Douglas [22] suggested that the limits t_1 and t_2 should be chosen in such a way as to maximize the resulting effective intensity. He showed that this maximum occurred when $I(t_1) = I(t_2) = I_e$. For a single flash, equation (6) may be re-written as

$$aI_e = \int_{t_1}^{t_2} [I(t) - I_e]\,.\,dt \qquad (7)$$

in which t_1 and t_2 are to be taken as those instants at which the instantaneous intensity rises above and drops below, respectively, the effective intensity I_e. Since t_1 and t_2 are thus functions of I_e, and, in equation (7), I_e is a function of t_1 and t_2, iterative methods of solution have normally to be used to determine I_e. Fig. 4 shows a graphical representation of equation (7) as applied to a particular flash form. The shaded column is of width a, and I_e has to be determined to make the two shaded regions have equal areas. This can be done by trying a succession of values of I_e and determining the areas by counting squares or by the use of a planimeter. A result of acceptable accuracy can generally be obtained after two or three trials. It is also possible to programme a digital computer to effect the necessary integrations and to adjust the trial value of I_e until the equality of equation (7) is established.

The extension of the method, as suggested by Douglas, to cover groups of flashes is not considered to be of general validity, and should be avoided.

(1) The explicit solution of equation (5) is

$$i(t) = \int_{t_1}^{t} \frac{I(u)}{A} e^{-\left(\frac{t-u}{A}\right)} du$$

where t_1 is a time before which there is no light exhibited.

For rotating optical systems and other apparatus producing flashes which do not fall to zeros of luminous intensity, the initial time t_1 should be taken at a level of luminous intensity not greater than 5% of the peak luminous intensity of the flash.

SECTION C

METHODS OF APPROXIMATE CALCULATION OF THE PEAK LUMINOUS INTENSITY OF THE BEAM FROM AN AID-TO-NAVIGATION LIGHT

1. PURPOSE

As stated in the Introduction, the formulae given in this Section are intended only for use as a means of approximate estimation of the luminous intensity in the axial direction when it is impossible to make photometric measurements. The accuracy is likely to be no better than ± 20% for sources approximating to spheres of uniform luminance and will usually be significantly lower for filament* and compact source arc discharge lamps*. The formulae may also be used in the design stage of a new lighted aid, when they may be very useful as a guide to the size of panel, luminance of source, etc., required to meet a given operational need.

2. TYPES OF BEAM PROJECTION APPARATUS

The formulae of this Section apply to the following types of beam projection apparatus:

(a) *Catoptric* systems*, including paraboloidal and parabolic cylindrical reflectors.

(b) *Prismatic lens systems* (with dioptric* and/or catadioptric* elements).

The calculations have been made for systems having a Fresnel profile*. It can be shown that the results are not very dependent on the shapes of the prisms, and the calculations may be applied with reasonable accuracy to other profiles, e.g. equi-angular*. When the Fresnel profile includes catadioptric elements, these may be arranged to recede at high angles, or to remain in one plane. In the latter case, dark spaces occur between the prisms. Two separate sets of formulae are given, applicable respectively to optical panels and to drum lenses*.

(c) *Auxiliary Systems*

(i) Diverting prisms*

(ii) Reinforcing mirrors*, e.g. spherical reflectors* of either catoptric or catadioptric type.

3. TYPES OF LIGHT SOURCE

The formulae apply strictly to sources having the form of spheres of uniform luminance. They are therefore capable of giving reasonably accurate results for sources which approximate to this form, such as mantle burners with large single incandescent mantles*.

Additional correction factors are tabulated to permit approximate calculations for the following common types of incandescent electric lamp* filaments:

(a) Grid*

(b) Cylindrical*

(c) Cruciform*

(d) Compact coiled-coil*

The application of the formulae to other forms of filament and other light sources such as open-flame burners, carbon arc lamps* and high pressure arc discharge lamps* is subject to great reserve in respect of accuracy.

4. LUMINANCE OF LIGHT SOURCES

For accuracy in use of the formulae, the light source must be a uniformly bright sphere. Large light sources of other shapes having nearly uniform surface luminance may also be expected to give beam intensity fairly close to the calculated values.

In a fixed directional optical system, the luminance L which is to be entered in the formulae of Section C.5 is the mean luminance in the direction of the axis of the optical system. In the case of rotating optical panels the axis rotates in the horizontal plane, while in the case of drum lenses there is no defined axis in the horizontal plane. In these cases it is necessary to consider possible variations in light intensity with bearing or to take a mean of effective source luminance at various bearings.

The luminance for any given direction is given by:

$$L = \frac{I}{S}$$

where L = Mean luminance of the source, in cd/m^2

I = Luminous intensity of light source, in the given direction, in candelas*

S = Projected area of light source, in m^2, on a plane surface normal to the given direction. (This direction will usually be the optical axis.)

In general, for complex filament structures, arc discharges of non-uniform luminance, etc., the best that can be done is to take S as the whole area within the smallest convex contour circumscribing the luminous element, even though this area may contain dark spaces within it.

The above method derives the mean luminance, for use in the formulae of Section C.5, from a measurement of the luminous intensity of the source. Such a measurement is subject to the general requirements of short-range photometric measurements described in Section A.2.2.1 but is usually possible even when measurement on the complete optical system is not possible. In the case of non-uniform light sources, it may be preferable to place the source at the focus* of a lens of photographic quality and to make a number of measurements in the beam at various directions close to the optical axis in order to determine the average value of the peak beam intensity. The formulae of Section C.5 below may then be used to calculate the mean luminance L. This method is essentially an application of the "ratio-ing" techniques described in Section D.

