Input paper: [[1]](#footnote-1) ENG4-9.11

Input paper for the following Committee(s): check as appropriate Purpose of paper:

**□** ARM **x** ENG **□** PAP **x** Input

**□** ENAV **□** VTS **□** Information

Agenda item [[2]](#footnote-2) 9 / Action 26 from ENG 3 report

Technical Domain / Task Number 2 TD#1 - Light and vision physics, Visual Signalling

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Note: a pdf version of this paper with Times Roman and GreekC fonts are available on the file share server.

Revision of E-200 Part 2 'Luminous Range'

# Summary

The series of IALA Recommendations E-200 is going to be reviewed. This input paper is directed to Part 2 of E-200.

It contains information about the purpose of E-200 Part 2 and some suggestions, how to handle it in a new IALA-strategy.

To be able to work on it, the paper contains the text, equations, tables and drawings of the annex of the Recommendation. They may be copy-and-pasted to the new documents.

Each part is marked whether it belongs to standardization, guideline or background information in my opinion.

## Purpose of the document

ENG working group 1 may consider the proposals for the revision of the recommendation E-200.

## Related documents

IALA Recommendation E-200

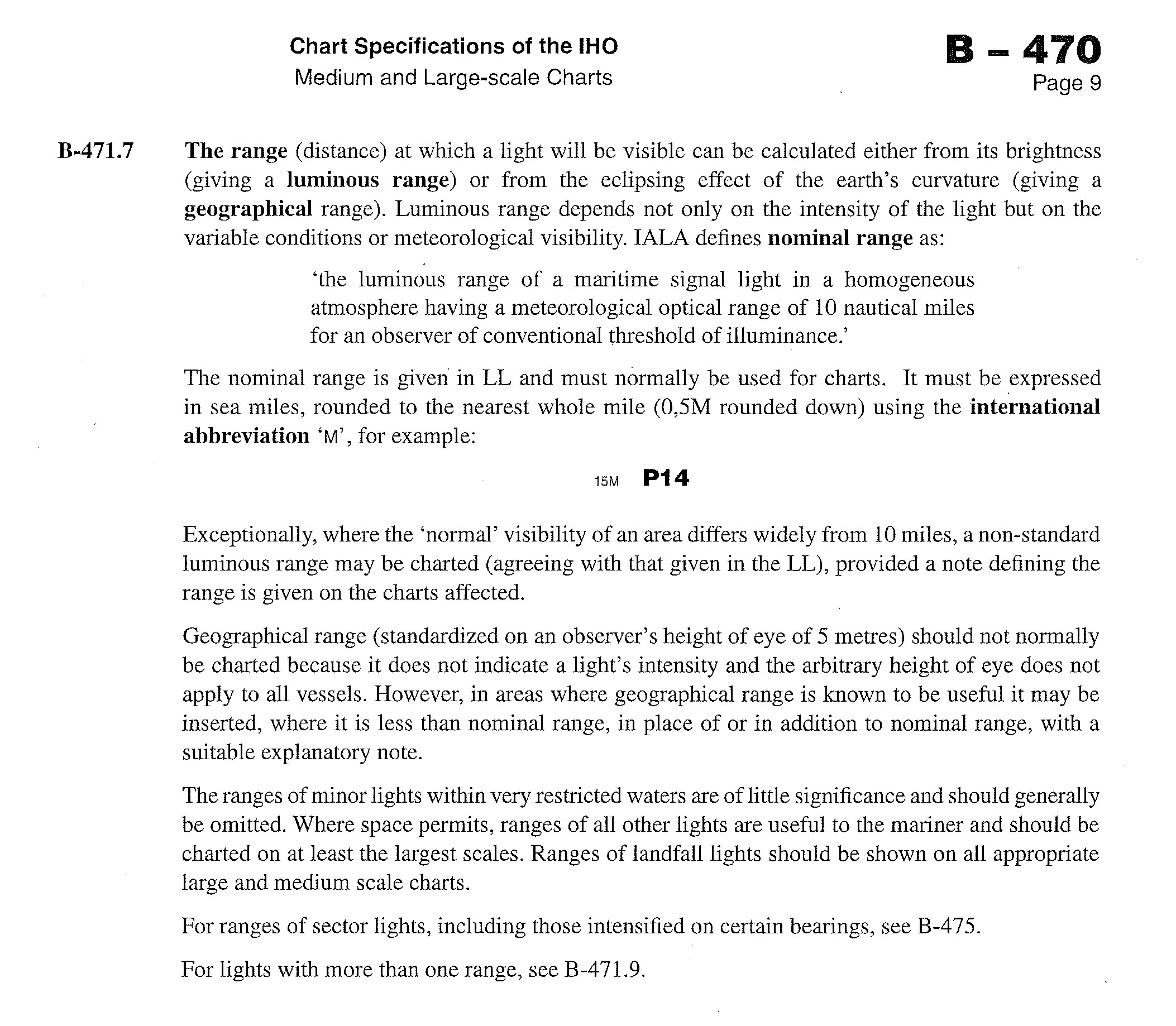
# Background

## Origin

IALA Recommendation E-200 On Marine Signal Lights Part 2 - Calculation, Definition and Notation of Luminous Range defines the way, how the luminous range has to be calculated.

The purpose of the original recommendation, which was probably the first IALA recommendation at all (November 1966), was to standardize the calculation for the luminous range in the list of lights and the charts.

This is still kept in the IHO Chart Specifications.



The definition cited may come from the 1966 recommendation. The IALA definition in the dictionary from the 1970s is slightly different.

**IALA range definitions in IALA dictionary**

**2-1-250**

Luminous Range (of a light)

The maximum distance at which a light can be seen, as determined by the luminous intensity of the light, the atmospheric transmission factor and the threshold of illuminance on the eye of the observer (2-1-390).

**2-1-255**

Nominal Range (of a light)

The nominal range of a light used as an aid to marine navigation is its luminous range in a homogeneous atmosphere in which the meteorological visibility (2-1-280) is 10 sea-miles.

A second purpose of the recommendation was to classify the luminous intensity of a marine signal light.

The classification is simply the luminous range rounded to the nearest nautical mile. This classification is still used by IALA Industrial members.

