Navguide: Chapter 3 - Aids to navigation

A marine **Aid to Navigation (AtoN)** is a device, system or service, external to vessels, designed and operated to enhance safe and efficient navigation of individual vessels and/or vessel traffic. A marine aid to navigation should not be confused with a navigational aid. A **navigational aid** is an instrument, device, chart, etc., carried on board a vessel for the purpose of assisting navigation.

This chapter describes the major types of visual and other physical aids to navigation in current use and provides comments on the application and performance of the various technologies.

Vessel Traffic Services (VTS), are also considered by IALA as satisfying the definition of an aid to navigation. However these are covered in separate chapters due to their increasingly significant role in contributing to navigation safety.

The concept of e-Navigation has recently gained significant momentum and a framework is being developed under the auspices of the IMO. IALA has been requested by the IMO to develop the shorebased aspects of the conceptual framework and systems architecture for e-Navigation. Chapter 4 of the Navguide covers e-Navigation. Radionavigation systems form a key element of the e-Navigation infrastructure and are therefore covered in Chapter 4.

3.1 Operational Requirements

This section to be developed by ARM

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The primary objective of aids to navigation is to mitigate transit
risks to promote the safe, economic, and efficient movement of vessels
by assisting navigators with determining their position, a safe course,
 and warning them of dangers and obstructions, especially when used in
conjunction with other aids within visual, audio, or radar range of the
 mariner.
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3.2 Visual and Audible Aids to Navigation Design Theory

Visual marks for navigation can be either natural or man-made objects. They include structures specifically designed as short range aids to navigation, as well as conspicuous features such as headlands, mountain-tops, rocks, trees, church-towers, minarets, monuments, chimneys, etc. Short range aids to navigation can be fitted with a light if navigation at night is required, or left unlit if daytime navigation is sufficient.

Navigation at night is possible, to a limited extent, if the unlit aids are provided with:

- a radar reflector, and the navigating vessel has a radar;
- retro-reflecting material, and the vessel has a searchlight. This approach would generally only be acceptable for small boats operating in safe waterways and with the advantage of local knowledge.

Visual aids to navigation are purpose-built facilities that communicate information to a trained observer on a vessel for the purpose of assisting the task of navigation.

The communication process is referred to as *marine signalling*.

Common examples of visual aids to navigation include lighthouses, beacons, leading (range) lines, buoys (lit or unlit), lightvessels, daymarks (dayboards) and traffic signals.

The effectiveness of a visual aid to navigation is determined by factors such as:

- type and characteristics of the aid provided;
- location of the aid relative to typical routes taken by vessels;

- distance (range) of the aid from the observer;
- atmospheric conditions;
- contrast relative to background conditions (conspicuity);
- the reliability and availability of the aid.

Visual aids to navigation can be distinguished by a wide range of characteristics such as:

- type; shape; size; colour; names, retro-reflective features; letters and numbers;
- lit/unlit; signal character; light intensity; sectors; inclusion of subsidiary aids;
- fixed structure; floating platform; construction materials;
- location; elevation; relationship to other aids to navigation and observable features.

Refer to IALA publications:

- Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation;
- Guideline 1035 on Availability and Reliability of Aids to Navigation.

Photo - Courtesy of Danish Maritime Authority

3.2.1 Visual Perception

~~*This section is under development*~~

When a navigator approaches a visual AtoN, for instance a buoy, the first thing the navigator will recognise is the shape or colour of the buoy depending on the viewing conditions.

The navigator will subsequently recognise the topmark and finally its numbers or letters. Thus, the process of identifying a visual AtoN goes through three different stages of perception.

~~Table x The three degrees of perception~~

Detection- The observer is aware of an object. The navigator sees an object, but will usually not be bale to deduce its shape or colour and will not know that it is an AtoN.

Recognition - The observer is aware that the object is an AtoN.

Identification - The observer is aware which AtoN the object is. At this distance, the navigator can perfectly discern the type of mark it is.

3.2.1.1 Signal Colours

IALA has made recommendations on colours for lighted aids to navigation and for surface colours for visual signals on aids to navigation.

Marine aid-to-navigation signal lights use a five-colour system comprising white, red, green, yellow and blue, as defined in IALA Recommendation E-200 Part 1. Although the colour regions defined in this IALA recommendation agree with those given in the International Commission on Illumination (CIE) Standard S 004/E 2001[1] "Colours of Light Signals", the boundaries of each colour region differ in some cases. Furthermore, in their standard, CIE recommend that signal systems should normally comprise no more than four colours.

Recommended surface colours for visual signals on aids to navigation are as follows:

- Ordinary colours should be limited to white, black, red, green, yellow or blue[2].
- Orange and fluorescent red, yellow, green or orange may be used for special purposes requiring high conspicuity.

Refer to IALA publications:

- Recommendation E-106 for the Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System;
- Recommendation E-108 for the Surface Colours Used as Visual Signals on Aids to Navigation;
- Guideline 1015 on Painting Aids to Navigation Buoys (including reference to the practical guide on surface colours).

The CIE standard on the measurement of colours (colorimetry) is based on three reference colours (ie. a tri-stimulus system) that in varying combination can generate the visual spectrum of colours. A particular **colour function** is described by the symbols; **X**, **Y** and **Z** that represent the proportions of the reference colours.

Using ratios of the tri-stimulus values, such that: $X + Y + Z = 1$, colours can be defined in terms of chromaticity using just the $x = X / (X+Y+Z)$ and $y = Y / (X+Y+Z)$ values. The advantage of this arrangement is that colours can be mapped on a two-dimensional **chromaticity diagram**.

CIE colour standards for marine signalling can be depicted as areas on the chromaticity diagram. These areas are defined by boundaries expressed as functions of x and y (equations).

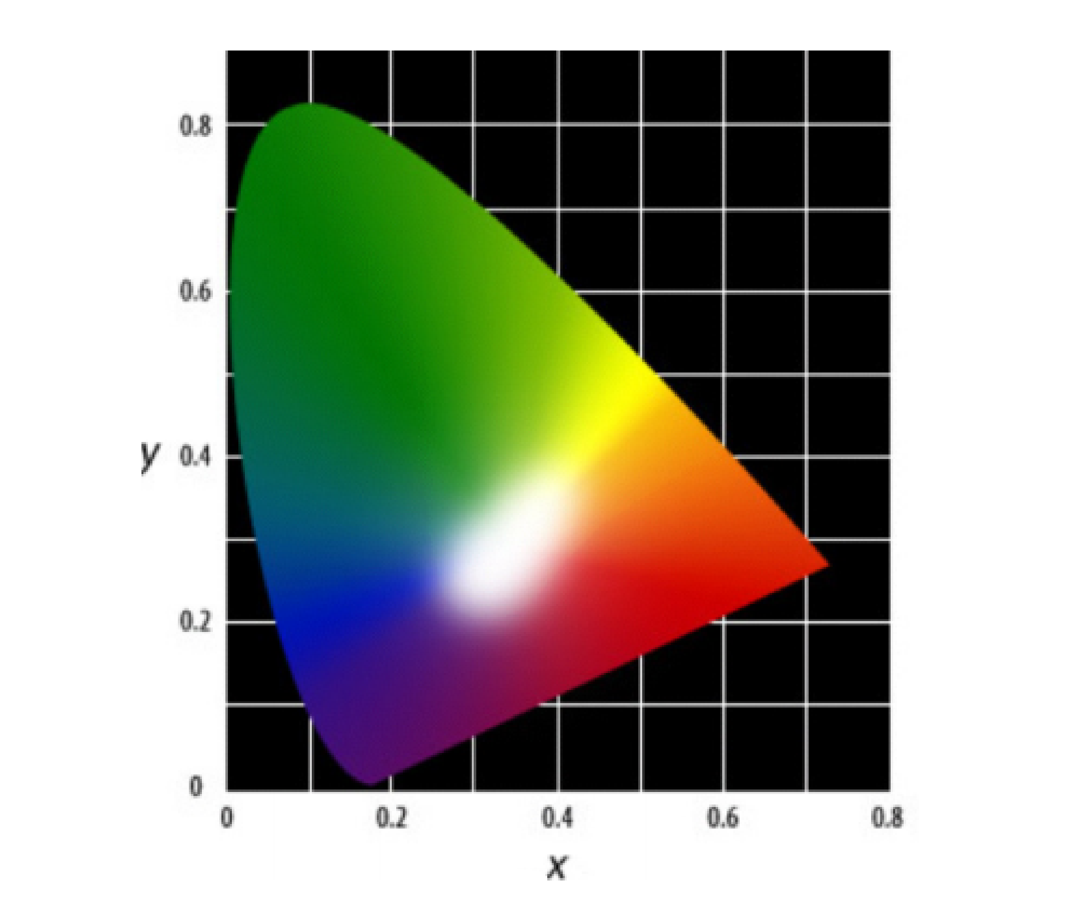


Figure 6 - Illustration of the Colour Zones on the 1931 CIE Chromaticity Diagram - Please note that the colour rendering is only indicative and should not be taken as fully accurate

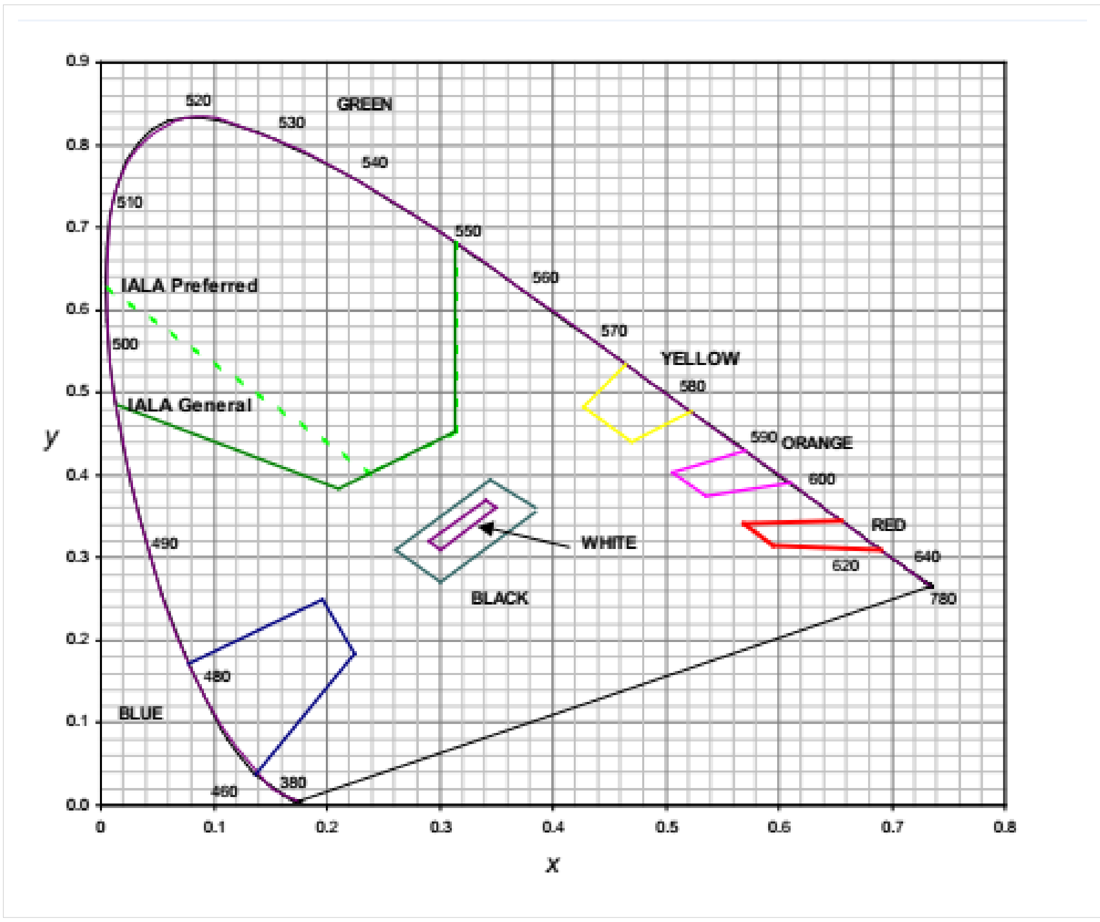


Figure 7 - IALA Chromaticity Areas of Ordinary Surface Colours - As plotted on the 1983 CIE Chromaticity diagram - courtesy of CIE

If the chromaticity co-ordinates of a coloured light, filter material or a paint product are known, its acceptability for marine signalling applications can easily be determined.

The CIE standard for signalling colours has recently been revised, with some adjustments to the boundaries of signal colours. Further information on surface colours can be found in IALA Recommendation E108 on the surface colours used as visual signals on aids to navigation. Information for light signal colours is shown in IALA Recommendation for the colours for light signals on aids to navigation, December 1977. For further details on this issue, refer to CIE S 004/E-2001 Colours of Light Signals. [3]

3.2.1.2 Meteorological Visibility

Meteorological visibility (V) is defined as the greatest distance at which a black object of suitable dimensions can be seen and recognised by day against the horizon sky, or, in the case of night observations, could be seen if the general illumination were raised to the normal daytime level. It is usually expressed in kilometres or nautical miles.

Photo Courtesy of Australian Maritime Safety Authority.

3.2.1.3 Atmospheric Transmissivity

The atmospheric transmissivity (T) is defined as the transmittance, or proportion of light from a source, that remains after passing through a specified distance through the atmosphere, at sea level. This is expressed as a ratio. But since the atmosphere is not uniform over the observing distances of most visual aids, a representative value is used:

- typically, the atmospheric transmissivity is taken as T = 0.74 over one nautical mile;
- a figure of T = 0.86 is occasionally used in regions where the atmosphere is very clear.

A number of countries collect data on atmospheric transmissivity for different parts of their coastline. This enables the luminous range of lights to be:

- calculated more precisely;
- better matched to local conditions and user requirements.

3.2.1.4 Atmospheric Refraction

This phenomenon results from the normal decrease in atmospheric density from the Earth's surface to the stratosphere. This causes light rays that are directed obliquely through the atmosphere to be refracted (or bent) towards the Earth in accordance with Snell's Law.

3.2.1.5 Contrast

The ability to detect differences in luminance between an object and an otherwise uniform background is a basic visual requirement and is used to define the term contrast. It is represented by the equation:

$$C = \frac{(L_o - L_B)}{L_B}$$

where:
- C = contrast
- L_B = luminance of background (cd/m^2)
- L_O = luminance of object (cd/m^2)

The contrast at which an object can be detected against a given background for 50% of the time, is called the threshold contrast. For meteorological observations, a higher threshold must be used to ensure that the object is recognised.

A contrast value of 0.05 has been adopted as the basis for the measurement of meteorological optical range.

3.2.1.6 Use of Binoculars

While it is generally assumed that observations will be made with the naked eye, mariners will quite often use binoculars. This can allow:

- a light being observed, or the characteristics resolved, at a greater luminous range than with the naked eye;
- a limited improvement in the sensitivity of leading lights;
- about a 30% improvement in the detectable difference from a given bearing;
- the identification of a light operating against background lighting conditions.

Generally, the most suitable binoculars for use at sea are considered to be the type with a magnifying power of 7 and an objective lens of 50 mm at night, and 10 x 50 binoculars by day.

3.2.1.7 Geographical Range

This is the greatest distance at which an object or a light source could be seen under conditions of perfect visibility, as limited only by the curvature of the earth, by refraction of the atmosphere, and by the elevation of the observer and the object or light.

As the observer moves further away from the object or light source, there will come a point where the object or light source is obscured by the Earth. This is illustrated in Figure 8.