If this method is used, it is necessary to ensure that the aperture of the lens is fully and reasonably uniformly illuminated. If the light source dimensions are very much less than 1/20 of the focal length* of the lens, this may not be possible and the derivation of the mean luminance from measurements on the source alone may be preferable.

When luminous elements of small dimensions are enclosed within a large glass or quartz envelope, there may be difficulty in determining the projected area S. In some cases the linear dimensions may be measured accurately by the use of a travelling microscope having an objective lens of sufficiently great object distance to permit focusing on the luminous element when the objective is outside the envelope. In the case of arc discharge lamps, it is customary for manufacturers to supply a typical contour diagram of luminance within the discharge. Inspection of this, and of the regions of rapid decrease of luminance with position, may enable a reasonable value of S to be assessed for the discharge. When information of this type is not available, a convenient method of estimation of S may be to use a projection lens of photographic quality to project a focused image of the luminous element on a screen at a convenient finite distance. The measured dimensions of the bright image may be reduced to the corresponding dimensions of the luminous element by multiplying by the ratio of object distance to image distance from the lens. By applying an illumination photometer* to the image, information may also be obtained on non-uniform distributions of luminance of the luminous element. In particular, a discharge or a filament may display a useful length (characterized by high luminance) somewhat less than its actual length obtained by direct measurements.

5. FORMULAE FOR CALCULATION OF PEAK BEAM INTENSITY

The luminous intensity (I_0) at the peak of the beam from a beam projection apparatus which is exhibiting a fixed white light may be calculated from the following formulae in which

(a) The term "net" shall be taken as including only that portion (height or area) of the projection apparatus which is actually illuminated on its emergent face (excepting the bases of the prisms, which are to be included although they will generally be only weakly illuminated). It shall exclude any portion unilluminated because of the intervention of framework or other obstruction, whether between light source and optic or between optic and observer. It shall also exclude dark spaces or areas due to openings in a catoptric or to the separation of the prisms in a catadioptric apparatus.

(b) The term "vertical surface" shall be taken as a plane surface normal to the optical axis through the focal point of the beam projection apparatus. In general, lighthouse beams are depressed through a very small angle towards the horizon, but the difference is insufficient to require other terminology.

5.1 PROJECTION APPARATUS FOR A FAN BEAM* (generated around a vertical axis)

5.1.1 Catoptric

$$I_0 = h_1 d L k_1 c_1$$

where h_1 = net height of reflectors*, in m, projected on to a vertical surface, less the height, similarly projected, of any obstruction other than the light source itself, unless it also is obscured.

d = horizontal width of light source, in m

L = luminance of light source, in cd/m^2

k_1 = correction factor depending on the vertical subtense angles θ_1 and θ_2 of the mirror, taken from Fig. 5. Where there is no obstruction to the beam such as an electric lamp bulb or burner, θ_1 equals zero.

c_1 = effective reflection factor* which for the purpose of this formula shall be taken as:

- 0.9 for vaporized silver or aluminium
- 0.8 for silvered glass mirror
- 0.75 for lacquered surface-silvered metallic mirrors and anodized aluminium electrolytically brightened mirrors
- 0.7 for tin, chromium and rhodium surface-plated mirrors
- 0.6 for nickel surface-plated mirrors.

5.1.2 Dioptric and Catadioptric

$$I_0 = h_2 d L k_2 + h_3 d L k_3 + h_4 d L k_4$$

where h_2 = net glass height of refractors*, in m, projected on to a vertical surface

h_3 = net glass height of upper reflectors, in m, projected on to a vertical surface

h_4 = net glass height of lower reflectors, in m, projected on to a vertical surface

d = horizontal width of light source, in m

L = luminance of light source, in cd/m²

k_2 = correction factor depending upon the subtense angle of refractors taken from Fig. 6

k_3 average correction factor depending upon the appropriate angular limits θ_1 and θ_2 of the upper reflectors calculated from Fig. 7

k_4 average correction factor depending upon the appropriate angular limits θ_3 and θ_4 of the lower reflectors calculated from Fig. 7.

Note (1) : In the correction factors k_1 to k_4 inclusive, allowance has been made for the variations of the width of the flashed area due to the change of focal distance across the apparatus.

Note (2) : The above formula is to be used for drum lenses having receding catadioptric rings. For drum lenses having a profile in which the lower catadioptric sections are arranged vertically over one another, the value of k_4 should be reduced by 20%.

Note (3) : For smaller drum lenses (dioptric only, and of focal distance 250 mm or less), the following values of k_2 should be used:

Pressed glass* drum lens	0.45
Cut glass* drum lens	0.55
Moulded acrylic* lens	0.6

5.2 PROJECTION APPARATUS FOR A PENCIL BEAM

5.2.1 Catoptric

$$I_0 = a_1 L c_1$$

where a_1 = net area of mirror, in m², projected on to a plane normal to the direction of concentration, less the area, similarly projected, of any obstruction other than the light source itself unless it also is obscured.

L = luminance of light source, in cd/m²

c_1 = effective reflection factor which, for the purpose of this formula, shall be as given in Section C.5.1.1.

5.2.2 Dioptric and Catadioptric

$$I_0 = a_2 L c_2 + a_3 L c_3$$

where a_2 = net glass area of refractors, in m², projected on to a plane normal to the direction of concentration

a_3 = net glass area of reflectors, in m², projected on to a plane normal to the direction of concentration

L = luminance of light source, in cd/m²

c_2 = correction factor depending on the subtense angle of refractors taken from Fig. 8.