## The way to E-200

Over the years IALA published definitions and information for luminous range in other documents. When establishing E-200, it was the aim to have a single document for luminous range (part 2), which can be referenced by all other documents following.

Therefore we added background information and some guideline into E-200.

However E-200 part 2 is not a guideline to find a value for the required intensity or the conspicuity of a light.

# Discussion of E-200-2

In the following chapters a copy of E-200 part 2 can be found. I suggest that the information of E-200-2 could be separated into 4 categories (I used the colours underneath for marking the chapters.).

* Standard (this could stay as IALA recommendation)
* Guideance (this could become part of a new IALA guideline)
* Background information (put this on IALA Wiki)
* Indefinite

A guideline may include some of the standard (recommendation) and a background paper may include either the standard and the guideline.

## The recommendation in itself

**Recommendation on Marine Signal Lights Part 2 - Calculation, Definition and Notation of Luminous Range (Recommendation E-200-2)**

**THE COUNCIL:**

**RECALLING** the function of IALA with respect to Safety of Navigation, the efficiency of maritime transport and the protection of the environment;

**RECOGNISING** the need to publish the performance of marine signal lights;

**RECOGNISING ALSO** the need to specify, design and quantify the performance of marine signal lights worldwide;

**NOTING** this document only applies to marine Aid-to-Navigation lights installed after the date of this publication;

**ADOPTS** the tables and charts in the annex of this recommendation; and,

**RECOMMENDS** that National Members and other appropriate Authorities providing marine aids to navigation services design, specify and publish the performance of marine Aid-to-Navigation signal lights in accordance with the Annex to this recommendation.

## The Annex of E-200-2

**1 INTRODUCTION**

**1.1 Scope / Purpose**

The scope of this recommendation is to permit providers and manufacturers of marine AtoN lights, as well as mariners (?), to determine the luminous range of lights as a function of their intensity and of the meteorological visibility. This recommendation provides a link between the physical and photometric features of marine AtoN lights and the luminous range information given to the mariner.

For providers of marine AtoN lights, this recommendation should be used to estimate the required luminous intensity when designing lights.