Observer Eye Heigth Meters	Elevation of Mark/metres										
	0	**1**	**2**	**3**	**4**	**5**	**10**	**50**	**100**	**200**	**300**
1	2.0	4.1	4.9	5.5	6.1	6.6	8.5	16.4	22.3	30.8	37.2
2	2.9	4.9	5.7	6.4	6.9	7.4	9.3	17.2	23.2	31.6	38.1
5	4.5	6.6	7.4	8.1	8.6	9.1	11.0	18.9	26.9	33.3	39.7
10	6.4	8.5	9.3	9.9	10.5	11.0	12.8	20.8	26.7	35.1	41.6
20	9.1	11.1	12.0	12.6	13.1	13.6	15.5	23.4	29.4	37.8	44.2
30	11.1	13.2	14.0	14.6	15.2	15.7	17.5	25.5	31.4	39.8	46.3

Table 8 - Graphical Range Table in Nautical Miles

The values in Table 8 are derived from the formula:

$$R_g = 2.03 \times \left(\sqrt{h_o} + \sqrt{H_m}\right)$$

where: R_g = geographical range (nautical miles)
h_o = elevation of observer's eye (metres)
H_m = elevation of the mark (metres)

The factor 2.03 accounts for refraction in the atmosphere. Climatic variations around the world may lead to different factors being recommended. The typical range of factors is 2.03 to 2.12.

3.2.2 Daymarks

~~*This section to be developed*~~

3.2.2.1 Visibility of a Mark

The visibility of a mark is affected by one or more of the following factors:

- observing distance (range);
- curvature of the Earth;
- atmospheric refraction;
- atmospheric transmissivity (meteorological visibility);
- height of the aid above sea level;
- observer's visual perception;
- observer's height of eye;
- observing conditions (day or night);
- conspicuity of the mark (shape, size, colour, reflectance, and the properties of any retroreflecting material);
- contrast (type of background such as lighting, vegetation, snow, etc.);
- mark lit or unlit;
- intensity and character.

Refer to IALA publications:

- Recommendation E-106 for the Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System.

- Recommendation E-108 for the Surface Colours Used as Visual Signals on Aids to Navigation.

3.2.2.2 Range of a Visual Mark

The range of an aid to navigation can broadly be defined as the distance at which the observer's receiver can detect and resolve the signal. In the case of visual marks the observer's receivers are his/her eyes. This broad definition of range leads to a number of more specific definitions that are described below.

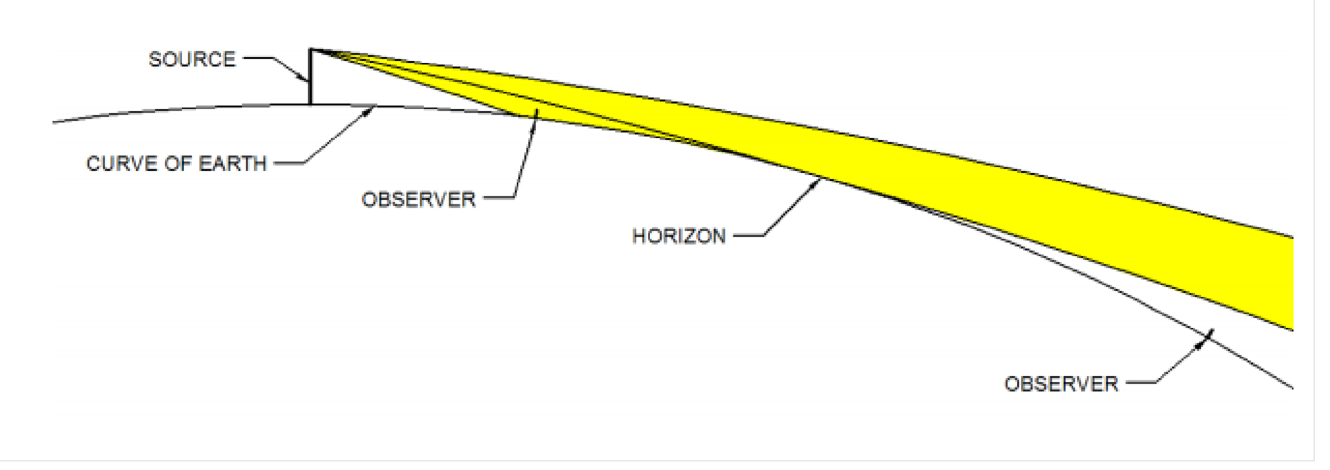


Figure 8 - Effect of Exceeding Geographical Range

3.2.3 Lights

This section to be developed

3.2.3.1 Photometry of Marine Aids to Navigation Signal Lights

~~Measurement of Light In science, the behaviour of light is normally seen in the context of either a form of electromagnetic radiation or particle motion. This is the so-called "wave/particle duality" nature of light. The latter includes the concept of "rays" of light that are used in analyzing the interactions of light and lenses. The units of interest for electromagnetic applications of light are generally metres (wavelength) and Watts (power).~~

The study of photometry and the use of lights for signal application has necessitated a parallel set of units to be developed to account for the physiological aspects of how the human eye evaluates a light source, as shown in Table 9.

The spectral sensitivity of the human eye (or the response of the eye to different coloured light) has been evaluated in tests of large numbers of people. The results have been presented as a standard spectral sensitivity distribution or V(λ) curve for photopic (daytime) observers and V'(λ) for scotopic (night time) observers.

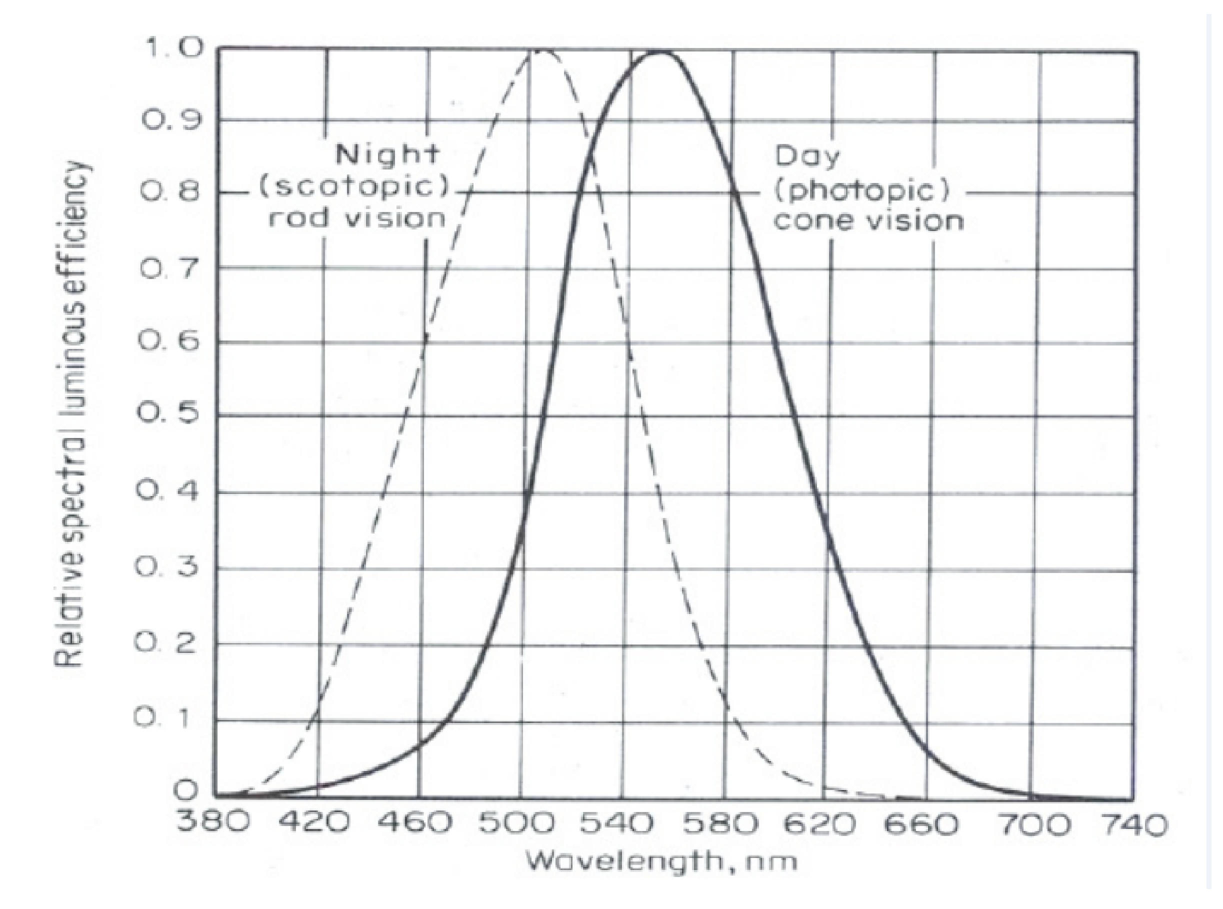


Figure 9 - Spectral Sensitivity Distributions or V(λ) and V'(λ) Curves for the Human Observer.

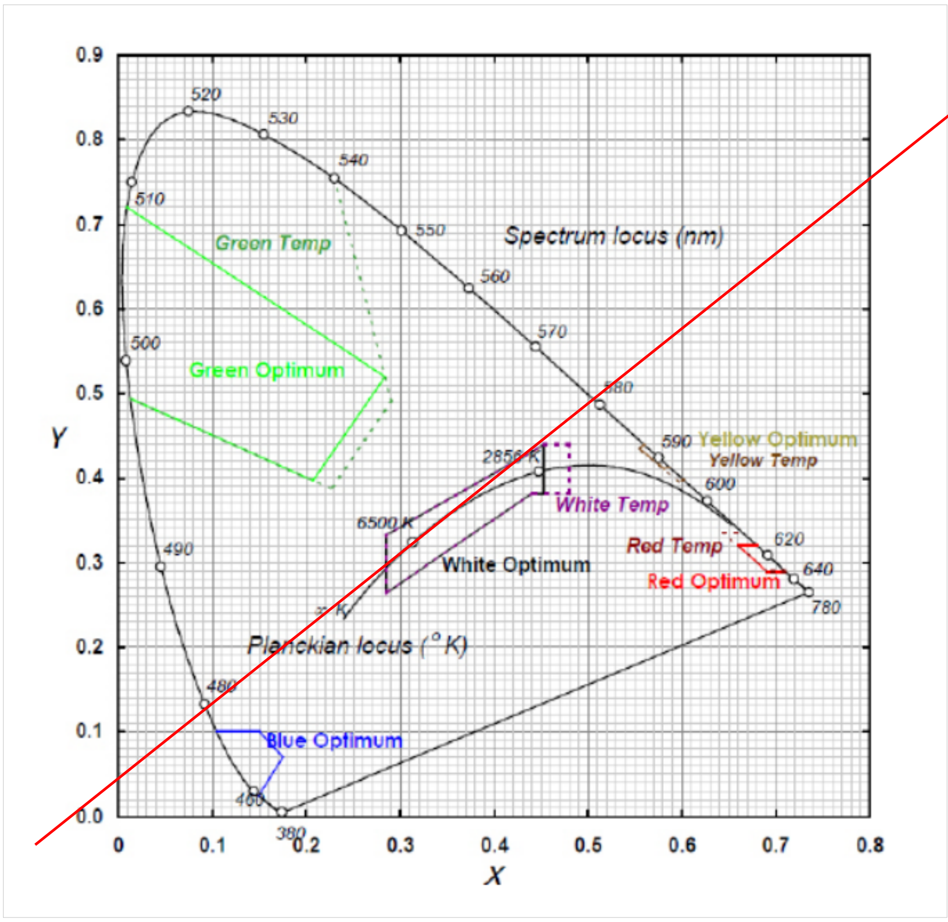


Figure 10 - Chromaticity Regions of the Recommended IALA Colours for Lights

IALA Optimum boundaries are represented by solid lines while IALA Temporary boundaries are represented by dashed lines.

Colorimetric Measurement of Lights (Colour Measurement)

The measurement of the colour of lights is described in CIE Publication No 15.2 (1986) Colorimetry. There are two main types of instrument for measuring the colour of a light: one is a colorimeter; the other is a **spectroradiometer**.

Colorimeters usually comprise three photoreceptors, each with a coloured filter. Each filter is matched to the response of one of the three eye receptors, red green and blue and such devices are called 'tristimulus' colorimeters. The colorimeter gives three outputs, one for each filtered receptor, and these correspond to the X, Y and Z functions of the human observer.

Spectroradiometers consist of a monochromator and photoreceptor. The monochromator splits the light into individual wavelengths (much like a prism makes a rainbow) and is usually rotated in steps past an exit slit. The photoreceptor, behind the exit slit, measures different sections of the spectrum as the monochromator is rotated. The output is a series of readings enabling a graph of power against wavelength to be displayed. Results may then be weighted with the X, Y and Z functions of the human observer to produce colour information.

Stepping monochromators of the type described previously are fairly slow in operation and are not suitable for measuring flashing lights. **Tristimulus colorimeters**, on the other hand, enable much faster measurements of colour. New types of spectradiometer, known as **'arraybased' spectroradiometers**, are now available. Instead of a single photoreceptor and a rotating monochromator, a fixed monochromator has its output directed at an array of charge-coupled devices (CCDs). Such devices are capable of much faster measurement speeds than stepping monochromators.

Recent developments in colour measurement have resulted from the technology of digital cameras. **'Imaging photometers'**, as they are known, are little more than calibrated digital cameras, some with tristimulus filtering. They are capable of fast measurement of a whole scene, making them useful for work outside the laboratory. ~~However, the accuracy of some cheaper devices leaves much to be desired.~~

In summary:

- Tristimulus colorimeters are fast, however cheaper models suffer errors when measuring narrowband light sources such as LEDs;
- Stepping monochromators are expensive and slow but very accurate;
- Array-based spectroradiometers are fast, relatively inexpensive, but can suffer with stray light errors;
- Imaging photometers are expensive and not very accurate, but can record a whole scene and not just one light.

Resultant data from colour measurements are usually displayed on a chromaticity chart, developed by the CIE in 1931. The three X, Y, Z values are reduced to two x, y values as shown in Figure 11.