Where the panel is asymmetric the right and left portions of the refractors have to be considered separately and the area of each portion multiplied by the appropriate value of c_2. The sum of these two quantities when multiplied by L corresponds to the first term on the right hand of the equation.

$$c_3 = \begin{cases} 0.85 & \text{for receding catadioptric elements} \\ 0.7 & \text{for vertically stacked catadioptric elements.} \end{cases}$$

Note: The above formulae apply with reasonable accuracy to uniform spherical light sources and to large mantle burners. For use with certain types of filament lamp in common use in lighthouse apparatus, the additional correction factors listed below should be applied. These factors are multipliers for that part of the intensity contributed by the catadioptric elements, and make allowance for the reduction in source luminous intensity in the direction of these elements.

The formula becomes

$$I_0 = a_2 L c_2 + a_3 p_f L c_3$$

$$\text{where } p_f = \begin{cases} 0.9 & \text{for compact coiled-coil filaments} \\ 0.8 & \text{for plane grid filaments} \\ 0.7 & \text{for cylindrical, bunch* and cruciform filaments.} \end{cases}$$

For all other sources, including linear coiled-coil filaments, filament structures of greater complexity and all discharge lamps, a value of $p_f = 0.5$ should be assumed.

Note: By "compact coiled-coil filament" is meant a filament structure consisting of a closely wound coil which is itself wound into a helix of small radius, presenting a compact structure of approximately cylindrical form.

5.3 AUXILIARY BEAMS

The luminous intensity of a converged* (or diverged*) beam may be derived from that of the initial beam by multiplication by two factors.
One factor is the quotient of the angle of divergence* of the beam *before* convergence (or divergence) by that of the converged (or diverged) beam; the other factor may be taken as 0.9 in the case of auxiliary optical systems made of glass and 0.92 for those made in plastics, to allow for reflection and transmission losses.
The luminous intensity of a diverted beam*, changed in direction without change in angle of divergence, is derived from that of the initial beam by multiplying by $(0.9)^n$ for glass systems or $(0.92)^n$ for plastics systems, where n is the number of diverting prisms traversed.

5.4 REINFORCING MIRRORS

5.4.1 Centred Reinforcing Mirrors

When a reinforcing mirror is employed in conjunction with any of the above beam projection apparatus, the intensity of the beam from the reinforced portion of the apparatus is increased and the intensity previously found should be multiplied by the appropriate factor from the following table:

Type of mirror	*Factor*
(i) *Catoptric* Vaporized silver, silvered glass, or aluminium, anodized aluminium, lacquered silver on metal	1.4
Rhodium or tin surface-plated	1.3
Chromium or nickel surface-plated	1.2
(ii) *Catadioptric*	1.2

5.4.2 **De-centred Reinforcing Mirrors**

By employing de-centred reinforcing mirrors with a fan beam it is possible to increase the effective width d of the light source over a given arc by forming an image or images to one side of it and so increasing the intensity of the beam over that arc. The increased intensity is given by multiplying the fixed intensity as calculated from Section C.5.1.3 above by:

$$1.0 + 0.7\, c_1 m$$

where m = number of supplementary images (number of de-centred auxiliary mirrors)

c_1 = reflection factor in Section C.5.1.1 above.

6. LIGHT DURATION OF RHYTHMIC BEAMS

6.1 ROTATING APPARATUS

When the beam projection apparatus rotates, the duration of each appearance of light is dependent upon the angle of divergence of the beam and the speed of revolution of the apparatus. If the beam divergence cannot be measured directly, its approximate value may be calculated from the formula:

$$\alpha = \frac{d}{f} \text{ radians or } \frac{180\, d}{\pi f} \text{ degrees}$$

where α = angle of divergence

d = width of light source in the case of horizontal divergence, or height of light source in the case of vertical divergence

f = focal length of the system

Consistent units of length must be used.

The width of the light source may be determined as described in Section C.4 above. In the case of a light source with diffused edges (e.g. a frosted lamp* or an arc discharge*), the width should be taken as that between points at which the intensity falls to 50% of the peak value. If any other percentage is used, due to previous custom, this should be stated.

The duration of an appearance of light is given by

$$t = \frac{\alpha}{2\pi N} = \frac{d}{2\pi N f}$$

where t = duration of the appearance of light

α = angle of divergence in the horizontal plane, in radians

N = rate of rotation (number of revolutions per second) of the apparatus.

6.2 BLANKING* SYSTEMS

For a flashing light produced by blanking the light source by the use of an occulting hood*, shutter*, revolving screen* or other mechanical device, the flash duration may be taken as the time interval between the passage of the screen or shutter through its mean position when exhibiting and eclipsing the light respectively. If the time variation of intensity can be measured, the time interval should be taken as that between the instants at which the intensity is 50% of the peak intensity.

6.3 EXTINCTION SYSTEMS

6.3.1 **Acetylene and other Gas Flames, and Discharge Lamps**

When the beam is eclipsed by a flasher* or coder mechanism which interrupts the supply of gas or electricity, the duration of each appearance of light is approximately the duration of the "on" time of the supply. When it is possible to measure the variation of luminous intensity with time directly, the duration of the appearance of light may be taken as the interval between the instants at which the intensity is 50% of the peak intensity.

6.3.2 **Incandescent Lamps and Mantle Burners**

Owing to the relatively slow thermal response of the filament or mantle, there is a delay in the time course of the luminance of the luminous element with respect to the time of "on" or "off" operation of the flasher or coder mechanism.

Figure 9 shows, *for the case of an incandescent filament*, the difference between the incandescence time* and the nigrescence time*, as a function of steady-state filament current. Two curves are given, defined for levels of 90% and 50% of the steady luminous intensity respectively.