Manufacturers of marine AtoN lights should quote the nominal luminous range (also known as the 'nominal range') of their lights in accordance with this recommendation.

**1.2 Background / History**

The IALA definition of the luminous range of lights was first introduced by a Recommendation in 1966 [1]. For many years this definition has been an important basis for the description of marine AtoN lights.

However, since 1966 several additions have been made to the definition of luminous range. These additions were spread over five IALA documents ([2], [3], [4], [5], [6]).

To avoid confusion the information from these six documents has been collated into a single document for the calculation, definition and notation of luminous range of lights, which helps to distinguish between the different required values for the illuminance (required at the eye of the observer) and their application.

The two basic recommendations [1] and [3] included nomograms for luminous range estimation. These nomograms are still supported. However, the wide-spread use of computer modelling makes it feasible to base the estimation of luminous range on formulae. Therefore, these have been provided in this recommendation.

Previous IALA Recommendations and the IALA Dictionary use the “sea mile” as the unit of measure for luminous range, nominal luminous range, and meteorological visibility. This document replaces the sea mile with the nautical mile as the preferred unit of measure and as the unit of measure used in definitions. The difference between a sea mile (about 1853.2 m) and a nautical mile (1852 m) is small, and of no practical consequence for these calculations. The nautical mile has been chosen as the unit of measure because it is used more widely than the sea mile.

For many countries the use of SI-units is obligatory. The 'nautical mile' and the units derived from it are outside this International System of Units. One aim of this recommendation is to give the reader the necessary formulae to convert between the SI-units and the units used in navigation.

**2 PHYSICAL BASICS - ALLARD'S LAW**

The illuminance of a signal light at the observer’s eye can be calculated by a physical law called Allard’s law.

**2.1 Allard’s law**

Allard’s law allows the calculation of the illuminance E as a function of distance d, luminous intensity I and an exponential factor z.

(equation 1)

The exponential factor z describes the atmospheric absorption and scattering (extinction). In practice, there are alternative ways of characterizing the prevailing atmosphere as follows.

**2.2 Allard's law using the atmospheric transmissivity T**

Atmospheric transmissivity (T) is defined as the ratio of the luminous flux transmitted by the atmosphere over a unit distance to the luminous flux which would be transmitted along the same path in a vacuum.

(equation 2)

Where:

T is the atmospheric transmissivity (dimensionless)

Φ(dU) is the luminous flux at the unit distance after passing through the atmosphere

Φvacuum(dU) is the theoretical luminous flux at the unit distance after passing through a vacuum

dU is the unit distance

Because the ratio of the luminous fluxes in equation 2 is the same as the ratio of the corresponding illuminance values, equation 2 can be rewritten as

(equation 3)

Where:

E(dU) is the illuminance at the unit distance after passing through the atmosphere

Evacuum(dU) is the theoretical illuminance at the unit distance after passing through a vacuum

Inserting expressions for E(dU) and Evacuum(dU) from equation 1 into equation 3, and noting that for Evacuum(dU) z = 0, equation 3 becomes

(equation 4)

Combining equation 1 and 4 yields

(equation 5)

**2.3 Allard's law using the transmissivity TM for 1 nautical mile**

The unit distance for transmissivity is chosen to be one nautical mile. Expressed in all metric units equation 5 takes the form

(equation 6)

Where:

E(d) is the illuminance at distance d in metres

I is the luminous intensity in candela

TM is the atmospheric transmissivity [dimensionless] for 1 nautical mile

d is the distance in metres

dU is the unit distance that corresponds to the transmissivity [1852 m]

COMMENT: Equation 6 needs a definition for TM so equation 3 is needed.

In practice the distance d is expressed in nautical miles. Using the fact that one nautical mile equals 1852 metres and suppressing the unit distance in the exponent equation 6 can be written as

(equation 7)

where d is the distance in nautical miles.

Simplifying and suppressing all units yields

(equation 8)

Where:

E(d) is the illuminance at the eye of the observer in lm/m2 [lx]

I is the luminous intensity of the light [cd]

TM is the transmissivity for one nautical mile of the atmosphere

d is the numerical value of the distance in nautical miles

COMMENT: Although equation 7 and 8 have a long tradition it might now be time to remove them from the recommendation.