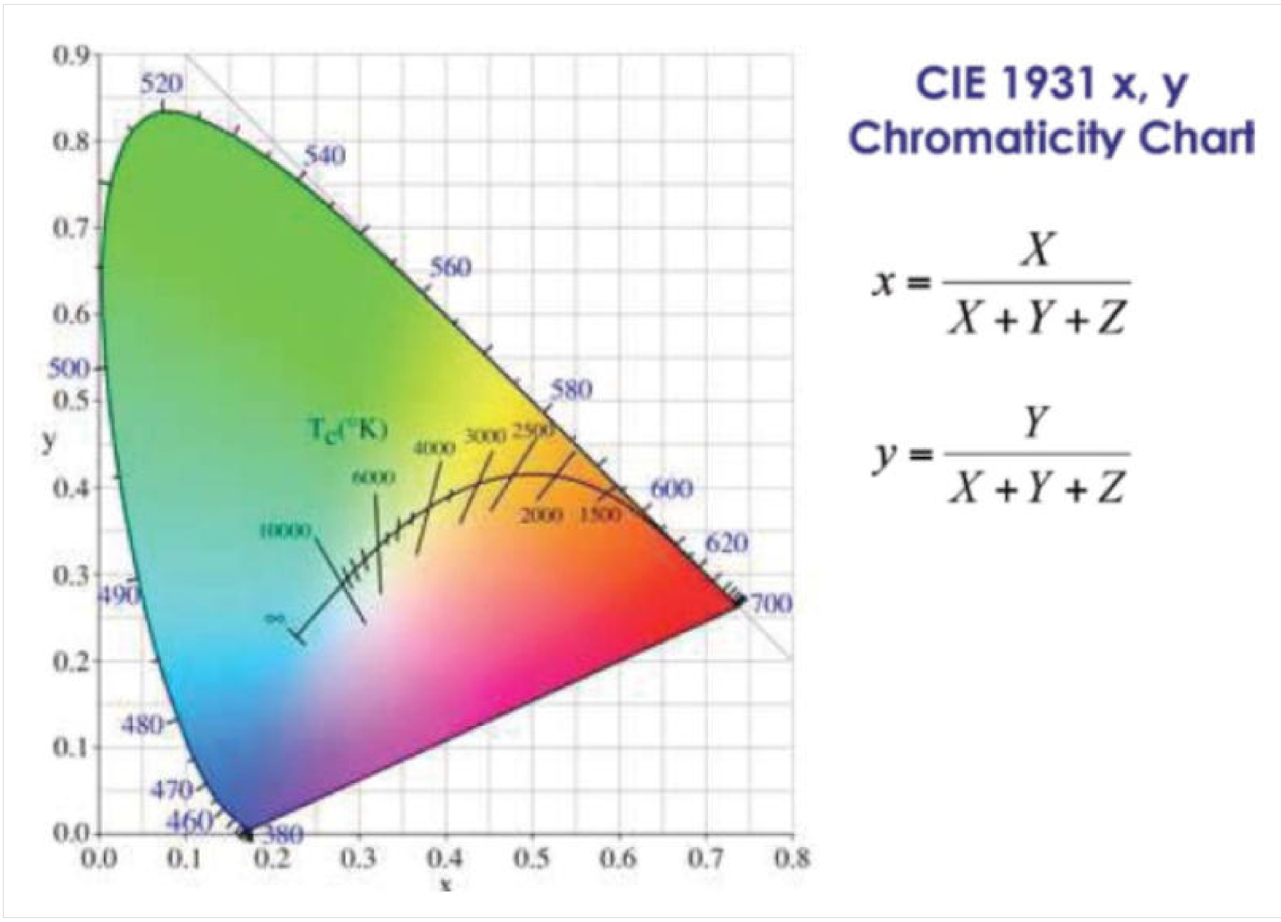


Figure 11 - CIE 1931 x,y Chromaticity Chart

Units of Measurement

Term	Description	Unit	Abbreviation
Luminous flux	This is the total light emitted from the source (ie. lamp) The peak sensitivity of the human eye occurs at about 555 nanometres, a wavelength that corresponds to green. At this wavelength, the photometric equivalent of one watt is defined as 680 lumens.	lumens	lm
Luminous intensity	This is the part of the luminous flux in a particular direction. Also expressed as the luminous flux per solid angle (or steradian [15])	candela	cd
Luminance (Brillance)	This is the portion of the luminous flux emitted in a specific direction by the surface area of a luminous body. This variable is an important term for rating the brightness impression of light sources and illuminated objects.	candelas per square meter and also as candelas per square centimeter	cd/m2 cd/cm2
Illuminance	This is the density of the luminous flux incident on a surface. It is the quotient of the luminous flux by the area of the surface when the surface is uniformly illuminated	lux (lumens/square metre)	lx
Luminous efficacy	This is the ratio of luminous output to radiometric output of a light source. It can also be applied to the efficiency with which electrical power is converted to visible radiation.	lumens per watt of electrical power consumed	
Colour temperature	This related to the temperature of a black body. As a body heats up, it goes through a series of different colours from red through yellow and white, to blue white. The colour appearance of a tungsten filament lamp is similar to a black body at the same temperature.	Kelvin	°K
Colour rendering index	Characterises the colour rendering quality of the light from a lamp. It is the same for all incandescent lamps by definition and equal to the maximum value of 100.		CRI

Table 9 – Photometric Units of Measurement

Threshold of Illuminance

In physical terms, the threshold of illuminance is the lowest level of illuminance from a point source of light, against a given background level of luminance, that causes a visual response at the eye. For visual signalling applications, the threshold of illuminance (E) is taken to be 0.2 μlux at the eye of the observer. In the case of leading lights of limited range and with a high level of shore illumination, the above figures may be found too low. It is recommended that to observe the relative position of the lights easily and to derive the maximum possible accuracy from leading and sector lights, it is generally necessary to have a minimum illuminance of 1 μlux at the eye of the observer.

This condition is to be met at the outer limits of the useful segment for the minimum meteorological visibility under which the leading lights are to be used. IALA Recommendation on the Definition of the Nominal Daytime Range of Maritime Signal Lights, Intended for the Guidance of Shipping by Day (1974) provides the method of designing AtoN lights for use in daylight. For lights on floating aids, care must be taken to provide adequate vertical divergence so that the minimum illuminance at the observer is maintained as the floating aid rolls and pitches.

Luminous Intensity

The luminous intensity of a navigation light is directly proportional to the luminance of the light source. The size of the light source is inversely proportional to its luminance and directly proportional to the divergence of the optic system.

Candela (cd) is the measurement unit used to quantify the luminous intensity of a lighted aid to navigation.

Inverse Square Law

Light emitted from a source radiates out in all directions. For a point source, the wave fronts of light can be imagined to generate a series of spherical surfaces. As shown in Figure 12, the further the light travels from the source, the greater is the surface area of the sphere and consequently, the lower the illuminance. Since illuminance is measured in lumens per square metre, and the surface area of a sphere increases in proportion to the square of the radius, the illuminance decreases in proportion to the square of the distance from the source. The decline in illuminance with distance is described as an inverse-square law.

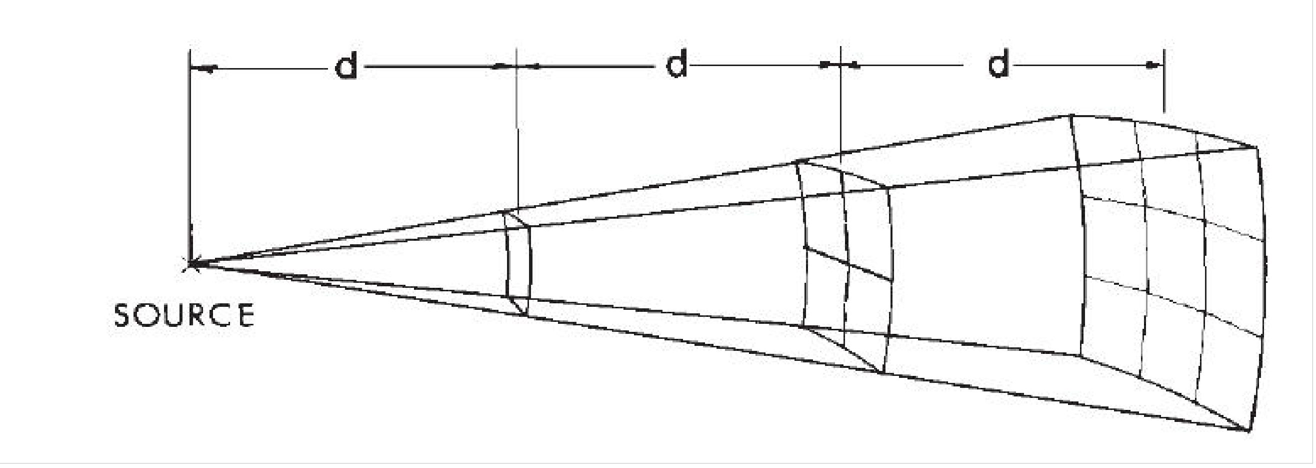


Figure 12 - Illustration of the Inverse Square Law Concept.

Allard's Law

The illuminance of a light source reaching an observer's eye determines whether the light is seen. The relationship between the illuminance produced at the observer's eye, the luminous intensity of the light source, the distance to the observer and the atmospheric transmissivity is given by the relationships shown in Allard's Law:

$$E = \frac{I \times T^d}{d^2}$$

where: E = illuminance at the observer's eye (lm/m²)

I = effective intensity of the light source (cd)

T = atmospheric transmissivity

d = distance between the light source and the observer.

Because T is measured per nautical mile, d in the numerator must also be in nautical miles. In the denominator, d is in metres.

Allard's law applies only when the luminance of the background is small compared to the average illuminance of the light.

Refer to IALA publication:

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

3.2.3.2 Rhythms and Characters

IALA has produced a recommendation on the characters for light on aids to navigation. The tables of classifications and specifications of aid to navigation characters are provided in Table 10.

Refer to IALA publication:

- Recommendation E-110 for the rhythmic characters of lights on aids to navigation.

The Rhythmic Characters of Lights are provided in Table 11.

	Class	Abbreviation	General description	IALA Specification	Particular use in the IALA Maritime Buoyage System
1	FIXED LIGHT	F	A light showing continuously and steadily.	A single fixed light should be used with care because it may not be recognized as an aid to navigation light.	A single fixed light shall not be used.
2	OCCULTING LIGHT		A light in which the total duration of light in a period is longer than the total duration of darkness and the intervals of darkness (eclipses) are usually of equal duration.	A light in which the total duration of light in a period is clearly longer than the total duration of darkness and all the eclipses are of equal duration.	
2.1	Single occulting light	Oc	An occulting light in which an eclipse is regularly repeated	The duration of an appearance of light should not be less than three times the duration of an eclipse. The period should not be less than 2 s d l l ≥ 3 d p ≥ 2 s Example: l = 3 s; d = 1 s; p = 4 s	A single occulting White light indicates a safe water mark.
2.2	Group occulting light	Oc(#) eg. Oc(2)	An occulting light in which a group of eclipses, specified in number, is regularly repeated.	The appearances of light between the eclipses in a group are of equal duration, and this duration is clearly shorter than the duration of the appearance of light between successive groups. The number of eclipses in a group should not be greater than four in general, and should be five only as an exception. The duration of an appearance of light within a group should not be less than the duration of an eclipse. The duration of an appearance of light between groups should not be less than three times the duration of an appearance of light within a group. In a group of two eclipses, the duration of an eclipse together with the duration of the appearance of light within a, group should not be less than 1 s. In a group of three or more eclipses, the duration of an eclipse together with the duration of an appearance of light within the group should not be less than 2 s. d l d l'	A group occulting Yellow light indicates a special mark.

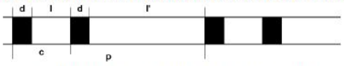
				$l' \geq 3d$ $l \geq d$ $(c = d + l) \geq 1$ Example: l'=6s; l=2s; d=1s; c=3s; p=10s	
2.3	Composite group occulting light	Oc(# + #) eg.Oc(2 + 1)	A light similar to a group occulting light except that successive groups in a period have different numbers of eclipses.	This class of light character is not recommended because it is difficult to recognize. d l d l' d l'' $l \geq d$ $l' \geq 3l$ $l'' \geq l'$ $(c = d + l) \geq 1s$ Example: l''=9; l'=3s; l=1s; d=1s; c=2s; p=16s	
3	ISOPHASE LIGHT	Iso	A light in which all the durations of light and darkness are clearly equal.	The period should never be less than 2 s, but preferably it should not be less than 4 s in order to reduce the risk of confusion with occulting or flashing lights of similar periods. d l d l $l = d$ $p \geq 2s$ Example: l = d = 2s; p=4s	An isophase White light indicates a safe water mark.
4	FLASHING LIGHT		A light in which the total duration of light in a period is shorter than the total duration of darkness and the appearances of light (flashes) are usually of equal duration.	A light in which the total duration of light in a period is clearly shorter than the total duration of darkness and all the flashes are of equal duration.	
4.1	Single flashing light	Fl	A flashing light in which a flash is regularly repeated (at a rate of less than 50 flashes per minute).	The duration of the interval of darkness (eclipse) between two successive flashes should not be less than three times the duration of a flash. The period should not be less than 2 s (or not less than 2.5 s in those countries where a quick rate of 50 flashes per minute is used). l d $d \geq 3l$ $p \geq 2s$ Example: d = 3s; l = 1s; p=4s	A single flashing Yellow light indicates a special mark.

4.2	Long flashing light	LFI	A single flashing light in which an appearance of light of not less than 2 s duration (long flash) is regularly repeated.	l d d ≥ 3l p ≥ 2s Example: d = 8s; l = 2s; p = 10s	A long flashing White light with a period of 10 s indicates a safe water mark.
4.3	Group flashing light	Fl(#) eg. Fl(2)	A flashing light in which a group of flashes, specified in number, is regularly repeated.	The eclipses between the flashes in a group are of equal duration, and this duration is clearly shorter than the duration of the eclipse between successive groups. The number of flashes in a group should not be greater than five in general, and should be six only as an exception. The duration of an eclipse within a group should not be less than the duration of a flash. The duration of an eclipse between groups should not be less than three times the duration of an eclipse within a group. In a group of two flashes, the duration of a flash together with the duration of the eclipse within the group should not be less than 1 s. In a group of three or more flashes, the duration of a flash together with the duration of an eclipse within a group should not be less than 2 s (or not less than 2.5 s in those countries where a quick rate of 50 flashes per minute is used). l d l d' Fl(2) d' ≥ 3d d ≥ l (c = l + d) ≥ 1 Example: d' = 6s; d = 2s; l = 1s; p = 10s	A group flashing White light with a group of two flashes, in a period of 5 s or 10 s, indicates an isolated danger mark. A group flashing Yellow light with a group of four, five or (exceptionally) six flashes indicates a special mark
4.4	Composite group flashing light	Fl(# + #) eg Fl(2 + 1)	A light similar to a group flashing light except that successive groups in a period have different numbers of flashes.	Light characters should be restricted to (2 + 1) flashes in general, and should be (3 + 1) flashes only as an exception. Fl(2+1) l d l d' l d'' Fl(2*1) d'' ≥ d' d' ≥ 3d d ≥ l (c = l + d)≥ 1s Example: d'' = 9s; d' = 3s; d = 1s; l = 1s; c = 2s; p = 16s	A composite group flashing Red or Green light with a group of (2 + 1) flashes indicates a modified lateral (preferred channel) mark. A composite group flashing Yellow light indicates a special mark.
5	QUICK LIGHT		A light in which flashes are repeated at a rate of not less than 50 flashes per minute but less than 80 flashes per minute.	A light in which identical flashes are repeated at the rate of 60 (or 50) flashes per minute. The higher rate of flashing is preferred.	
5.1	Continuous quick light	Q	A quick light in which a flash is regularly repeated.	d ≥ l 1 s ≤ p ≤ 1.2 s Example: l = d = 0.5 s; p = 1 s	A continuous quick White light indicates a north cardinal mark.

5.2	Group quick light	Q(#) eg Q(3) eg Q(9) eg Q(6) +LFl	A quick light in which a specified group of flashes is regularly repeated.	The number of flashes in a group should be three or nine. An exceptional light character is reserved for use in the IALA Maritime Buoyage System to indicate a south cardinal mark. Q(3) d ≥ l d'>d 1 s ≤ c ≤ Q(9) d ≥ l d'>d 1 s ≤ c ≤ Q(6)+LF1 d' ≥ 3 l' l' ≥ 2 s d ≥ l 1 s ≤ c ≤ 1.2 s Example: d' = 7 s; l' = 2 s; l = d = 0.5 s; c = 1 s.; p = 15 s	A group quick White light with a group of three flashes, in a period of 10 s, indicates an east cardinal mark. A group quick White light with a group of nine flashes, in a period of 15 s, indicates a west cardinal mark. A group quick White light with a group of six flashes followed by a long flash of not less than 2 s duration, in a period of 15 s, indicates a south cardinal mark.
6	VERY QUICK LIGHT		A light in which flashes are repeated at a rate of not less than 80 flashes per minute but less than 160 flashes per minute.	A light in which identical flashes are repeated at the rate of 120 (or 100) flashes per minute. The higher rate of flashing is preferred.	
6.1	Continuous very quick light	VQ	A very quick light in which a flash is regularly repeated.	d ≥ l 0.5 s ≤ p ≤ 1.6 s Example: l = d = 0.25 s; p = 0.5 s	A continuous very quick White light indicates a north cardinal mark.