The time during which the luminous intensity from the filament exceeds respectively 90% and 50% of steady luminous intensity is given by the contact closure time (i.e. the time during which the supply current is switched on) less the time read from the appropriate curve of Figure 9. If the contact closure time is less than the corresponding time from Figure 9 for 90% level, no guidance can be obtained from the figure, and it is recommended that such short closure times should not be used. If the contact closure time is greater than the time from Figure 9 for 90% level, the flash duration may be taken as contact closure time less the time from Figure 9 for 50% level. This duration may be used in the approximate calculation of effective intensity as in Section C.7 below.

Note: Figure 9 corresponds to the behaviour of lamps operated at rated voltage and with effectively zero circuit resistance.

Underrunning a lamp increases both incandescence and nigrescence times, but the net effect on the correction in Figure 9 is to increase it. If the reduction is of only a few per cent, then in general the effect on the correction will not be important.

The use of Figure 2 may be extended to tungsten-halogen lamps* operating at filament temperatures above 3 000 K. The difference of the incandescence and nigrescence times of these lamps from those of ordinary filament lamps is unlikely to be significantly greater than the spread of values of these quantities from lamp to lamp.

The use of a series resistance in the external circuit will increase incandescence time, as shown in Figure 11 of B.S. 942: 1949 [29]. The correction in Figure 9 is thereby also increased.

The use of a shunt resistance across the circuit switch, to produce a simmering current*, will reduce incandescence time and increase nigrescence time. The correction in Figure 9 is thereby decreased. For a simmering current of not more than one quarter of rated current, the correction will not in general be decreased by more than 20%.

In the case of doubt as to the magnitude of the correction, it is recommended to measure the time variation of intensity of the switched light source; the optical system need not be used.

From the measured curve, the duration of the appearance of light should be taken as that between the instants at which the intensity is 50% of peak intensity. If any other percentage is used, due to previous custom, this should be stated.

7. EFFECTIVE INTENSITY OF RHYTHMIC LIGHTS

The formulae given above permit the approximate calculation of the luminous intensity obtainable from a given optic-source combination. If a rhythmic light is produced by eclipsing the light source or by rotating the optic, it is necessary to evaluate approximately the effective intensity as defined in Section B.

The formula (2) of Method I, described in Section B.3.1, may be used. For flashes approximating to a rectangular form, produced by blanking or switching, F may be taken as unity, so that C/F becomes 0.2 second. For flashes produced by rotating optical systems, F may be taken as 2/3, so that C/F becomes 0.3 second.

8. USE OF COLOUR FILTERS

The luminous intensity of a coloured light obtained by the use of a colour filter may be calculated approximately by applying the above methods to derive the luminous intensity of the white light obtained from the optical system in the absence of the filter, and then applying to it the transmission factor of the appropriate filter, which may be separately measured (see Section A.2.4).

If transmission factor measurements on the colour filter to be used in an installed light are not available, approximate luminous intensity may be found by the use of the appropriate value from the table below, which shows typical average values of percentage transmission factor of colour filters made in glass or dyed plastics.

TRANSMISSION FACTORS OF COLOUR FILTERS (IN %)

Colour Temperature or Correlated Colour Temperature	*Light Source*	*Colour of Filter*					
		Red	*Green*		*Yellow*	*Blue*	
		Glass & Plastics	*Glass*	*Plastics*	*Glass & Plastics*	*Glass*	*Plastics*
1 900-2 200 K	Oil flame	30	8	10	70	—	—
2 200-2 500 K	Vacuum lamp	25	10	15	60	—	—
2 500-3 200 K	Acetylene flame Gas-filled lamp Incandescent mantle	20	12	20	50	1	2
5 000-7 000 K	Xenon discharge	13	15	23	—	2	3

It should be noted that with some colour filters, particularly those which give greater certainty of colour recognition, transmission factors may be significantly lower than those given in the table. It is therefore recommended that, as far as possible, values of transmission factor of colour filters should be measured, as discussed in Section A.2.4.

9. EFFECT OF LANTERN GLAZING AND SERVICE CONDITIONS

The formulae given above give approximate beam luminous intensities at emergence from the beam projection apparatus. When such apparatus is housed in a lantern, calculated intensities should be reduced by a factor, as given in Section A.4. The factor to cover practical service conditions, as discussed in Section A.5, may also be applied; if so, this should be stated.

10. LIMITATIONS OF THE CALCULATIONS

The accuracy of the results obtained from the above calculations is very limited, being of the order of $\pm$ 20% for a uniform spherical light source (approximated by a mantle burner). For light sources of other shapes, particularly planar filaments and discharge lamps, the accuracy becomes very much lower in an unpredictable way. The calculations are intended only for use when no other method of estimating beam intensity is available.

When it is required to estimate the beam intensity for a given source-optic combination on which direct measurements cannot be made, it may be that measured data are available for the same optic with other sources, or for the same source with other optics. In such cases, a better estimate of beam intensity may possibly be obtained by methods described in Section D.

SECTION D

ESTIMATION OF BEAM INTENSITY BY RATIO-ING TECHNIQUES [30]

1. PURPOSE

This section is intended as a guide to estimation of the luminous intensity and angle of divergence of the beam from various types of beam projection apparatus when data can be obtained by direct measurement on similar but not identical combinations of light source and optical system. The methods described are referred to as comparison or "ratio-ing" techniques.

Accuracy of results obtained by using ratio-ing techniques is only as good as the first-order geometrical relations which they represent. The precision of the results is limited by inaccuracies in the assumptions made. However, the ratio-ing technique is to be preferred to that of direct computation, of the type given in Section C. There is less likelihood of error in an estimation of optical performance based on comparisons between source/optic combinations of similar design where measurements are available for one such design, than in estimation of performance for a new combination.

Similar optical systems can be scaled, within reasonable limits, to predict performance with more confidence than can be placed in the use of the formulae given in Section C.