**2.4 Meteorological Visibility**

The meteorological visibility is an alternative way to describe the extinction of the atmosphere, which in the development above is quantitatively characterised by the atmospheric transmissivity.

Meteorological visibility is the greatest distance at which a black object of suitable dimensions can be seen and recognized by day against the horizon sky, or, in the case of night observations, could be seen and recognized if the general illumination were raised to daylight level.

By definition the relationship between the meteorological visibility (V) and the transmissivity is

(equation 9)

Where:

V is the meteorological visibility in nautical miles

TM is the transmissivity [dimensionless] for one nautical mile

dU is the unit distance of 1 nautical mile

Suppressing ~~the units and suppressing~~ the unit distance yields:

(equation 10)

**2.5 Allard’s Law based on Meteorological Visibility**

It is recommended in the IALA dictionary that the atmospheric extinction be described by using meteorological visibility V rather than the transmissivity TM.

Allard's law can be expressed using meteorological visibility V by combining equations 8 and 10.

(equation 11)

Where:

E(d) is the illuminance at the eye of the observer [lx]

I is the luminous intensity of the light [cd]

d is the distance in nautical miles

V is the meteorological visibility in nautical miles

the units (not shown) associated with (3.43×106) are m2/M2

Preferred version using SI units:

(alternative - equation 11)

Where:

E(d) is the illuminance at the eye of the observer [lx]

I is the luminous intensity of the light [cd]

d is the distance in metres [m]

V is the meteorological visibility in metres [m]

**3 LUMINOUS RANGE**

COMMENT:

The intensity I is not unambigiuous. It is therefore necessary that IALA gives more information about the luminous intensity which is used for range calculations.

This was done before by part 3 to 5 of the original E-200.

It should be assumed that the intensity I is 75% of the minimum effective intensity in the useful sector. This still should be part of a future recommendation.

In the case of a light that appears as a point source, the **luminous range** **D** is defined as the maximum distance at which a light can be seen, as determined by the luminous intensity I of the light, the meteorological visibility V and the required illuminance Er at the eye of the observer. At this distance, the illuminance E at the observer’s eye is reduced to the value Er.

Inserting these parameters into equation 11 and rearranging yields:

(equation 12)

Where:

I is the luminous intensity of the light [cd]

Et is the required illuminance at the eye of the observer [lx] (see 4.1)

D is the luminous range in nautical miles

V is the meteorological visibility in nautical miles

Preferred version using SI units:

(equation 12)

Where:

I is the luminous intensity of the light [cd]

Et is the required illuminance at the eye of the observer [lx] (see 4.1)

D is the luminous range in metres [m]

V is the meteorological visibility in metres [m]

Equation 12 is recommended for the calculation of the luminous range of signal lights. Due to the numerical character of equation 12, numerical iteration is necessary in order to calculate the luminous range D. A rough estimation of D can be derived from the nomograms provided in this recommendation.

**4** Nominal Range

**4.1 Definition of the nominal luminous range of lights intended for the guidance of shipping**

IALA recommends that the nominal luminous range of maritime signal lights intended for the guidance of shipping should be defined as follows:

*The nominal luminous range of a maritime signal light is the distance in nautical miles at which this light produces an illumination at the eye of the observer:*

* *of 2 × 10-7 lx for night time range*
* *of 1 × 10-3 lx for day time range*

*It should be assumed that meteorological visibility V equals 10 nautical miles (TM = 0.7411) and that the atmosphere is homogenous.*

*Note: Please see Appendix 3.1 and 4.2 for further considerations of required illuminance values.*

The value 2 x 10-7 lx, agreed upon at the International Technical Conference of Lighthouse Authorities in Paris 1933, is the internationally accepted value of the illuminance required for observation of a light at night under typical maritime conditions.

It is important to note that a leading light, like any other night-time light, will have a nominal luminous range that corresponds to the distance at which the illumination at the eye of the observer is 2 × 10-7 lx. However, per IALA recommendation for leading lights [5] the illumination required for an observer to use the leading lights for alignment must be at least 1 × 10-6 lx. Because the illumination level that corresponds to nominal luminous range is 5 times less than the level needed to align the lights, the concept of nominal range for a leading light is not typically used.