6.2	Group very quick light	VQ(#) eg VQ(3) eg VQ(9) eg VQ(6)+LFl	A very quick light in which a specified group of flashes is regularly repeated.	The number of flashes in a group should be three or nine. An exceptional light character is reserved for use in the IALA Maritime Buoyage System to indicate a south cardinal mark. VQ(3) d' ≥ 1,5 s d ≥ l 0.5 s ≤ c ≤ 0.6 s Example: d' = 3.75 s; l = d = 0.25 s; c = 0.5 VQ(9) d' ≥ 1.5 s d ≥ l 0.5 s ≤ c ≤ 0.6 s Example: d' = 5.75 s; l = d = 0.25 s; c = 0.5 VQ(6)+LF1 d' ≥ 1.5 l' l' ≥ 2 s d ≥ l 0.5 s ≤ c ≤ 0.6 s Example: d' = 5 s; l' = 2 s; l = d = 0.25 s; c = 0.5 s; p = 10 s	A group very quick White light with a group of three flashes, in a period of 5 s, indicates an east cardinal mark. A group very quick White light with a group of nine flashes, in a period of 10 s, indicates a west cardinal mark. A group very quick White light with a group of six flashes followed by a long flash of not less than 2 s duration, in a period of 10 s, indicates a south cardinal mark.
7	ULTRA QUICK LIGHT		A light in which flashes are repeated at a rate of not less than 160 flashes per minute.	A light in which flashes are repeated at a rate of not less than 240 flashes per minute and not more than 300 flashes per minute.	
7.1	Continuous ultra quick light	UQ	An ultra quick light in which a flash is regularly repeated.		
8	MORSE CODE LIGHT	Mo(#) eg. Mo(A)	A light in which appearances of light of two clearly different durations are grouped to represent a character or characters in the Morse Code.	Light characters should be restricted to a single letter in the Morse Code in general, and should be two letters only as an exception. The duration of a "dot" should be about 0.5 s, and the duration of a "dash" should not be less than three times the duration of a "dot". l d l' d' Mo (A) | l' ≥ 3l | d ≥ l | l = 0,5s | Example: l' = 1,5s; l = 0,5s; d = 0,5s; d' = 4,5s; p = 7s	A Morse Code White light with the single character "A" indicates a safe water mark. A Morse Code Yellow light, but not with either of the single characters "A" or "U"*, indicates a special mark.

9	FIXED AND FLASHING LIGHT	FFl	A light in which a fixed light is combined with a flashing light of' higher luminous intensity.	This class of light character should be used with care because the fixed component of the light may not be visible at all times over the same distance as the rhythmic component. d ≥ 3 l l ≤ 1 s Example: d = 3 s; l = 1 s; p = 4 s	
10	ALTERNATING LIGHT	Al## eg A1WR	A light showing different colours alternately.	This class of light character should be used with care, and efforts should be made to ensure that the different colours appear equally visible to an observer. l d ALWR l = d Example: l = d = 2s; p = 4s	
10.1 New	OCCULTING ALTERNATING LIGHT	OAL	A light showing different colours alternately and a light in which the total duration of light in an period is longer than the total duration of darkness and the intervals of darkness (eclipses) are of equal duration	This class of light is particular to the use of Emergency Wreck Marking, and efforts should be made to ensure that the different colours appear equally visible to an observer. l d l d OAL l = 1s d = 0,5s p = 3s Example: lb = 1s; d = 0,5s; ly = 1s; d = 0,5s; p = 3s	An Occulting-Alternating Blue and Yellow light indicates an Emergency Wreck Marking Buoy mark.

	Class	Abbre-viation	General Description	IALA Specifications	Use in the Martime Buoyage System
1	FIXED LIGHT	F	A light showing continuously and steadily.	A single fixed light should be used with care because it may not be recognized as an aid to navigation light.	A single fixed light shall not be used.
2	OCCULTING LIGHT		A light in which the total duration of light in a period is longer than the total duration of darkness and the intervals of darkness (eclipses) are usually of equal duration.	A light in which the total duration of light in a period is clearly longer than the total duration of darkness and all the eclipses are of equal duration.	
2.1	Single-Occulting Light	Oc	An occulting light in which an eclipse is regularly repeated	The duration of an appearance of light should not be less than three times the duration of an eclipse. The period should not be less than 2 s  1 ≥ 3 d p ≥ 2 s Example: 1 = 3 s; d = 1 s; p = 4 s	A single occulting *White* light indicates a safe water mark.
2.2	Group-Occulting Light	Oc(#) eg. Oc(2)		The appearances of light between the eclipses in a group are of equal duration, and this duration is clearly shorter than the duration of the appearance of light between successive groups. The number of eclipses in a group should not be greater than four in general, and should be five only as an exception. The duration of an appearance of light within a group should not be less than the duration of an eclipse. The duration of an appearance of light between groups should not be less than three times the duration of an appearance of light within a group. In a group of two eclipses, the duration of an eclipse and the duration of the appearance of light within a group should not be less than 1 s. In a group of three or more eclipses, the duration of an eclipse and the duration of an appearance of light within the group should not be less than 2 s. Oc(2)  l' ≥ 3 l 1 ≥ d c ≥ 1 s Example: l' = 6 s; l = 2 s; d = 1 s; c = 3 s; p = 10 s	

	Class	Abbre-viation	General Des
2.3	Composite Group-Occulting Light	Oc(# + #) eg. Oc(2 + 1)	A light similar to occulting light e that successive a period have d numbers of ecli
3	ISOPHASE LIGHT	Iso	A light in which durations of ligh darkness are cle
4	FLASHING LIGHT		A light in which duration of ligh is shorter than t duration of dark the appearance (flashes) are usu duration.
4.1	Single-Flashing Light	Fl	A flashing light flash is regularly (at a rate of less flashes per minu
4.2	Long-Flashing Light	LFl	A single-flashing which an appea light of not less duration (long f regularly repeat

Table 10 - Classification of the Rythmic Characters of Lights

Mark	Rhythmic character of the light	Remarks and further recommendations
LATERAL	All recommended classes of rhythmic character , but a composite group flashing light with a group of (2 + 1) flashes is solely assigned to modified lateral marks that indicate preferred channels.	Only the colours Red and Green are used.
Modified lateral (preferred channel)	Composite group flashing light with a group of (2 + 1) flashes, in a period of not more than 16 s	The duration of the eclipse after the single flash should not be less than three times the duration of the eclipse after the group of two flashes.
CARDINAL		Only the colour White is used.
North cardinal	(a) Continuous very quick light. (b) Continuous quick light.	
East cardinal	(a) Group very quick light with a group of three flashes, in a period of 5 s. (b) Group quick light with a group of three flashes, in a period of 10 s.	
South cardinal	(a) Group very quick light with a group of six flashes followed by a long flash of not less than 2 s duration, in a period of 10 s. (b) Group quick light with a group of six flashes followed by a long flash of not less than 2 s duration, in a period of 15 s.	The duration of the eclipse immediately preceding a long flash should be equal to the duration of the eclipses between the flashes at the very quick rate. The duration of a long flash should not be greater than the duration of the eclipse immediately following the long flash. The duration of the eclipse immediately preceding a long flash should be equal to the duration of the eclipses between the flashes at the quick rate. The duration of a long flash should not be greater than the duration of the eclipse immediately following the long flash.

West cardinal	(a) Group very quick light with a group of nine flashes, in a period of 10 s. (b) Group quick light with a group of nine flashes, in a period of 15 s.	
ISOLATED DANGER	(a) Group flashing light with a group of two flashes, in a period of 5 s. (b) Group flashing light with a group of two flashes, in a period of 10 s.	Only the colour White is used. The duration of a flash together with the duration of the eclipse within the group should be not less than 1 s and not more than 1.5 s. The duration of a flash together with the duration of the eclipse within the group should be not less than 2 s and not more than 3 s.
SAFE WATER	(a) Long flashing light with a period of 10 s. (b) Isophase light. (c) Single occulting light. (d) Morse Code light with the single character "A".	Only the colour White is used.
SPECIAL	(a) Group occulting light. (b) Single flashing light, but not a long flashing light with a period of 10 s. (c) Group flashing light with a group of four, five or (exceptionally) six flashes. (d) Composite group flashing light. (e) Morse Code light, but not with either of the single characters "A" or "U"` .	Only the colour Yellow is used. A group flashing light with a group of five flashes at a rate of 30 flashes per minute, in a period of 20 s, is assigned to Ocean Data Acquisition Systems (ODAS) buoys.
EMERGENCY WRECK MARKING BUOY	Occulting Alternating light with a period of 3s	Only the colours Blue and Yellow are used

Table 11 - Rhythmic Characters[4] of the Lights in the IALA Maritime Buoyage System[5]

Maximum Periods for Light Characters

Character Class	Maximum period (seconds)
Isophase light	12
Single-occulting light	15
Single-flashing light	15
Group very quick light	15
Group-occulting light of two eclipses	20
Long-flashing light	20
Group-flashing lights of two flashes	20
Group-quick light	20
Group-occulting light of three or more eclipses	30
Group-flashing light of three or more flashes	30
Composite group-flashing light	30
Morse code light	30

Table 12 - Maximum Period for Rhythmic Characters of Aids to Navigation Lights

Refer to IALA publication:

- Recommendation E-110 for the rhythmic characters of lights on aids to navigation.

Timing of Astronomical Events

The nighttime operation of lighted aids to navigation is emphasised but daytime role is often as important. The astronomical events that define the transitions from day to night are shown below.

Event	Condition	Typical Illumination Lux	Comment
Sunset/Sunrise	Upper edge of the sun's disc is coincident with the horizon.	600	
Civil Twilight (start / end)	Centre of sun is at a depression angle of six (6) degrees below the horizon.	6	Large objects are seen but detail are not discernible. Brightest stars and planets are visible and the sea horizon is clearly defined.
Nautical Twilight (start / end)	Centre of sun is at a depression angle of twelve (12) degrees below the horizon.	0.06	It is dark for normal practical purposes and the sea horizon is not normally visible.
Astronomical Twilight (start / end)	Centre of sun is at a depression angle of eighteen (18) degrees below the horizon.	0.0006	Illumination is less than that from starlight and other natural light sources in the sky.

Table 13 - Timing of Astronomical Events

Switch-on / Switch-off Light Levels

For lighted aids to navigation that only operate at night, the ambient light levels at which an AtoN light switches on should be chosen so that the AtoN light switches on while the ambient light level is sufficiently high to allow safe navigation, while not switching on during overcast conditions when the AtoN is not necessary for safe navigation.

Refer to IALA publications:

- Guideline 1038 on Ambient Light Levels at which Aids to Navigation Should Switch On and Off.

Night Operations

Nominal Range and Luminous Intensity

Table 14 is an extract of the IALA recommendation for the notation of luminous intensity and range of lights and provides a conversion between nominal range and luminous intensity.

Nominal Range (nautical miles)	Luminous Intensity (candela)	Nominal Range (nautical miles)	Luminous Intensity (candela)
1	0.9	12	3600
1.5	2.4	13	5700
2	5	14	8900
2.5	9	15	14000
3	15	16	21000
3.5	24	17	32000
4	36	18	49000
4.5	53	19	73000
5	77	20	110000
6	150	21	160000
7	270	22	240000
8	480	23	360000
9	820	24	520000
10	1400	25	770000

11	2200	26	1100000

Table 14 - IALA Conversion Table for Luminous Intensity and Nominal Range for Night Observations

This table assumes an atmospheric transmissivity of T=0.74 and a threshold of illumination of 0.2 µlux.

3.2.3.3 Background Lighting

Nominal range at night is calculated with no allowance for glare from background lighting. Excessive background lighting, from street lights, neon signs etc., frequently makes an aid to navigation light less effective and, in some cases, it becomes completely lost in the general background clutter. Such a light can be made more conspicuous by increasing its intensity, changing its colour or by varying its rhythm.

3.2.3.4 Glare

Glare can be caused by bright lights emitted from the shore, such as car headlights, or from another vessel indiscreetly using a search-light. An aid to navigation light can also cause glare if it is too bright for the shortest viewing distance, especially when the focal plane of the light and the observer's eye are at the same height. This situation can arise with two station leading lines. For aids to navigation lights it is generally accepted that the illuminance at the eye of the navigator from the light:

- should not exceed 0.1 lux;
- should be reduced to 0.01 lux if the background is very dark.

Refer to IALA publications:

- Recommendation E-112 for Leading Lights (including excel program);
- Guideline 1023 for the Design of Leading Lines.

In situations where glare is a problem, one or more of the following alterations may lead to a satisfactory result:

- raise the focal plane of the light so that the mariner uses the loom of the light or a less intense part of the vertical distribution of the light;
- reducing the intensity of the light source;
- reducing the size of the optic;
- masking the optic with, for example, perforated metal sheet;
- screen unnecessary arcs of the light;
- use two or more lower intensity lights instead of one higher intensity light.

Whatever methods are used, it will be necessary to measure or calculate the intensity and distribution of the modified light or lighting system.

3.2.3.5 Intensity Losses

Some lighting equipment has to be installed inside a protective lantern housing. Unless it is practicable to measure the luminous intensity of the complete installation, it is normal practice to apply a de-rating factor to the intensity of the lighting equipment to allow for the reflection and transmission losses at the lantern glazing, generally referred to as the glazing loss factor.

Glazing bars or astragals may reduce the intensity of the light at certain bearings. The installation of non-vertical astragals will overcome this reduction to a certain extent. The focal plane of the light should be positioned away from any horizontal glazing bars or intersection.

IALA recommends that, in the absence of more definitive information, the glazing loss factor be taken as 0.85 for a system in clean condition.

Refer to IALA publication:

- Recommendation E200-0 on Marine Signal Lights Part 0 - Overview.

3.2.3.6 Service Conditions Factor

Under normal operating conditions the luminous intensity of a light is likely to degrade between service (maintenance) intervals. There are several components to this degradation:

- meteorological conditions (which may only be temporary);
- dirt and salt deposition (which can be minimised by an efficient regular programme of cleaning of the optical system and housing);
- progressive deterioration of the light source over the service interval.

It is clearly impossible to represent such a complex array 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 the performance of the light under normal operating conditions than when the luminous intensity is measured in a laboratory or on a photometric range, it may be appropriate to apply a service conditions factor to the measured intensity.

3.2.3.7 Day Operations

A number of authorities have established daytime lighted leading lines in major ports and waterways to achieve a more consistent performance than is possible with dayboards.

Nominal Daytime Range and Luminous Intensity

Refer to IALA publications:

- Recommendation E200-2 On Marine Signal Lights Part 2 – Calculation, Definition and Notation of Luminous Range;
- Recommendation E-111 on Port Traffic Signals.

Figure 13 and Table 15 are extracts of Recommendation E200-2 On Marine Signal Lights Part 2 – Calculation, Definition and Notation of Luminous Range (December 2008) and provides a conversion between nominal daytime range and luminous intensity.

The Luminous Range Diagram, shown in Figure 13 enables the mariner to determine the approximate range at which a light may be sighted, by day in the meteorological conditions prevailing at the time, and for various levels of sky luminance (refer to Table 16).