2. EXAMPLES OF ESTIMATION OF LUMINOUS INTENSITY

2.1 FIXED LENSES

2.1.1 Change of Source

It is required to find the luminous intensity of the fan beam produced by a fixed lens when used with a light source of luminance L and width d. The luminous intensity is assumed to have been measured for an identical fixed lens with a light source of luminance L′ and width d′, and has been found to be I′.

From Section C.5.1.2

$$I' = h_2\, d'L'\, k_2 + h_3\, d'L'\, k_3 + h_4\, d'L'\, k_4$$

and the required intensity is

$$I = h_2\, dLk_2 + h_3\, dLk_3 + h_4\, dLk_4$$

hence $\frac{I}{I'}$ is given by $\frac{dL}{d'L'}$.

2.1.2 Change of Fixed Lens Size

In this case the intensity is assumed to have been measured for an identical light source in a fixed lens of different focal length and dimensions but with the same, or nearly the same, relative areas and angular subtenses of dioptric, upper and lower catadioptric portions. Thus the coefficients k_2, k_3 and k_4 are virtually unaltered, and the heights of the various portions of the unknown system may be taken as a constant (say p) times the corresponding heights of the measured system.

From Section C.5.1.2

$$\frac{I}{I'} = \frac{h_2\, dLk_2 + h_3\, dLk_3 + h_4\, dLk_4}{h'_2\, dLk_2 + h'_3\, dLk_3 + h'_4\, dLk_4} = p$$

so that the intensity is scaled directly as the linear dimensions of the fixed lens.

2.2 OPTICAL PANELS

2.2.1 Change of Source

In this case, from Section C.5.2.2

$$I' = a_2 L'c_2 + a_3 L'c_3$$

and the required intensity is

$$I = a_2 Lc_2 + a_3 Lc_3$$

so that

$$\frac{I}{I'} = \frac{L}{L'}$$

and the intensity is scaled directly as the luminance of the source.

2.2.2 Change of Optical Panel Size

In this case, measurements of intensity are assumed to have been made on a combination consisting of an identical source with an optical panel of different dimensions but having approximately the same relative areas and angular subtense angles for the various dioptric and catadioptric portions. (This will apply to panels of different focal length with all dimensions scaled proportionally, or to panels of similar section but extended over different ranges of azimuth angle.)

The coefficients c_2 and c_3 are thus virtually unchanged, and the areas of the various portions of the unknown panel may be taken as a constant (say q) times the corresponding areas of the measured panel.

From Section C.5.2.2

$$\frac{I}{I'} = \frac{a_2 Lc_2 + a_3 Lc_3}{a'_2 Lc_2 + a'_3 Lc_3} = q$$

so that the intensity is scaled directly as the area of the optical panel.

Note 1: The beam intensities referred to in the above calculations are *uncorrected beam intensities* corresponding to steady light intensities measured for the source/optic combination alone, at rated lamp voltage. They make no allowance for glazing losses, effects of supply voltage variation or visual effects of flashing lights.

Note 2: Application of the ratio-ing technique to optical systems of somewhat different shape, so that the constants k and c are not unchanged, is possible within limits, provided that care is exercised to avoid unduly gross approximations.

3. EXAMPLES OF ESTIMATION OF BEAM DIVERGENCE

According to Section C.6.1, the beam divergence in radians may be calculated as $\alpha = \frac{d}{f}$. The uncertainties in estimating the proper value for the source dimension d make the ratio-ing technique the preferred method of estimation of divergence when photometric data is available for an identical light source in a similar optical system of different focal length.

If, for this second system, the divergence has been found to be α', and the focal length of the system is f', then from Section C.6.1

$$\alpha' = \frac{d}{f'}$$

The required divergence is therefore obtainable from

$$\frac{\alpha}{\alpha'} = \frac{f'}{f}$$

The use of this technique often gives significantly better agreement with measured values than does the method of direct calculation.

3.1 SCALING OF FLASH DURATION

For a rotating optic at a rotation speed N rev/s, the divergence α is related to the flash duration τ by

$$\tau = \frac{\alpha}{2\pi N}$$

Suppose that it is required to find the flash duration for an optic of focal length f and rotation speed N. It has been found that a similar optic of focal length f' and rotation speed N' gives a flash duration τ'. Then the required flash duration τ is obtained from.

$$\tau = \frac{f' N'}{f N} \tau'$$

For rotating optical systems with fairly large light sources giving smooth distributions of intensity, changes in rotation speed or focal length result in changes of flash duration without change in flash shape. By the use of the above expression, measured data for one such system may be scaled to yield flash durations for a wide range of similar optical systems of different focal lengths and/or rotation speeds. By application of the methods of Section B, tables or graphs of the ratio of effective intensity to peak intensity can be deduced over the whole range.

APPENDIX I

SYMBOLS

Symbol	*Meaning*	*Unit*
A	Time-constant in Allard's formula for effective intensity	s
a_1, a_2, etc.	Area of part of projection apparatus	m^2
a	Time constant in Blondel-Rey formula for effective intensity	s
C	Time constant in form-factor method for effective intensity	s
c_1, c_2, etc.	Constants in calculation of intensity for pencil beams and auxiliary beams	—
d	Dimension of light source	m
E	Illuminance at eye of an observer	lx
f	Focal distance of projection apparatus	m
h_1, h_2, etc.	Height of optical panel	m
i	Instantaneous effective intensity	cd
I	Luminous intensity	cd
I_0	Maximum value of luminous intensity within a beam or within a flash	cd
I_e	Effective intensity of a flash	cd
J	Integrated intensity of a flash	cd.s
k_1, k_2, etc.	Constants in calculation of intensity for fan beams	—
L	Luminance of a light source	cd/m^2
N	Rotation rate of a rotating optical apparatus	rev/s
n	Number of changes of direction of a diverted beam	—
p_f	Additional factor characterising filament shape, in calculation of intensity for pencil beams	—
S	Area of luminous surface	m^2
t	Time variable	s
τ	Duration of a flash	s
α	Plane angle of divergence of a beam	rad
θ	Angle between normal to surface and direction of light	rad
Φ	Luminous flux	lm
Ω	Solid angle	sr