**4.2 Notation of the nominal luminous range of lights intended for the guidance of shipping**

IALA recommends that the nominal range of lights intended for the guidance of shipping should be published in the “Lists of Lights”.

*The following information should be published in the “Lists of Lights”:*

* *The nominal range of lights intended for the guidance of shipping by night;*
* *Where applicable, the nominal range of lights intended for the guidance of shipping by day;*
* *Nomograms permitting mariners to estimate the luminous range of lights intended for the guidance of shipping by day or by night as a function of their nominal range, the prevailing meteorological visibility and, where applicable, the sky luminance in the direction of observation.*

Note:

The nominal range of leading lights is typically omitted for reasons as described in Section 4.1.

The published nominal luminous range of a light should include a reference to the value of illuminance used.

**5 IMPORTANT FACTORS IN THE DESIGN OF MARINE SIGNAL LIGHTS**

The following important factors should be taken into account when selecting marine AtoN signal lights for installation. As a result, a different luminous intensity may be required to achieve the required range.

**5.1 Service Condition Factor**

In practical installations, the degradation of luminous intensity under service conditions, due to light source degradation, dirt and salting of lanterns etc., should be taken into consideration. It is recommended that the intensity used to calculate the nominal range for publication should include a service factor. It is recommended that this service factor be taken as 0.75 (corresponding to a reduction in intensity of 25%). Although this service conditions factor includes degradation of the light source output, it should be noted that some light sources, such as discharge lamps and LEDs, can degrade significantly more than 25% over their lifetime. When designing and installing AtoN signal lights, degradation over the service period as well as the lifetime of the equipment should be taken into consideration.

**5.2 Local Conditions**

The prevailing visibility conditions will vary over different geographical locations. Therefore, when selecting a light, this should be taken into account. Selection should be based on a practical luminous range value and not on nominal range.

**5.3 Zone of Utilisation**

The required range may vary over the zone of utilization of the light.

**5.4 Background Luminance**

Different levels of background luminance may require different values of required illuminance values (see Appendix 1).

**5.5 Leading Lights**

It is important to note that a leading light, like any other night-time light, will have a nominal range that corresponds to the distance at which the illuminance at the eye of the observer is 2\*10-7 lx. However, IALA recommendation E-112 for leading lights [5] states that the illuminance required for an observer to use the leading lights for alignment at night must be at least 1\*10-6 lx. Because the illuminance level that corresponds to nominal range is 5 times less than the level needed to align the lights in the useful segment, the concept of nominal range for a leading light is not typically used.

**5.6 Assessment of Suitability**

Where practicable, a subjective assessment of the signal light should be carried out to confirm the suitability of the signal light within its arc of utilisation.

**APPENDIX 1 Diagrams and Tables**

**1 METEOROLOGICAL VISIBILITY AND TRANSMISSIVITY**



*Figure 1 A graph of meteorological visibility versus atmospheric transmissivity (TM)*

**2 LUMINOUS RANGE FOR NIGHT TIME**

The required value for illuminance is .

where I is in candela, and D & V are numerical values in M (nautical miles)

Preferred version using SI units

where I is in candela, and D & V are numerical values in metres [m]



Figure 2 Luminous Range diagram - night time

COMMENT: Add range in metres?

**3 NOMINAL RANGE FOR NIGHT TIME**

Table 1 should be used to determine the night time nominal range rounded off to the nearest nautical mile.