Threshold value for illuminance: $E_t = 1x10^{-3}lx$

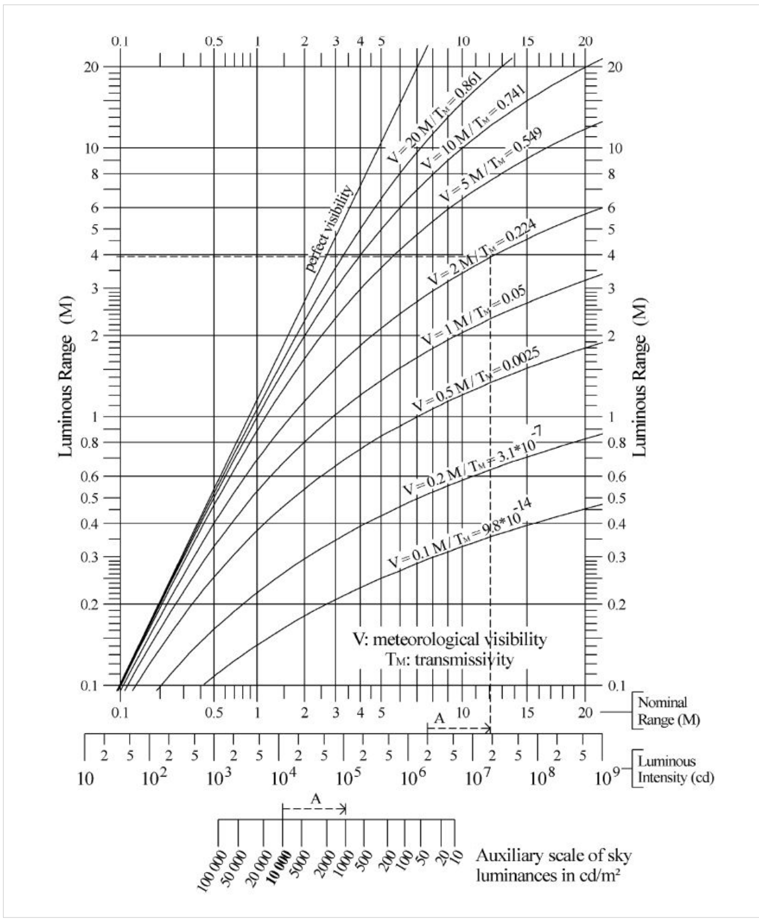


Figure 13 – Daytime Luminous Range Diagram

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 auxiliary 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 the graduation corresponding to 2 000 000 cd ($2x10^6$ 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. It should read approx. 4 nautical miles.

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

Table 15 – IALA Conversion Table for Luminous Intensity and Nominal Daytime Range

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

Table 16 – Required Illuminance in Varying Meteorological Conditions

3.2.3.3 Meteorological Optical Range

This is the distance through the atmosphere that is required for 95% attenuation in the luminous flux of a collimated beam of light using a source colour temperature of 2700ºK.

The meteorological optical range is related to the atmospheric transmissivity by the formula:

$$V = d\frac{\log 0.05}{\log T} \quad \text{or} \quad T = 0.05^{d/V}$$

Where: V = meteorological optical range (nautical miles)
d = distance (nautical miles)
T = atmospheric transmissivity

It is often convenient to simplify the above expression by giving the distance term a value of one, such that:

$$T = 0.05^{1/V} \quad \text{or} \quad T^V = 0.05$$

3.2.3.8 Visual Range

This is the maximum distance at which the contrast of the object against its background is reduced by the atmosphere to the contrast threshold of the observer. The visual range can be enhanced if the observer uses binoculars, although the effectiveness depends on the stability of the observer's platform. Visual Range can be interpreted as the distance that a given light is seen by an observer.

3.2.3.9 Luminous Range

This is the maximum distance at which a given light signal can be seen by the eye of the observer at a given time, as determined by the meteorological visibility prevailing at that time. It does not take into account the: height of the light, observer's height of eye, or curvature of the Earth.

3.2.3.10 Nominal Range

Nominal range is the luminous range when the meteorological visibility is 10 nautical miles, which is equivalent to a transmission factor of T = 0.74. Nominal Range is generally the figure used in official documentation such as nautical charts, Lists of Lights, etc. Nominal range assumes that the light is observed against a dark background, free of background lighting.

3.2.4 Miscellaneous

This section to be developed

3.2.4.1 Audible Signals

The following provides a brief overview of audible AtoN signals, more detailed information is provided by referring to the following IALA publications.

Refer to IALA publications:

- Recommendation E-109 for the Calculation of the Range of a Sound Signal;
- Guideline 1090 on the Use of Audible Signals.

Nominal Range Audible AtoN signal range is calculated as nominal and is expressed in nautical miles. The nominal range is defined by a probability of 90% of hearing the signal when subjeced to a noise as defined in IALA Guideline 1090. Specific ranges cited in the above paragraphs refer to the nominal range calculation.

Hazard Warning It has been IALA policy since 1985 that audible signals, also referred to as sound signals, should only be used as a hazard warning. These hazards refer to certain man-made structures such as offshore structures, renewable energy infrastructure, bridges, breakwaters, and isolated AtoN. The Competent Authority shall determine whether a hazard requires an audible signal and the level of reduced visibility per year that justifies its installation (e.g. 10 days of visibility under 1 nautical mile per year).

Where provided, audible signals for navigational hazards should have a nominal range of at least 1 nautical mile. In addition, Competent Authorities may require a backup audible signal of a reduced range (these do not necessarily need to be separate units); 0.5 nautical mile nominal range is considered adequate for these backup audible signals.

Augmentation of Floating Aids to Navigation Audible signals may also be used to augment buoys, both lighted and unlighted, to enhance their effectiveness to the mariner in reduced visibility. Audible signals on buoys are most often powered by the motion of the sea and include bells, gongs, and whistles. Buoys may also be fitted with electronic horns. Audible signals on buoys should be used to warn mariners of a particular hazard, such as proximity to shoals, rocks or other hazards; or to alert the mariner to a change in navigational requirements, such as the entrance to a restricted channel. Where electronic audible signals are used to augment buoys, they should have a nominal range of 0.25 to 0.5 nautical miles.

3.2.4.2 llumination of Structures

This section to be developed

3.2.4.3 Retroreflective Materials

This section to be developed - the notes below are from revised guideline E106. Tables with examples for standard and comprehensive codes are requried to be added

1. No special code for preferred channel marks is provided, the predominant colour of the buoy only being used.
2. It may be difficult for the observer to discriminate between green and blue retroreflecting material, particularly where only one of these colours is being observed on its own. In principle, green buoys should carry only one green band, whereas blue is always used in combination with another colour, except in the case of East Cardinal marks which have two blue bands. However, this principle may be violated where one of the bands has become damaged.
3. It may be difficult for the observer to discriminate between yellow and white retroreflecting material particularly where only one of these colours is being observed on its own. Thus only one yellow band may be used on a special mark to avoid confusion with a West Cardinal mark in the comprehensive code.
4. Care should be taken that the amount of white retroreflecting material used on an aid does not detract from its daytime appearance.
5. The coefficient of retroreflection of blue and red is very much less than white or yellow, and to ensure proper recognition the following must be observed:

- Safe water marks: The red bands or stripes must be at least twice the width of the white bands or stripes. The separation distance between the colours must be at least twice the width of the white bands or stripes.
- North and South Cardinal Marks: The blue bands must be at least twice the width of the yellow bands. The separation distance must be at least twice the width of the yellow bands.

1. To ensure proper recognition of isolated danger marks the blue and red bands should be of equal width and separated by a distance at least equal to the width of a band.

3.3 Visual Aids to Navigation Technology

Until the first application of electricity for lights late in the nineteenth century, all artificial light was produced by fire. Illuminants progressed from pyres of wood (used up until the 1800's), to oil wick lamps, vaporised oil and gas burners, then electric arc and tungsten filament lamps. Optical devices matched these developments, first with reflector systems and later with lenses.

It is interesting to note that the efforts to understand the human perception of light, to improve the efficiency and effectiveness of aids to navigation illuminants and optical apparatus, were at the forefront of scientific endeavours for many years.

The glass lens design pioneered by Augustine Fresnel around 1820 remains a principal element of the modern aid to navigation light, although present day lenses are often made of plastic rather than glass.

A few countries still use aids to navigation lighting systems that burn acetylene or propane gas. They are typically preferred for their robustness and simplicity of operation. However, the majority of aids to navigation lighting systems use electricity of various types as their power source. Electricity is generally more efficient than gas. Increasingly, electric AtoN lights are powered by renewable energy sources such as solar, wind or wave power.

Lamps used in electric light systems have been specifically designed for aids to navigation applications. However, lamps selected from the enormous range of commercial products have also been used or adapted for aids to navigation. The use of Light Emitting Diode (LED) technology as an alternative to filament lamps in Aids to Navigation is rapidly expanding and in some countries now makes up the majority of all lighted AtoN.

3.3.1 Daymarks

The size of a dayboard should be determined for the maximum useful viewing distance and minimum visibility conditions. Daymarks used on leading lines are typically rectangular with the long side vertical. The aspect ratio for the rectangle is commonly 2:1 (height = 2 x width).

The typical operational range of daymarks under different visibility conditions is shown in Table 17.

Operational Range of Daymarks (Nautical Miles)					
Minimum visibility (Nautical Miles)	**Daymark height (metres). Aspect ratio h=2w**				
	1.8	**2.4**	**3.7**	**4.9**	**7.3**
1	0.5	0.7	0.9	1.0	1.1
2	0.6	0.9	1.2	1.4	1.5
3	0.6	1.1	1.5	1.9	2.1
4	0.7	1.3	1.8	2.3	2.7
5	0.8	1.5	2.1	2.7	3.3
6	0.8	1.6	2.3	2.9	3.6
7	0.9	1.7	2.4	3.3	4.0
8	0.9	1.7	2.6	3.5	4.2
9	0.9	1.9	2.8	3.8	4.5
10	1.0	2.0	3.0	4.0	5.0

Table 17 – Typical Operational Range of Daymarks

Guidance on the impact of background lighting and meteorological conditions on light intensity required to achieve a particular range is provided in Table 18.

Nominal Range	**Intensity (cd)**	**Intensity (cd)**	**Intensity (cd)**	**Intensity (cd)**	**Intensity (cd)**	**Intensity (cd)**	**Intensity (cd)**	**Intensity (cd)**	**Intensity (cd)**
Background lighting or Metrological condition (see 1.3.3)	None	Minor	Substantial	Day VDO	Day DO	Day OO	Day BO	Day BC	Day VBC
Luminance (cd/m^2)				100	200	1000	5000	10000	20000
Illuminance (bc)	2.00E-07	2.00E-06	2.00E-05	1.30E-05	2.39E-05	1.07E-04	5.06E-04	9.99E-04	1.98E-03
Transmissivity (per M)	0.74	0.74	0.74	0.74	0.74	0.74	0.78	0.79	0.81
Visability (M)	10	10	10	10	10	10	12	13	14
Range (M)									
0.2	0.03	0.3	3	2	3	16	73	144	284
0.5	0.20	2	20	13	24	107	429	961	1,890
0.7	0.41	4	41	27	50	222	1,010	1,970	3,870
1	1	9	93	60	111	495	2,230	4,310	8,410
2	5	50	500	325	597	2,670	11,400	21,700	41,700
3	15	152	1,520	986	1,810	8,110	33,000	61,600	116,000
4	36	364	3,640	2,360	4,350	19,460	75,400	138,000	256,000
5	77	767	7,670	4,990	9,170	41,000	151,000	271,000	495,000
6	149	1,490	14,900	9,690	17,800	79,700	279,000	492,000	883,000
7	274	2,740	27,400	17,800	32,700	146,000	488,000	843,000	1,490,000
8	482	4,820	48,200	31,300	57,600	258,000	818,000	1,390,000	2,410,000
9	824	8,240	82,400	53,500	98,400	441,000	1,330,000	2,210,000	3,770,000
10	1,370	13,700	137,000	89,200	164,000	734,000	2,110,000	3,430,000	5,770,000
11	2,240	22,400	224,000	146,000	268,000	1,200,000	3,270,000	5,230,000	8,650,000
12	3,600	36,000	360,000	234,000	430,000	1,920,000	5,000,000	7,840,000	
13	5,700	57,000	570,000	370,000	681,000	3,050,000	7,530,000		
14	8,910	89,100	891,000	579,000	1,070,000	4,770,000			
15	13,800	138,000	1,380,000	897,000	1,650,000	7,390,000			
16	21,200	212,000	2,120,000	1,380,000	2,530,000				
17	32,300	323,000	3,230,000	2,100,000	3,860,000				
18	48,800	488,000	4,880,000	3,170,000	5,840,000				
19	73,400	734,000	7,340,000	4,770,000	8,770,000				
20	110,000	1,100,000		7,130,000					
21	163,000	1,630,000							
22	242,000	2,420,000							
23	357,000	3,570,000							
24	524,000	5,240,000							
25	767,000	7,670,000							
26	1,120,000								
27	1,630,000								

28	2,360,000								
29	3,420,000								
30	4,940,000								

Abbreviation	**Metrological Condition**	**Luminance (cd/m^2)**
Day VDO	Very Dark Overcast Sky	100
Day DO	Dark Overcast Sky	200
Day OO	Ordinary Overcast Sky	1,000
Day BO	Bright Overcast Sky Away From Sun	5,000
Day BC	Bright Sky or Cloud Near Sun	10,000
Day VBC	Very Bright Cloud	20,000
Day GC	Glaring Cloud	50,000

Table 18 – Night and Day with Background.
This table is intended as guidance only. It is not to be used for Nominal Range Publication.

3.3.2 Light Sources

Much of this information will move to 3.3.3 Optics

Electric Lights

Light Emitting Diode (LED)

Coloured LED

Electronic semiconductor devices that produce near monochromatic light. The semiconductor junction is encapsulated in a clear plastic housing that usually incorporates a lens. Several LEDs may be grouped together in a cluster, or an array, to provide a light source of the required size and intensity with lamp redundancy. LEDs operate from a low voltage DC supply. Correct operation depends on accurate control of the supply current. LED marine lanterns are sometimes reported as having intense colours and ranges longer than the current IALA calculation method would suggest. IALA is currently investigating this.

White LED

A semiconductor junction emitting blue/violet light is encapsulated with an integral phosphor such that both blue and broad band yellow light are emitted together to form a near white light. Research is in progress on combining red and green LED lights to produce a white light within the IALA chromaticity specification.

Typical Use:

- Lighted beacons on buoys and other short and medium range AtoN, but longer range LED lanterns are increasingly available in the market;
- Range lights consisting of flat arrays of LEDs or single high power LEDs;
- Signs and signals formed by arrays of LEDs in the shape of letters, numerals, signs etc.

Technical data:

- Power: Single LED: 1milliWatt to over 32 Watts, Cluster LED: 1 to 60 Watts of higher
- Efficiency: Luminous Efficacy of LEDs is improving steadily.
- Lifetime: 100,000 hours Advantages:
- Very long life (if input power and temperature are carefully controlled) and hence low whole life costs;
- Life is so long that lampchangers are not considered necessary;
- High luminous efficiency in red and green;

- Light produced in saturated signal colours therefore coloured filters not needed;
- Mechanically robust when compared with conventional lamps;
- Light switching times are very fast;
- Relatively cool operation;
- Easy to cluster LEDs.

Disadvantages:

- Complex electronic control needed to achieve long life and high performance;
- Generally difficult to match to existing optics;
- Luminous efficiency decreases slowly with life;
- White LEDs will be outside the new CIE (2001) white colour region;
- White LEDs will be very inefficient with red and green filters;
- Lamp life can be severely reduced if input power and temperature are not carefully controlled.

Safety:

- No special hazard.

Disposal:

- Consult local and national disposal regulations.

Operating lifetime will depend on the LED junction operating temperature and operating environment.