APPENDIX II

TERMS DEFINED IN CHAPTER 2 OF THE I.A.L.A. "INTERNATIONAL DICTIONARY OF AIDS TO MARINE NAVIGATION"

Term	*Term number*
Allard's Law	2-1-265
Angle of divergence	2-1-100
Appearance of light	2-5-125
Arc discharge	2-3-385
Astragal	2-4-015
Beam (Luminous)	2-1-085
Blanking screen	2-4-105
Bunch filament	2-3-220
Candela	2-1-040
Candela per square metre (cd/m^2)	2-1-050
Carbon arc lamp	2-3-400
Catadioptric	2-2-070
Catoptric	2-2-065
Coiled-coil lamp	2-3-185
Colour filter	2-2-200
Compact source arc discharge lamp	2-3-420 N
Converged beam	2-2-215
Cruciform filament	2-3-205
Cut glass	2-2-245
Cylindrical filament	2-3-210
Dioptric	2-2-060
Discharge lamp	2-3-310
Diverged beam	2-2-220
Diverted beam	2-2-225
Divergence	2-1-100 N
Diverting prism	2-2-210
Drum lens	2-2-100
Effective intensity	2-1-400
Electric lamp, Incandescent	2-3-080
Equi-angular profile	2-2-145
Fan beam	2-1-090
Filament	2-3-090
Fixed lens	2-2-090
Fixed light	2-5-105
Flash	2-5-130
Flasher	2-4-100
Flashing light	2-5-145
Flash tube	2-3-435
Flicker photometer	2-1-555
Fluorescent lamp	2-3-340
Focal length	2-2-160
Focus	2-1-125
Fresnel profile	2-2-135
Frosted lamp	2-3-230
Geographical range	2-1-245
Grid filament	2-3-195
High pressure arc discharge lamp	2-3-415
Illuminance	2-1-055
Illumination photometer	2-1-570
Incandescent mantle	2-3-025
Incandescence time	2-3-275
Inverse square law	2-1-065
Landfall mark (or buoy)	2-6-095
Landfall light	2-5-050
Lantern	2-4-000
Lantern glazing	2-4-005
Luminance	2-1-045
Luminosity	2-1-365
Luminous efficiency, Spectral	2-1-015
Luminous intensity	2-1-035
Luminous range	2-1-250
Lux	2-1-060
Mantle burner	2-3-030
Meteorogical visibility	2-1-280
Moulded glass (or plastic)	2-2-240
Neutral density filter	2-2-205
Nigrescence time	2-3-280
Nominal range	2-1-255
Occultation	2-5-140
Occulting hood	2-4-110
Occulting light	2-5-170
Optical axis	2-2-110
Optical panel	2-2-175
Order (of an optic)	2-2-260
Pencil beam	2-1-095
Photometer	2-1-535
Physical photometer	2-1-545
Pressed glass	2-2-240
Prismatic lens	2-2-085
Projector	2-2-005
Reflection factor	2-1-150
Reflector	2-1-130
Refractor	2-1-235
Reinforcing mirror	2-2-040
Revolving screen	2-4-120
Rhythmic light	2-5-110
Screen	2-4-105
Sealed beam lamp	2-3-245
Shutter	2-4-115
Simmering current	2-3-270
Spherical reflector	2-2-045
Stray light	2-2-265
Threshold of illuminance	2-1-390
Transmittance	2-1-185
Transmission factor	2-1-185
Tungsten-halogen lamp	2-3-160
Working standard	2-3-260

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— **Table I**

POUR DIVERSES FORMES D'ÉCLAT
la Méthode II — Méthode d'ALLARD
BLONDEL-REY-DOUGLAS

FOR VARIOUS FLASH FORMS
Method II — the Method of ALLARD
BLONDEL-REY-DOUGLAS

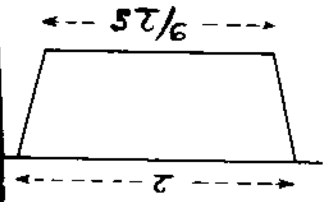
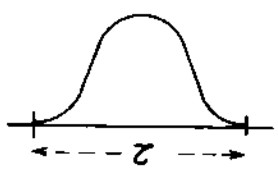
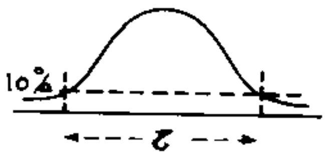
Trapezium			En sinus carré *Sine-squared*			En courbe de Gauss *Gaussian*		
								
Méthode — *Method*			Méthode — *Method*			Méthode — *Method*		
I	II	III	I	II	III	I	II	III
.004562	.004572	.004561	.002494	.002494	.002488	.002912	.002908	.002895
.009083	.009121	.009076	.004975	.004976	.004952	.005806	.005793	.005747
.02240	.02263	.02236	.01235	.01235	.01221	.01439	.01433	.01407
.04383	.04471	.04366	.02439	.02442	.02388	.02837	.02820	.02729
.08397	.08726	.08339	.04762	.04779	.04583	.05518	.05476	.05165
.1864	.2031	.1839	.1111	.1124	.1028	.1274	.1268	.1131
.3143	.3628	.3082	.2000	.2053	.1774	.2260	.2275	.1910
.4783	.5901	.4674	.3333	.3509	.2829	.3687	.3804	.2981
.6962	.8889	.6825	.5556	.6103	.4553	.5935	.6400	.4692
.8209	.9874	.8094	.7143	.7992	.5880	.7449	.8187	.5978
.9016	.9998	.8939	.8333	.9230	.7044	.8538	.9307	.7127
.9582	~ 1	.9544	.9259	.9849	.8208	.9359	.9861	.8253
.9786	~ 1	.9766	.9615	.9961	.8810	.9669	.9964	.8846