Table 1 Night time nominal range table (rounded off to the nearest nautical mile)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Luminous  intensity | Nominal  range (rounded) | Luminous intensity | Nominal range (rounded) | Luminous intensity | Nominal range (rounded) |
| candelas  (cd) | nautical miles (M) | kilocandelas  (103 cd) | nautical miles (M) | Megacandelas  (106 cd) | nautical miles (M) |
| 1 - 2 | 1 | 0.633 – 1.06 | 9 | 0.927 – 1.35 | 26 |
| 3 - 9 | 2 | 1.07 – 1.75 | 10 | 1.36 – 1.96 | 27 |
| 10 - 23 | 3 | 1.76 – 2.84 | 11 | 1.97 – 2.84 | 28 |
| 24 - 53 | 4 | 2.85 – 4.53 | 12 | 2.85 – 4.11 | 29 |
| 54 - 107 | 5 | 4.54 – 7.13 | 13 | 4.12 – 5.93 | 30 |
| 108 - 203 | 6 | 7.14 – 11.1 | 14 | 5.94 – 8.53 | 31 |
| 204 - 364 | 7 | 11.2 – 17.1 | 15 | 8.54 – 12.2 | 32 |
| 365 - 632 | 8 | 17.2 – 26.1 | 16 | 12.3 – 17.5 | 33 |
|  |  | 26.2 - 39.7 | 17 | 17.6 – 25.1 | 34 |
|  |  | 39.8 – 59.9 | 18 | 25.2 – 35.9 | 35 |
|  |  | 60.0 – 89.8 | 19 | 36.0 – 51.2 | 36 |
|  |  | 89.9 - 133 | 20 | 51.3 – 72.9 | 37 |
|  |  | 134 -198 | 21 | 73.0 - 103 | 38 |
|  |  | 199 - 293 | 22 | 104 -147 | 39 |
|  |  | 294 - 432 | 23 | 148 - 209 | 40 |
|  |  | 433 - 634 | 24 |  |  |
|  |  | 635 - 926 | 25 |  |  |

Required value for illuminance

QUESTION:

Do we need intensities exceeding 10 Megacandelas?

**3.1 Compensation for Background Lighting (nighttime)**

The required illuminance of at the eye of the observer corresponds to a situation with no background lighting. In most real situations the lights are viewed against a background that does have lights. This will reduce the luminous range.

The recommended method for compensating for background lighting is to use different values for the required illuminance.

Two different values should be used:

minor background lighting: factor 10 x

substantial background lighting: factor 100 x

For a light of given intensity the introduction of background lighting will reduce the luminous range.

According to equation 12 the required intensity should be increased by the factors above in order to compensate for background lighting and achieve the same luminous range.

The graph in figure 2 has been drawn for a required illuminance of . For the other values of required illuminance (minor and substantial background lighting) mark off along the scale of abscissae the distance between 'No Background lighting (NONE)' and that under consideration as it appears on the auxiliary scale.

*Example:*

Suppose that it is required to find the luminous range of a light with a nominal range of 17 M and a luminous intensity of 32,300 cd for substantial background lighting and a visibility of 5 M.

Measure the distance A separating 'no background lighting (NONE)' and 'substantial background lighting (SUBSTANTIAL)'. Transfer this distance to the scale of the abscissae from graduation to 17 M (32,300 cd) in the same sense. A point slightly to the right of graduation corresponding to 7 nautical miles is obtained. Erect from this point a parallel to the axis of ordinates to meet the curve for 5 nautical miles visibility. Read off the luminous range on the vertical scale against the point so obtained. We read approx. 5 nautical miles.

**4 LUMINOUS RANGE FOR DAYTIME**

**4.1 Estimation of Required Illuminance for Daytime Range**

The mariner should be able to estimate the luminous range of lights by day for different sky luminances. However, the required illuminance Et in lx, produced by a light, depends on the luminance L of the sky in candelas per square metre, in the direction of observation according to the formula:

equation 13

Where:

*Et* is the required illuminance at the observer’s eye in lm/m2 [lx]

*L* is the sky (background) luminance in cd/m2

Preferred version with all units visible:

The required illuminance thus corresponds to a sky luminance of 10,000 candelas per square metre. The calculated required illuminance should be inserted in equation 12.

COMMENT:

This chapter assumes that the mariner himself tries to estimate the range of a light by day. This might have been important in earlier years. I don’t know if this is still relevant now. However a IALA document is not a document for a mariner. So if this information is not passed on to a ‘mariner’s document’ there is no need to put it into a recommendation. In this case 4.1 and 4.2 should become part of a guideline.

The required value for illuminance is

where I is in candela, and D & V are numerical values in M (nautical miles)

Preferred version using SI units

where I is in candela, and D & V are numerical values in metres [m]



Figure 3 Luminous Range diagram - daytime

COMMENT: Add range in metres?