Integrated Power Supply Lanterns

Integrated Power Supply Lanterns (IPSL) have application advantages for certain situations. By incorporating modern technologies, they can be small, durable, reliable, cost effective and fully self contained. Technological advances in light emitting diodes (LEDs), photovoltaics (Solar Panels) and batteries complement each other and facilitate a compact lantern. In order to operate efficiently, these lanterns must be designed for a wide range of solar conditions (i.e. sunlight available to charge the lantern) while maintaining a specified optical output over the expected operating lifetime.

The application criteria for IPSL include nominal light ranges up to 5nm, areas with good solar insolation, areas that suffer from vandalism or theft and small buoys with limited weight carrying ability. They are not suitable where high duty cycle rhythmic characters are required or in areas suffering from icing. An IPSL device houses power source, power storage, LED light source, rhythmic character coding and switching together in a single unit. IPSL can accept external programming commands and include options for GPS, synchronization, and communication modules.

Refer to IALA publication:

- Guideline 1064 on Integrated Power Systems Lantern.

Incandescent Filament Lamps

Tungsten filament

These light sources have been in use since the early 1900's. Many special lamp designs have been used over the years, as filament size, shape, and location must be well matched to the lens system. It can be operated directly from an appropriate electrical supply and has a nominal voltage of 6 to 240 V, both Alternating Current (AC) and Direct Current (DC).

Typical use:

All types of lighted beacons (for example, leading lights, sector lights, 360° lights, lanterns on light buoys). Some countries and manufacturers have adopted standard designs, with reference codes, for lamps designed especially for lighthouse applications. These designs typically include filament supports to maintain filament shape and ensure an even output over 360 degrees in azimuth.

Technical data:

- Power: 2 to 1000 Watts are typical with some exceptions as large as 3,500 Watts
- Efficiency: 9 to 19 lumens per Watt
- Lifetime: 300 to 1500 hours

Advantages:

- Coding can be easily achieved by interrupting the electrical supply;
- Filament geometry can be designed to match the optic;
- Diffusing envelope (e.g. pearl or etched) can improve lens illumination when used in older optics, but at the expense of reduced intensity;
- Broad colour spectrum output provides good performance with most coloured filters;
- Optical output is reasonably stable over its lifetime, but the lamp envelope may start to blacken before lamp failure;
- Remote monitoring by current sensing is simple.

Disadvantages:

- Relatively short lifetime;
- Safe disposal appropriate for metal and glass waste;
- Specialised AtoN lamps are expensive;
- As LED technology expands to include longer range AtoN, there are fewer manufacturers producing these lamps;
- Colour rendering ~~is not~~ in the preferred white region (tends towards yellow);
- Efficiency poor.

Safety:

- High envelope temperature when in use;
- Operating voltages may be hazardous;
- Possible risk of electrical arcing which is harmful to the human eye;
- General glass hazard.

Disposal:

- Safe disposal appropriate for metal and glass waste.

Tungsten Halogen

The tungsten halogen lamp encloses a small amount of halide with inert gas, and the tungsten evaporating from the hot filament combines with the halogen to diffuse around the envelope wall. Due to careful design the envelope operates at high temperature, and this prevents deposition of tungsten on the glass. The tungsten-halide is then carried by convection towards the filament where it is decomposed and the tungsten metal deposited back onto the filament. It can be operated directly from an appropriate electrical supply and has a nominal voltage of 12 to 240 V, both AC and DC.

Typical use:

All types of lighted beacons, but several lamps could be used in a cluster in large rotating optics, to produce a large light source similar to the original non-electric light source.

Technical data:

- Power: 5 to 1000 Watts, with some exceptions up to 1500 to 2000 Watts
- Efficiency: 20 to 25 lumen per Watt
- Lifetime: 300 to 4000 hours Some very bright lamps have a short working life.

Some very bright lamps have a short working life

Advantages:

- Coding can be easily achieved by interrupting the electrical supply, but see below;
- Higher luminance than tungsten lamps;
- Output very stable over lifetime;
- Colour rendering good in white preferred region;
- High performance general-purpose lamps available at low cost;
- Small lamp sizes (10 to 100W) are very mechanically robust;
- Envelope sizes are typically smaller than tungsten lamps, and may allow smaller optic system sizes.

Disadvantages:

- The filament size is usually small hence the geometry is poor when modernising old lens systems;
- Generally low operating voltage results in high current requiring careful design of lamp holder and associated wiring;
- A cluster of several lamps will be required to match these small lamps to existing large optics;
- Lamps are not made specifically for AtoN use and specifications may change without notice;
- The flashing of tungsten halogen lamps may lead to the interruption of the halogen cycle with consequent blackening of the envelope and premature failure.
- Practical trials are recommended with the proposed operating voltage and duty cycle or consultation with other IALA members;
- Lamps should not be touched with bare hands as the oils from the skin may increase heat and lead to a consequential reduction in lamp life.

Safety:

- Operating voltage may be hazardous;
- General glass hazards;
- Very high surface temperatures because of the small envelope size;
- Possible high UV radiation risk (dependant on lamp type);
- Risk of explosion with high-pressure lamp types.

Disposal:

- Consult local and national disposal regulations.

Discharge Lamps

Fluorescent

Operates 110 to 240 V system voltage with control circuitry to provide a high starting voltage.

Typical use:

- Direction arrows, signs and light tubes or bars used for leading lights;
- Applications where large areas of illumination are an advantage.

Technical data:

- Power: 8 to 100 Watts
- Efficiency: 80 to 100 lumen per Watt
- Lifetime: Up to 20,000 hours Advantages:
- High luminous efficiency;
- Large illuminated areA. In suitable applications no optical elements are needed thus providing a very low cost AtoN;
- Very wide range of commercially available products at low prices;
- Many colours available (no additional colour filters needed).

Disadvantages:

- Low luminance;

- Difficult to use with lens systems due to source size;
- Light output falls considerably over lifetime;
- Requires control circuitry matching lamp and supply voltage;
- Complex circuitry needed to flash;
- Possible interference problems.

Safety:

- Mains voltage;
- General glass hazard;
- Internal tube coatings may be hazardous if exposed and they contain traces of gaseous mercury;
- High voltage due to starting equipment.

Disposal:

- Tube coatings may be hazardous and contain traces of mercury;
- Consult local and national disposal regulations.

Low Pressure Sodium Vapour Lamps

110 and 240 V AC with associated control circuitry. Only available in yellow colour.

Typical use:

- Flood lighting and external illumination of structures, towers, locks etc.

Technical data:

- Power: 20 to 180 Watts
- Efficiency: 180 lumen per Watt
- Lifetime: 10,000 hours

Advantages:

- Long life;
- High luminous efficiency;
- Mercury free;
- Low envelope surface temperature;
- Can be used to provide yellow signal colour;
- Minimum attraction for insects.

Disadvantages:

- Only produces yellow light;
- Low luminance;
- Not practical to flash;
- Limited operating positions.

Safety:

- General glass hazards;
- High AC voltage;
- Chemical hazard due to sodium content.

Disposal:

- Consult local and national disposal regulations.

High Pressure Sodium Vapour Lamps

110 or 240 V AC with associated control circuitry.

Typical Use:

- White lamps may be used as AtoN light source.

Technical data:

- Power: 50 to 400 Watts
- Efficiency: 90 lumen per Watt
- Lifetime: 10,000 hours Advantages:
- Long life;
- Mercury free;
- High efficiency;
- Available in white.

Disadvantages:

- Cannot be flashed;
- Only practical as white;
- Low red content makes colour filtering impractical;
- High strike voltage to start;
- Complex lamp changer required due to long warm-up period and cool-down necessary before restart;
- Arc tube geometry is poor for most optics;
- Light output falls over life and white colour degrades to yellow.

Safety:

- General glass hazards;
- High AC voltage;
- Chemical hazards giving rise to disposal or health problems.

Disposal:

- Consult local and national disposal regulations.

Metal Halide

The metal halide lamp is one of a family of High Intensity Discharge (HID) lamps. Its arc tube is made of silica glass. The principles of emission are as follows: 1) High voltage from the ballast initiates current flow between the electrodes; 2) As the lamp temperature rises, metals in the lamp evaporate, and light emission occurs. Working with control circuitry allows input voltages of 12 V to 240 V for 110 V and 240 V power sources.

Typical Use:

- Used as a fixed light source in rotating optics, fixed lenses with rotating screens and general floodlighting.

Technical data:

- Power: 10 to 2,000 Watts
- Efficiency: 80 to 110 lumen per Watt
- Lifetime: 6,000 to 20,000 hours

Operating lifetime is very dependent on the number of times that lamp is switched on.

Advantages:

- High luminous efficiency;
- Clear envelope types have high illuminance;
- Coated envelope types have good geometry for traditional lenses;
- Long life;
- Many commercial lamp types available;
- Colour rendering is good, within IALA preferred white region;
- Absence of a filament means good resistance to vibration and shock.

Disadvantages:

- Not practical to flash;
- Initial warm-up is slow;
- Cooling time needed before re-strike hence complex lamp changer design;
- Difficult to remote monitor by simple current sensing;
- Light output falls with life;
- Red spectrum is limited so red filtering is possible but poor, green is good.

Safety:

- High voltage hazards;
- High UV radiation;
- Possible interference problems;
- Possible explosion hazard;
- General glass hazard;
- May contain hazardous metal.

Disposal:

- Consult local and national disposal regulations as there may be some mercury content.

Xenon Lamps

Typically 110 V and 240 V. Xenon lamps are discharge lamps, with the xenon gas enclosed in a silica tube at high pressure. An electrical discharge through the xenon gas generates a high intensity white light. Xenon discharge is commonly used in camera flash guns. Charging DC supply requires complex control circuitry. These lamps are available as pulsed or continuous discharge types.

Typical Use:

- A specialised light source used where high intensity is of paramount importance. Can be used in fixed or rotating optics.

Technical data:

- Power: 150 to 2,000 Watts
- Efficiency: 35 lumen per Watt
- Lifetime: 2,000 hours

Advantages:

- High luminance enabling high intensities to be achieved with suitable optics;
- Broad white colour spectrum allowing good colour filtering.

Disadvantages:

- Electrical control system is complicated;
- Lamp changer design is very complex;
- Short lamp life;
- Electronic control components have short life;
- Relatively expensive;
- Power consumption is variable due to the charging/discharging cycle of the system, resulting in varying loads on the power supply system.

Safety:

- High voltage hazard;
- Possible danger of explosion as the pressure in the lamp is high;
- High UV radiation;
- High surface temperature;
- General glass hazards.

Disposal:

- Consult local and national disposal regulations as there may be some mercury content.

Lasers

A laser is a device that produces a coherent collimated beam of monochromatic light. Their use has not been established in AtoN light systems, despite efforts over recent decades. However, research continues into the use of lasers to improve the visibility and sector distinction of fairway lighting.

Typical Use:

- High power lasers can be used to provide a line of light in the sky where particles of dust, water, etc., are illuminated by the laser beam to provide a leading line. These devices require considerable electrical power (several kW);
- Low power lasers are being tested by the Canadian Coast Guard where the laser is aimed directly at the mariner. Different coloured lasers are used to identify areas of navigational importance. Laser light is visible at useful range in daylight.

Technical data:

- Power requirements are modest (tens of Watts);
- Laser projectors are expensive and require complex control systems.

Advantages:

- Single wavelength (Monochromatic);
- Highly directional;
- Simple optic design.

Disadvantages:

- High power requirements for high power lasers;
- System complexity may be a problem at some locations.

Safety:

- Possible eye damage under certain conditions;
- Apply appropriate American Society for Testing and Materials (ASTM) safety standards;
- Detailed procedures are required for safe servicing.

Refer to IALA publication:

- Guideline 1043 on Light Sources Used in Visual Aids to Navigation.

Gas Lights

Acetylene

Acetylene (Carbide gas) lighting systems originated from the inventions of Gustaf Dalén in the early 20th century and were made by a number of suppliers. Acetylene gas has the unusual property of burning with a white flame when correctly mixed with air. This enabled the development of exceptionally reliable open flame lanterns.

Acetylene lighting technology was further enhanced by the development of the Dalen “mixer” that allowed gas and air to be drawn into a chamber and then consumed in an incandescent mantle to produce a brighter light source than the open flame type. The incandescent mantle can be operated as a flashing source inside a fixed lens or as a continuous source inside a rotating lens. Related developments included a gas-operated mechanism for rotating a lens and a clockwork powered automatic mantle changing device.

Propane

Propane gas has been used as fuel for gas burning light systems. The lighting equipment uses an incandescent mantle burner to make a white flame as the gas burns with a yellow/orange flame when an open flame burner is used.

Refer to IALA publication:

- Practical Note for the Safe Handling of Gases.

3.3.3 Optics

Much of the information in 3.3.2 Light Sources will be moved here.

3.3.4 Light Control Systems

This section to be developed

3.4 Maritime Buoyage System and other Aids to Navigation

The IALA Maritime Buoyage System (MBS) represents one of IALA's major contributions to enhancing the safety of navigation. As recently as 1976 there were more than thirty buoyage systems in use worldwide and conflicting sets of rules applied. In 1980 Lighthouse Authorities from fifty countries and representatives from nine international organisations reached agreement on the rules for a single system. In 2010 the MBS was revised. Key changes made included the introduction of an emergency wreck marking buoy and fixed marks. The full name of the revised system is therefore IALA Maritime Buoyage System and other Aids to Navigation, still being referred to as the MBS.

The MBS uses 7 types of Aids to Navigation, which may be used in combination. The mariner can distinguish between these aids by identifiable characteristics. The system includes:

- Lateral Marks[6];
- Cardinal Marks;
- Isolated Danger Marks;
- Safe Water Marks;
- Special Marks;
- Emergency Wreck Marking Buoy;
- Other Marks.

The General Principles and Rules of the IALA Maritime Buoyage System can be found in Annex D.

Below are additional considerations when using the MBS.

3.4.1 Lateral Marks

This section is under development

There are two international Buoyage Regions A and B, where lateral marks differ. The current geographical divisions of these two regions are shown on the world map in the MBS.

Synchronisation of lateral marks can be used to improve conspicuity of channels. Synchronised lights [all flash at the same time] or sequential lights [flash on after another] or a combination of both may be utilised.

3.4.2 Cardinal Marks

As stated in paragraph 3.2.4 of the MBS, it is very important to take into consideration possible confusion when using a number of Cardinal Marks in proximity to each other. The Competent Authority should therefore be cautious in the use of cardinal marks when planning the overall AtoN system in a specific area.

In areas with large tidal ranges the colour scheme for identification should be above the Highest Astronomical Tide (HAT).

3.4.3 Isolated Danger Marks

The extent of a danger is often not uniform, and the nautical chart should be consulted to verify its extent.

When planning the overall AtoN system, the Competent Authority should if possible ensure that Isolated Danger Marks are used only to mark dangers where there is navigable water all-round.

3.4.4 Safe Water Marks

This section to be developed

3.4.5 Special Marks

Although Special Marks are not generally intended to mark channels or obstructions, these could be used where there is a specific need for navigational guidance and where other marks would not be suitable. For example, to define a route within a channel, such as for deep draught vessels in a fairway marked by lateral marks, or special purpose channels for small craft.

The Competent Authority should be aware that when Special Marks are used for different purposes in proximity to each other it may be difficult for mariners to distinguish between them. In such situations the use of other marks may be more appropriate. The use of Special Marks with pictograms could also be considered.

3.4.6 Marking New Dangers

The Emergency Wreck Marking Buoy (EWMB) is meant for prompt response to mark new dangers such as a wreck. It should therefore only be on station until the Competent Authority is satisfied that information concerning the new danger has been sufficiently promulgated or the danger is otherwise resolved. An appropriate risk assessment should be used to determine how long the EWMB should be deployed. If the new danger is expected to remain, the Competent Authority should mark it with a regular marking scheme.

The EWMB should be equipped and of a size that facilitates its detection under all sea conditions.