Tableau 3 — Table 3

VALEURS CALCULÉES DE I_e/I_o POUR DES GROUPES D'ÉCLATS RECTANGULAIRES
suivant la Méthode II — Méthode d'ALLARD

CALCULATED RATIOS I_e/I_o FOR TRAINS OF RECTANGULAR FLASHES
according to Method II — Method of ALLARD

τ Durée d'éclat en secondes *Flash duration in seconds*	Rapport entre la durée d'éclat et la période = 1/10 *Ratio of flash duration to period = 1/10*							
	Nombre d'éclats dans le groupe — *Number of flashes in train*							
	1	2	3	4	6	8	10	∞
.001	.004988	.009732	.01425	.01854	.02651	.03372	.04024	.1023
.002	.009950	.01895	.02710	.03447	.04718	.05758	.06609	.1046
.005	.02469	.04392	.05889	.07056	.08671	.09651	.1025	.1116
.01	.04877	.07835	.09629	.1072	.1178	.1217	.1231	.1240
.02	.09516	.1302	.1431	.1478	.1502	.1505	.1505	.1505
.05	.2212	.2394	.2408	.2410	.2410	.2410	.2410	.2410
.1	.3935	.3961	.3961	.3961	.3961	.3961	.3961	.3961
.2	.6321	.6321	.6321	.6321	.6321	.6321	.6321	.6321
.5	.9179	.9179	.9179	.9179	.9179	.9179	.9179	.9179
1	.9933	.9933	.9933	.9933	.9933	.9933	.9933	.9933
2	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1
5	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1
10	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1

τ Durée d'éclat en secondes *Flash duration in seconds*	Rapport entre la durée d'éclat et la période = 1/2 *Ratio of flash duration to period = 1/2*							
	Nombre d'éclats dans le groupe — *Number of flashes in train*							
	1	2	3	4	6	8	10	∞
.001	.004988	.009925	.01481	.01965	.02919	.03854	.04770	.5013
.002	.009950	.01970	.02926	.03863	.05682	.07430	.09109	.5025
.005	.02469	.04818	.07052	.09177	.1312	.1669	.1992	.5063
.01	.04877	.09290	.1328	.1690	.2312	.2822	.3240	.5125
.02	.09516	.1731	.2369	.2891	.3669	.4190	.4539	.5250
.05	.2212	.3554	.4367	.4861	.5342	.5519	.5584	.5622
.1	.3935	.5382	.5915	.6111	.6209	.6223	.6224	.6225
.2	.6321	.7177	.7297	.7308	.7311	.7311	.7311	.7311
.5	.9179	.9241	.9241	.9241	.9241	.9241	.9241	.9241
1	.9933	.9933	.9933	.9933	.9933	.9933	.9933	.9933
2	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1
5	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1
10	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1	~ 1