**4.2 Explanation of daytime diagram**

Calculation of required illuminance by day

Et : required illuminance

L : luminance of sky in the direction of observation

*Table 2 Background luminance in various meteorological conditions*

|  |  |  |
| --- | --- | --- |
| Meteorological condition | Luminance in cd/m² | Required illuminance  Et in 10-3 lx |
| Very dark overcast sky | 100 | 0.013 |
| Dark overcast sky | 200 | 0.024 |
| Ordinary overcast sky | 1 000 | 0.107 |
| Bright overcast sky or clear sky away from the direction of the sun | 5 000 | 0.506 |
| Bright cloud or clear sky close to the direction of the sun | 10 000 | 1 |
| Very bright cloud | 20 000 | 1.98 |
| Glaring cloud | 50 000 | 4.91 |

4.2.1 Use of the graph (Figure 3):

The graph has been drawn for a sky luminance of 10 000 cd/m². For other values of sky luminance mark off along the scale of abscissae the distance between the luminance of 10 000 cd/m² and that under consideration as it appears on the auxilliary scale.

Example:

Suppose that it is required to calculate the luminous range of a light of 2 000 000 cd for a meteorological visibility of 2 nautical miles under an ordinary overcast sky (luminance 1 000 cd/m²).

Measure the distance A separating graduations 10 000 cd and 1 000 cd on the auxiliary scale. Transfer this distance to the scale of abscissae from graduation corresponding to 2 000 000 cd (2´106 cd) in the same sense. A point slightly to the right of graduation corresponding to 12 nautical miles is obtained. Erect from this point a parallel to the axis of ordinates to meet the curve for 2 nautical miles visibility. Read off the luminous range on the vertical scale against the point so obtained. We read approx. 4 nautical miles.

**5 NOMINAL RANGE FOR DAYTIME**

Table 3 should be used to determine the daytime nominal range rounded off to the nearest nautical mile

Table 3 Day time nominal range table (rounded off to the nearest nautical mile)

|  |  |  |  |
| --- | --- | --- | --- |
| Luminous  intensity | Nominal  range (rounded) | Luminous intensity | Nominal range (rounded) |
| kilocandelas  (103 cd) | nautical miles (M) | Megacandelas  (106 cd) | nautical miles (M) |
| 1 – 12.0 | 1 | 1.02 – 1.82 | 7 |
| 12.1 – 45.3 | 2 | 1.83 – 3.16 | 8 |
| 45.4 – 119 | 3 | 3.17 – 5.32 | 9 |
| 120 – 267 | 4 | 5.33 – 8.78 | 10 |
| 268 – 538 | 5 | 8.79 – 14.2 | 11 |
| 539 – 1010 | 6 | 14.3 – 22.6 | 12 |
|  |  | 22.7 – 35.6 | 13 |
|  |  | 35.7 – 55.5 | 14 |
|  |  | 55.6 – 85.6 | 15 |
|  |  | 85.7 – 130 | 16 |
|  |  | 131 – 198 | 17 |
|  |  | 199 – 299 | 18 |
|  |  | 300 – 449 | 19 |
|  |  | 450 – 669 | 20 |
|  |  | 670 – 993 | 21 |
|  |  | 994 – 1460 | 22 |

QUESTION:

Do we need intensities exceeding 10 Megacandelas?

*Table 4 Nominal range table for various background luminance values (night and day)*

**For Guidance Only – not to be used for Nominal Range Publication**

Table 4 is missing

Who has this table?

**6 References**

[1] Recommendation for the notation of luminous intensity and range of lights.

(IALA, November 1966)

[2] International Dictionary of Aids to Marine Navigation, Chapter 2, Visual Aids

2-1-265 to 2-1-285 (IALA 1970)

[3] Recommendation for a definition of the nominal daytime range of marine  
 signal lights intended for the guidance of shipping by day (IALA 1974)

[4] Recommendations on the determination of the luminous intensity of a marine

aid-to-navigation light (IALA 1977)

[5] Recommendation for leading lights (IALA, E-112, May 1998)

[6] Recommendation on the photometry of marine aids to navigation Signal lights

(IALA, E-122, June 2001)

1. Inputocument number, to be assigned by the Committee Secretary [↑](#footnote-ref-1)
2. Leave open if uncertain [↑](#footnote-ref-2)