Upon a decision to use the EWMB, it should be deployed without unnecessary delay. This can be met by the use of EWMBs that are stored onboard a vessel ready for deployment. It should be taken into consideration that a smaller buoy, in some instances, may be deployed more rapidly. If necessary it could subsequently be replaced with a larger buoy.

Refer to IALA publications:

- Maritime Buoyage System (with supporting guidelines);
- Guideline 1046 on a Response Plan for the Marking of New Wreck.

IALA also has a consolidated recommendation and guidelines for marking areas for specific navigational needs in relation to a variety of man-made structures including aquaculture facilities and offshore resource production and energy generation structures.

3.4.7 Other Marks

Other Marks are visual marks, intended to aid navigation as information to mariners, not necessarily regarding channel limits or obstructions.

3.4.7.1 Leading Lines/Ranges

Transits / Leading (Range) Lines

A transit is defined as the alignment of two or more marks. A Leading (or Range) light is a specialised application of a transit.

Leading (Rear Range) Light - Photo Courtesy of the Canadian Coast Guard

A simple transit can be used to:

- Provide a turning reference;
- Define a clearing line for the limits of safe navigation;
- Provide a distance mark along a waterway.

Leading Lines

A leading line is an aid to navigation system that comprises two separated structures with marks or lights that, when viewed from the centreline or deepest route along a straight section of channel, are aligned.

In a two station leading line, the structures lie along an extension of the centreline of the nominated channel. The rear structure must have a greater elevation than the front structure to enable both marks or lights to be viewed simultaneously.

A leading line provides a vessel with a heading reference and a visual indication of the size and direction of any cross track error.

Purposes of Leading Lines

A leading line may be used to:

- indicate the centreline of a straight section of a navigable channel;
- indicate to deep draught vessels the deepest part of the waterway;
- indicate the navigable channel where fixed and floating aids to navigation are not available[7] or do not satisfy the accuracy requirements for safe navigation;

- define a safe approach bearing to a harbour or river entrance, particularly where there are cross currents;
- separate two-way traffic (ie. when passing a bridge).

Design Considerations for Leading Lines

A well-designed leading line will enable the type and size of vessels that typically use the channel to:

- Identify the marks or lights when the ship is at the inner and outer sections of the channel and readily detect cross track position errors from the centreline of the channel;
- Detect cross track position errors with sufficient sensitivity that the channel can be utilised without abrupt changes to the vessel's heading and speed;
- Observe both lights together, by selection of leading light character rhythms that appropriately overlap in their free running condition. In some situations it may be preferable to provide additional equipment to synchronise the light characters;
- Observe the lights in all ambient conditions for which they are designed to be used without glare. If lights are to be used for both day and night operations light intensities will need to be varied.

The characters of rhythmic leading lights should be selected so that the front and rear lights, in their free running states, can generally be observed together.

In some situations it may be preferable to provide additional equipment to synchronise the light characters. If lights are to be used both day and night, the light intensities should be adapted for each situation to avoid glare at night. Radar transponders (RACONs) may be used as leading line markers.

Refer to IALA publications:

- Recommendation E-112 for Leading Lights (including excel program);
- Guideline 1023 for the Design of Leading Lines;
- Recommendation for a Definition of Nominal Daytime Range of Maritime Signal Lights Intended for Guidance of Shipping by Day.

3.4.7.2 Sector Lights

A sector light is an aid to navigation that displays different colours and/or rhythms over designated arcs. A common means of creating a sector is to fit a coloured filter in front of the main light. However, sector lights with LED light sources are being introduced to the market thereby reducing the need for filters as they produce the coloured light. A sector can also be produced by filtering or by using a secondary light (or several lights) on the same structure. The secondary light can take any of the following forms:

- Range (directional) light;
- Beacon with a coloured lens, masked to achieve the sector angle;
- Beacon fitted with internal or external filter panels;
- Beacon or beacons with different coloured light sources, masked to achieve the sector angle;
- Precision Direction Light.

The limits or boundaries of a sector are not always precisely cut off due to the characteristics of the light source, fading of colours or changing rhythms between adjacent sectors.

For a beacon fitted with coloured filter panels, the reason for the lack of a precise transition at the sector boundary is readily apparent from Figure 15 which shows the light source, lens and filter geometry. The transition zone is defined by an "angle of uncertainty". A similar geometry exists with multiple coloured beacons and masking

Bearings, directions of leading (range) lines and limits of sectors should always be stated in terms of the bearings that would be seen by the mariner. Bearings may carry a suffix 'TBS" or True Bearing from Seaward as confirmation.

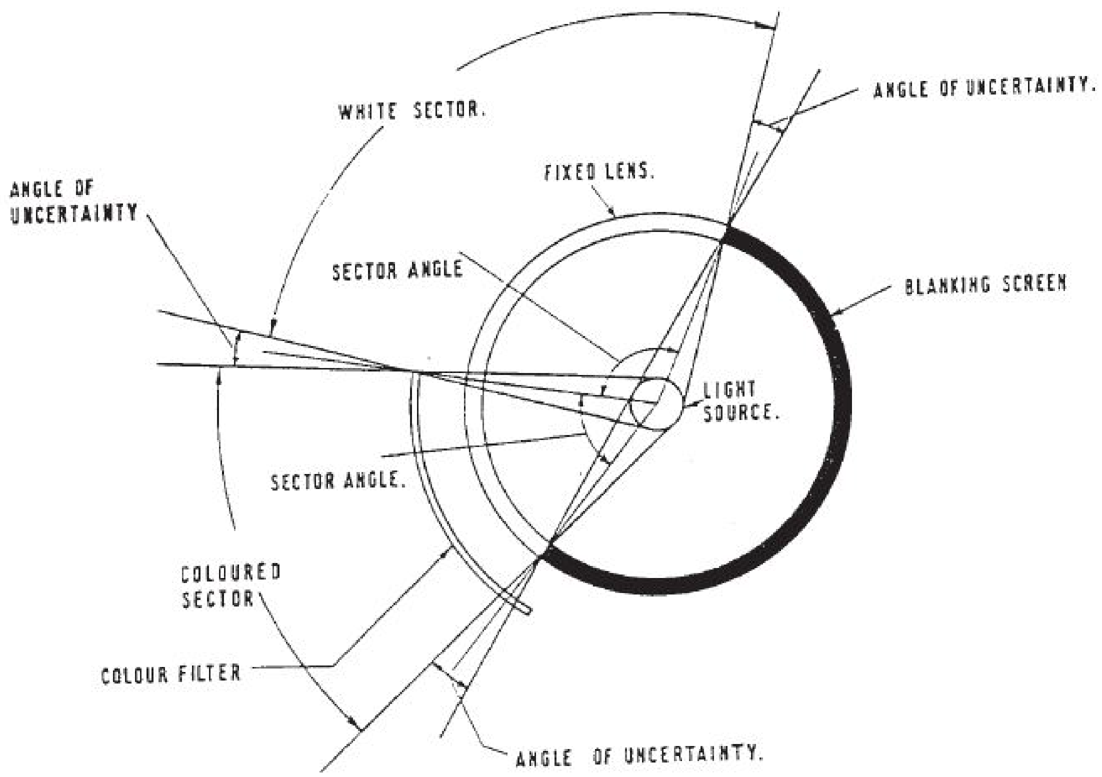


Figure 15 – Angle of Uncertainty

It can also be noted that:

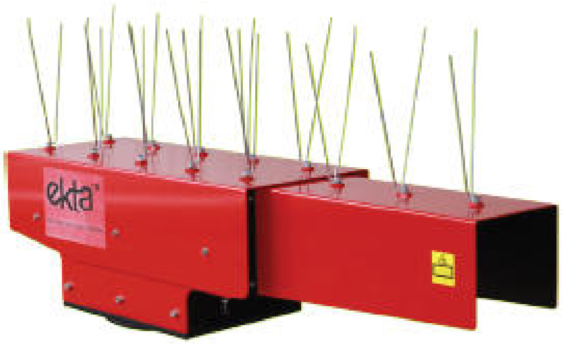
- the observed angle of uncertainty is generally less than the geometric angle due to the relative intensities of sector colours (ie. colour mixing) as the observer passes through the transition zone;
- if space on the aid to navigation structure is not a limiting factor, it is usually possible to achieve an angle of uncertainty of around 0.25o with this type of sector arrangement;
- the angle of uncertainty can be reduced by decreasing the physical width of the light source or by increasing the radial distance to the coloured filter;
- in situations where the main light has a large projected area, such as a rotating lens or reflector array, it is generally preferable to use a separate sector light rather than installing a coloured filter in front of the main light.

From time to time specialised sector lights have been developed to exhibit different rhythms over different sector bearings. This capability is found in some **Precision Direction Lights** (PDL)[8].

A PDL is a specialised form of sector light that can generate sharply defined sector boundaries. This feature is particularly useful for applications that require one or several narrow sectors or high precision boundaries. The PDL may use a white light source with coloured filter, but newer designs are utilising LED and possibly laser as a light source.

PDL sector lights are very precise, allowing a complete colour change at a sector boundary to occur over an angle of less than 1 minute of arc in most models.

Applications



LED Sector Projector Light - Photo Courtesy of Cybernetica AS

The design of sector lights can be a complex task. The process should be carried out with reference to an accurate chart of the areA. In some cases good local knowledge is also required.

A sector light may indicate one or more of the following:

- boundaries of a navigable waterway;
- change of course position;
- shoals, banks, etc.;
- an area or position (eg.an anchorage);
- the deepest part of a waterway;
- position checks for floating aids.

A PDL allows for further applications that include the ability to:

- produce narrow sectors with an angle of uncertainty down to approximately one minute of arc;
- define the central zone of a channel;
- accurately mark one side of a straight channel (a pair of PDLs can cover the permutations of converging, diverging and parallel channels);
- define different rhythms over adjacent sectors.

Examples

Some examples of sector lights applications are illustrated in Figure 16 and Figure 17.

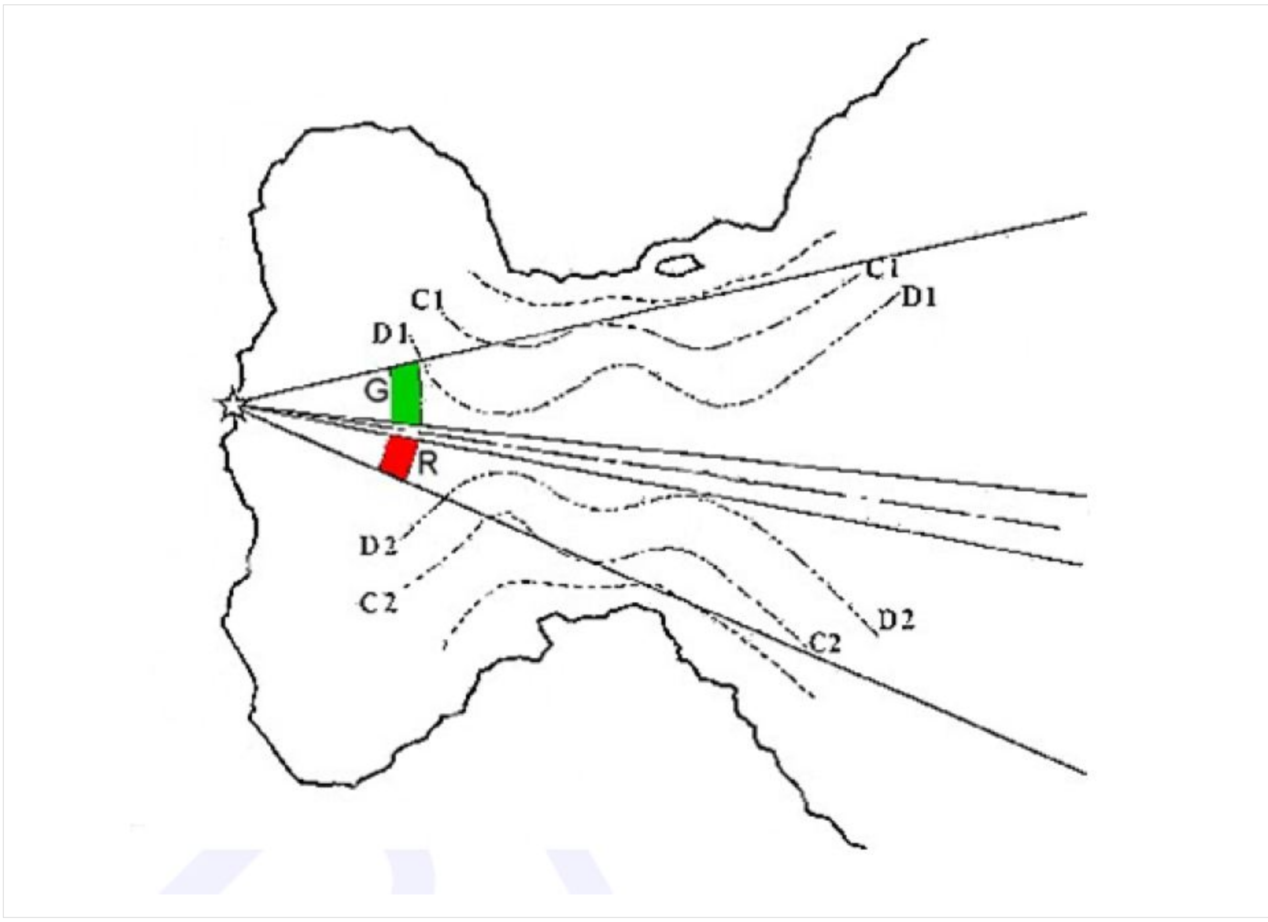


Figure 16 - Sector Light Application

This illustration follows the IALA Maritime Buoyage System colour convention for Region A (‘red to port when approaching the aid from seaward’). The white sector should, if possible, be wide enough to provide a margin of safety for a vessel that inadvertently leaves the white sector. Curves C and D indicate depth contours or limiting dangers that dictate the boundaries of sectors.

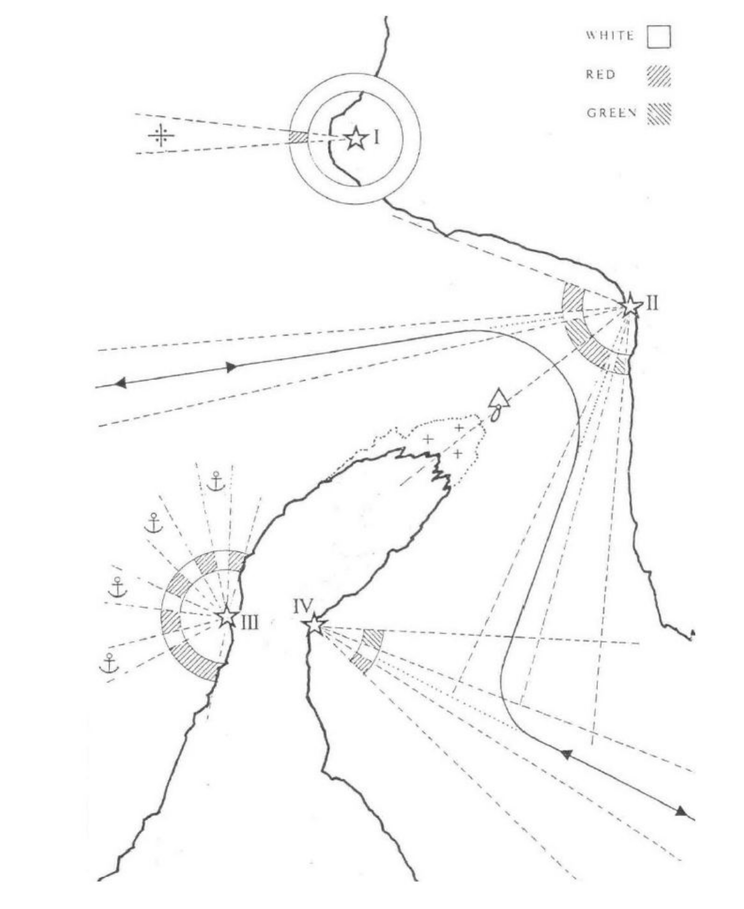


Figure 17 - Various Applications for Sector Lights

The function of each light in Figure 17 is described below:

- Light I is a coastal white light with a red sector indicating a danger.
- Light II is a sector light obscured over the shore, with two white sectors indicating a safe channel. When sailing towards the sector light it shows red to port and green to starboard following the IALA Maritime Buoyage System colour convention for Region A and vice versa for Region B. The boundary between the red and the green sector also indicates the position of a buoy.
- Light III is a sector light with a red light and 4 white sectors indicating four anchorage positions. It is obscured over the shore.
- Light IV is a sector light with a white sector indicating a safe channel.