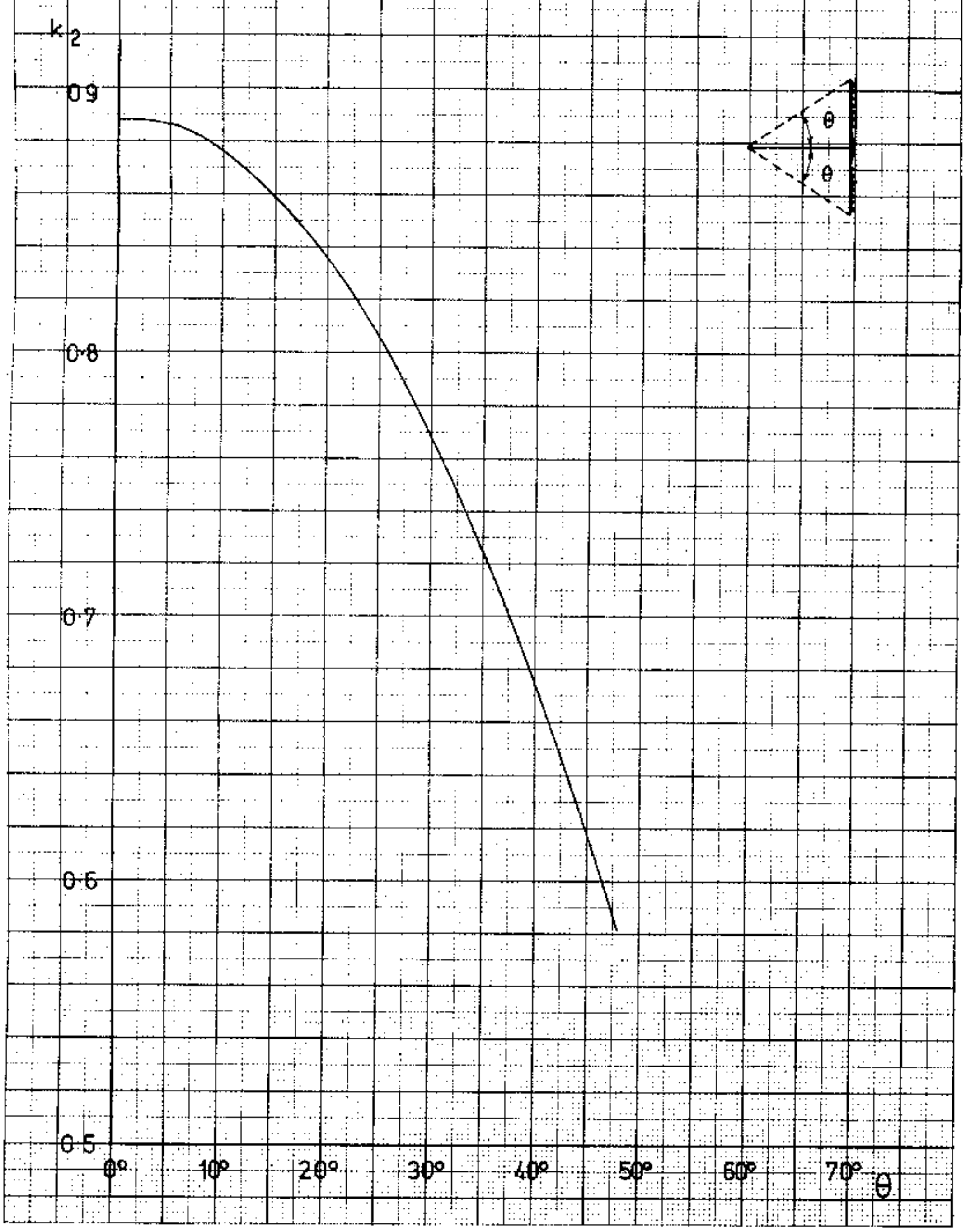


Figure 6 — Optique d'horizon dioptrique : Profil de Fresnel (Facteur de correction)

Figure 6 — Fan beam dioptric : Fresnel profile (Correction factor)

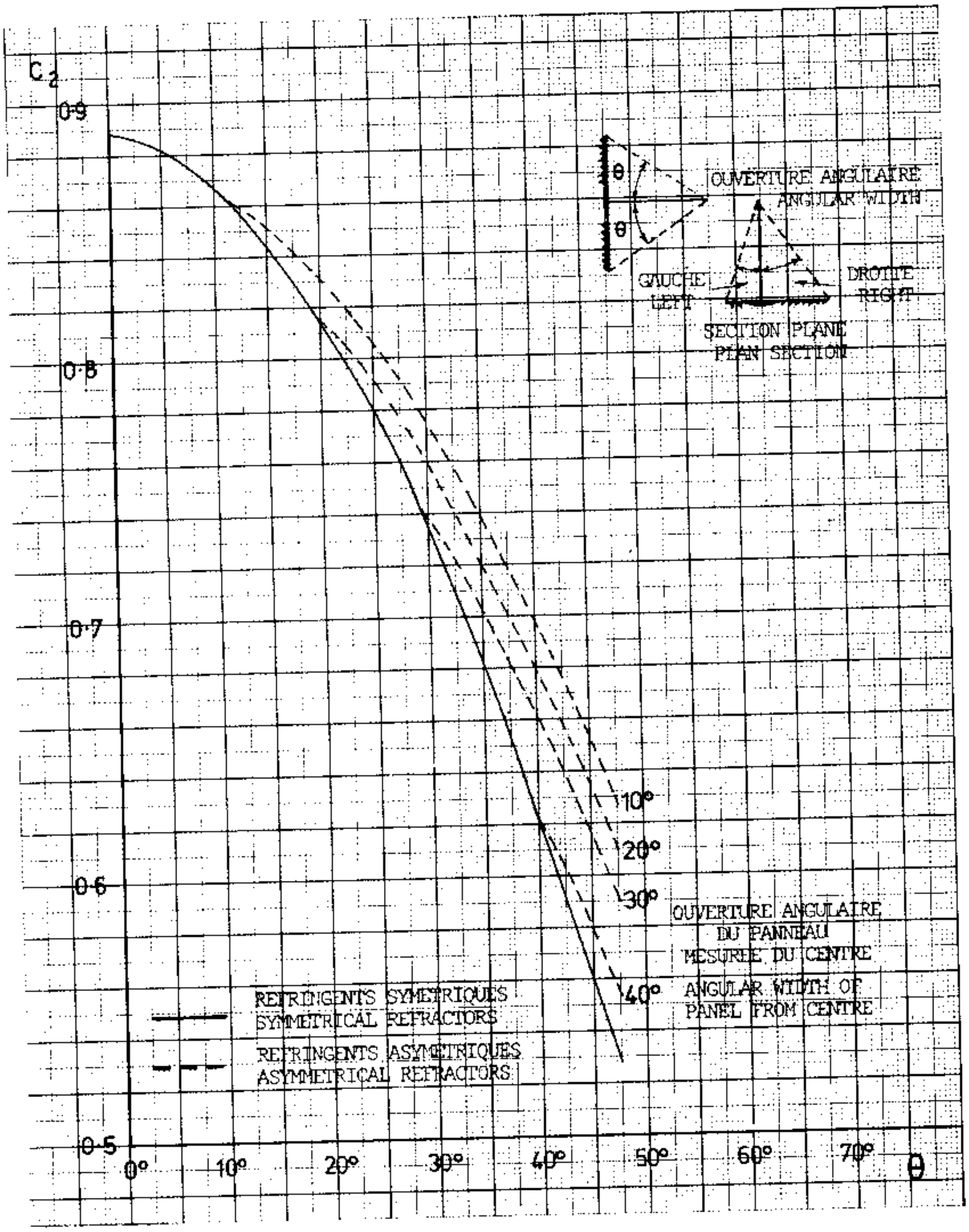


Figure 8 — Optique de direction dioptrique : Profil de Fresnel (Facteur de correction)

Figure 8 — Pencil beam dioptric : Fresnel profile (Correction factor)