Design Considerations for Sector Lights

Where a single sector light defines a navigable channel the following points should be considered:

- **Lateral Position:** There is no reference of the vessel's lateral position within the channel until a sector boundary is reached. This may cause a problem in channels subject to a strong cross current. For vessels with local knowledge, the zones defined by the angle of uncertainty can sometimes provide a useful guide to the vessel's proximity to a sector boundary;
- **Safety Margin:** Where practicable, there should be a margin of safety between the sector boundary and adjacent hazards. If an appropriate safety margin cannot be achieved within the sector boundary, the hazards could be marked separately.
- **Angle of Uncertainty:** Zones defined by the angle of uncertainty should be considered an additional margin of safety over the actual sector boundary;
- **Vessel Size:** The design process for a sector light needs to consider the draught and manoeuvrability of the largest vessels likely to utilise the sector, how quickly they can respond once they cross a sector boundary and the

situations that may develop when other vessels are in the vicinity;

- **Lights and Filters:** When using an incandescent light source the sector design should take account of the spectral distribution of the light source and the proportion of this light transmitted through the filter material as this will affect the resultant colour and intensity of the light exhibited. The process should also check for potential glare problems;
- **Flash Characteristic:** The period of the light flash should be selected to provide ample time for a mariner to recognise the transitional phases that occur at the sector boundary ;
- **Sector Colours:** A white light is normally the first preference for a lighthouse or beacon. If a single coloured sector is added, red is often used. If a white sector light is used to mark a navigation channel, coloured sectors may be used either side of the white to indicate the lateral limits. In such cases it is common practice to use red and green sectors that follow the convention of the IALA Maritime Buoyage System;
- **Lamp Position and Type:** The position of the light source within the optical system is critical for the correct alignment of the sectors. When replacing lamps or using lampchangers, it is important to ensure that the light source (e.g. filament) position is identical. If a lampchanger is incorporated, the sector system should be designed for the widest light source used in the lampchanger.

Refer to IALA publication:

- Guideline 1041 on Sector Lights.

3.4.7.3 Fixed Aids to Navigation - Lighthouses and Beacons

The IALA International Dictionary of Aids to Marine Navigation defines a beacon as “a fixed artificial navigation mark” that can be recognised by its shape, colour, pattern, topmark or light character, or a combination of these. While this functional definition includes lighthouses and other fixed aids to navigation, the terms lighthouse and beacon are used more specifically to indicate importance and size.

Lighthouse: A lighthouse is generally considered to be a large conspicuous structure (visual mark) on land, close to the shoreline or in the water that:

- acts as a daymark;
- provides a platform generally for higher range marine AtoN signal lights.

Other aids to navigation such as audible signals and radio aids to navigation may be located on or near the lighthouse. A lighthouse may be a staffed or an automated facility, although the staffing of lighthouses is becoming less common. An automated lighthouse may be remotely monitored and in some cases remotely controlled.

Beacon: Visual characteristics of a beacon are often defined by daymarks, topmarks, and by numbers. A marine signalling light, if fitted, would generally be of a lower range than lighthouses. In navigable channels a pile beacon may be used as an alternative to a buoy[9].

Purpose of Lighthouses and Beacons

A lighthouse or beacon may perform one or more of the following navigational functions:

- mark a landfall position;
- mark an obstruction or a danger;
- indicate the lateral limits of a channel or navigable waterway;
- indicate a turning point or a junction in a waterway;
- mark the entrance of a Traffic Separation Scheme (TSS);
- form part of a leading (range) line;
- mark an area;
- provide a reference for mariners to take a bearing or line of position (LOP).

Other purposes for which a lighthouse can be used include:

- base for AIS equipment; racon; radar; radionavigation systems; reference station for DGNSS;
- coastwatch or coastguard functions;
- VTS functions;
- base for audible (fog) signals;
- collection of meteorological and oceanographic data;
- radio and telecommunication facilities;
- tourist facilities.

3.4.7.4 Floating Aids to Navigation - Minor and Major

A floating aid to navigation serves a similar purpose to a beacon or a lighthouse. However the floating aid to navigation is normally associated with locations where:

- it would be impractical due to water depth, seabed conditions or cost to establish a fixed aid;
- the hazard shifts over time (eg. sand banks, an unstable wreck, etc.);
- the aid is at high risk of damage or loss from ice flows or ship impacts and as a consequence is treated as expendable;
- a temporary mark is required.
- a seasonal mark is required.

Buoys: Buoys are defined as minor floating aids and whilst it is normal that they are lit there are instances where no light is installed. These types of aids to navigation are specifically covered by the IALA Maritime Buoyage System and tend to have circular hull forms up to 3 m diameter. Buoys may be fitted with sound signals. Most buoys are equipped with a radar reflector.

In addition, due to limitations of the structure, the following may apply:

- where lights are exhibited, they are usually solar or primary battery powered. There are gas powered buoys still in operation, although gas powered buoys are not normally used for new installations;
- where lights are exhibited, due to power limitations and/or operational requirements, light ranges are typically restricted to 1 to 5 nautical miles; although longer ranges may be required in some applications;
- additional services are restricted due to limited power on a buoy, but RACONs, AIS AtoNs, and remote monitoring units are sometimes installed in addition to a light;
- audible signals are used on buoys in some countries.

Light Vessels, Lightships and Large Navigational Buoys: Light Vessels, Lightships, and Large Navigational Buoys (LNB), sometimes referred to as LANBYs, are defined as major floating aids and may carry one or more of: RACONs, AIS AtoNs or audible signals in addition to the aid to navigation light. A light vessel may also display a white riding light to signify a vessel at anchor. All major floating aids should be equipped with a radar reflector and a monitoring unit.

Major aids to navigation:

- generally have high operating costs;
- are only deployed at critical locations;
- are often assigned an aid availability target that is higher than for a buoy;
- are not specifically covered by the IALA Maritime Buoyage System.

Refer to IALA publication:

- Recommendation O-104 for ‘Off Station’ Signals for Major Floating Aids to Navigation.

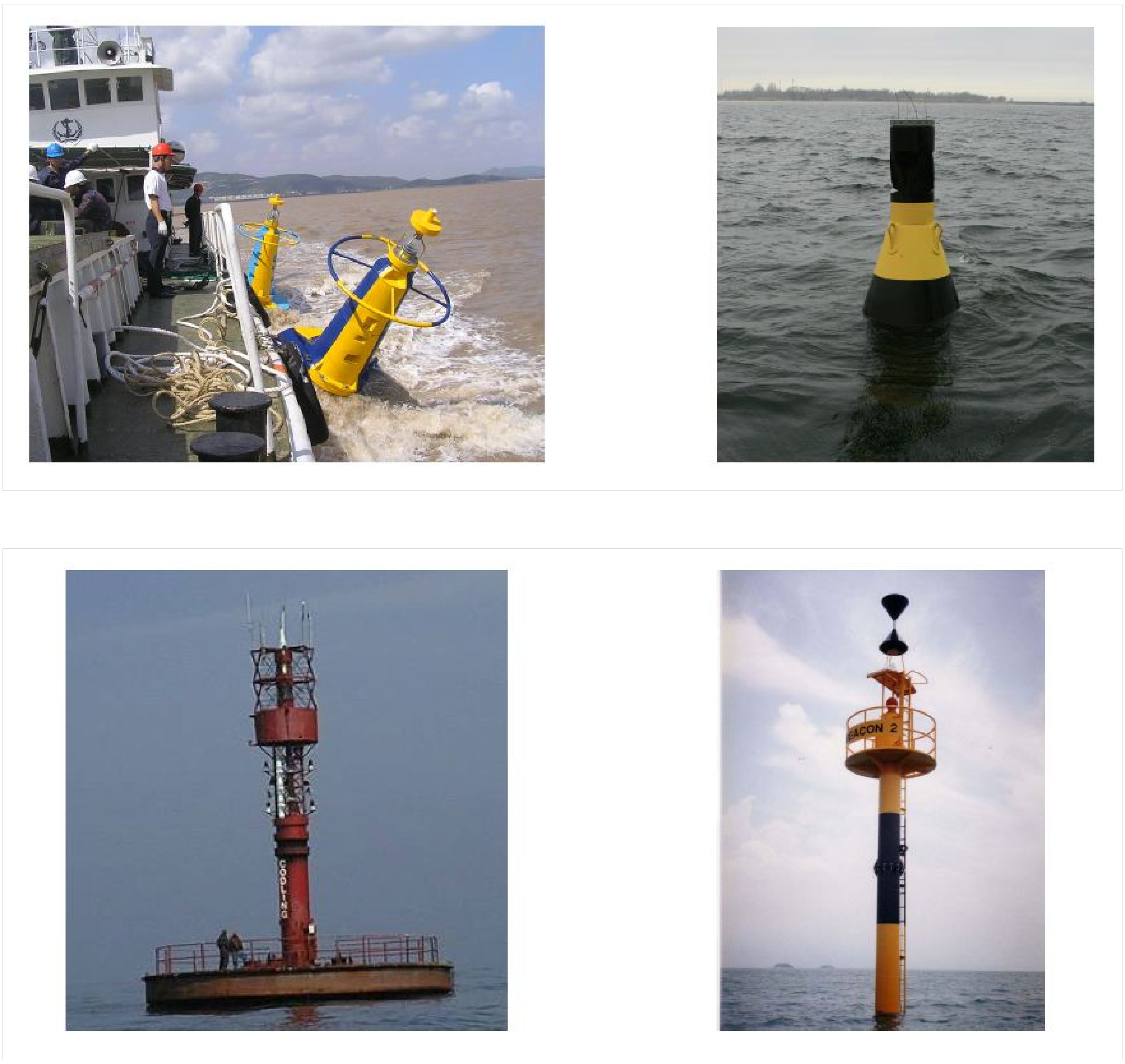


Figure 14 – Examples of Floating Aids

Performance Criteria for Floating Aids

Availability is defined as the probability that an aid to navigation or a system of aids to navigation, as defined by the Competent Authority, is performing its specified function at any randomly chosen time. This is expressed as a percentage of total time that an aid to navigation or a system of aids to navigation should be performing their specified function[10].

The availability of a floating aid is the principal measure of performance determined by IALA. The recommended availability targets are indicated in Table 19. The availability objective assigned to floating aids to navigation conforming to the IALA Maritime Buoyage System should also apply to the topmark.

Description of Aid	Availability Target	
Floating aids to navigation that are considered to be of primary navigational significance	Category 1	at least 99.8%
Floating aids to navigation that are considered to be of navigational significance	Category 2	at least 99%
Floating aids to navigation that are considered to be of less navigational significance than Category 1 or 2.	Category 3	at least 97%

Table 19 - Availability Targets

Refer to IALA publications:

- Recommendation O-130 on Categorisation and Availability Objectives for Short Range Aids to Navigation;
- Guideline 1035 on Availability and Reliability of Aids to Navigation.

Technical Considerations for Floating Aids to Navigation

There are various technical considerations that should be taken into account, including: cost, design factors, positioning, water conditions and markings.

Cost

The cost of establishing a floating aid at a given location will generally be less than for a fixed structure. The cost difference increases with increasing water depth and exposure to wind and waves.

In contrast, the maintenance cost of floating aids to navigation tends to be high relative to the capital value. This has caused many authorities to critically examine the potential for savings through design changes, use of alternative materials, alternate service deliveries (contracting out) and amending maintenance practices, generally with the aim of extending maintenance intervals.

Where an authority operates a large number of floating aids, it may become practicable to operate a dedicated buoy tender vessel with specialised equipment to minimise buoy change-out times and to improve occupational safety.

Refer to IALA publication:

- Guideline 1047 on Cost Comparison Methodology of Buoy Technologies.

Floating Aid Design

The process of designing a buoy to meet specific requirements is a specialised task. It involves, but is not limited to:

- defining the operational performance characteristics;
- defining the equipment, power requirements and power source(s);
- defining the type and capabilities of the vessels that will be used to service the buoy;
- selecting the initial type proportions and mooring for the buoy;
- integrating of equipment and power supply;
- considering of the maintenance requirements;
- identifying deployment and recovery techniques;
- protecting equipment from damage;
- providing the ability to rectify faults without having to lift the buoy;
- determining the buoy response to the wave, wind and current conditions at the site(s);
- optimising the design.

Refer to IALA publications:

- Maritime Buoyage System (and supporting guidelines);
- Guideline 1006 on Plastic Buoys;
- Guideline 1011 on a Standard Method for Defining and Calculating the Load Profile of Aids to Navigation;
- Guideline 1036 on Environmental Considerations in Aids to Navigation Engineering;

- Guideline 1037 on Data Collection for Aids to Navigation Performance Calculation;
- Guideline 1040 on the Maintenance of Buoys and Small Aids to Navigation Structures;
- Guideline 1042 on Power Sources and Energy Storage for Aids to Navigation;
- Guideline 1043 on Light Sources Used in Visual Aids to Navigation;
- Guideline 1094 on Daymarks for Aids to Navigation;
- Guideline 1099 on the Hydrostatic Design of Buoys;
- Recommendation E-106 on the Use of Retroreflecting Material on Aids to Navigation Marks within the IALA Maritime Buoyage System.

Mooring Design

The mooring system for a floating aid to navigation is the sum of the components that keep the aid within a nominated area. These components have to withstand the forces of wind, wave, current and ice on the floating aid and drag on the mooring line.

The basic assumptions made are that the:

- mooring system tethered to the buoys sinker is usually tangential to the sea bed;
- buoy axis is vertical under the most common conditions of current and wind;
- ratio of the breaking stress of the mooring system to the calculated stress is not less than 5 under the most unfavourable conditions of current and wind;
- reserve buoyancy of the fully equipped floating aid is greater than the combined loads of current and wind under the most unfavourable conditions.

An approximate value for the minimum length of a chain mooring is given by the following formula:

- L_{min} = 3H for depths less than 50 metres;
- L_{min} = 2H for depths greater than 50 metres.
  L = Length of mooring line (m)
  H = Depth[11] of water (m)

All moorings should be designed as per Guideline 1066 on Design of Floating Aids to Navigation Moorings.

Refer to IALA publications:

- Guideline 1066 on the Design of Floating Aids to Navigation Moorings.

Positioning of Floating Aids

The charted position of a floating aid defines the nominal (or true) position for the anchor. With most floating aids there is potential for the mooring anchor/sinker to be moved off-station during storms or due to ice flows. Additionally, positional errors can occur while laying the anchors/sinkers.

The positioning process for anchors/sinkers should utilise radionavigation or radio-positioning aids. The use of DGNSS position fixing is increasingly seen as the preferred method. The benefits of DGNSS position fixing are: convenience, accuracy and repeatability. A buoy tender using DGNSS can generally be brought to within 10 metres of the nominal buoy position at the time of releasing the anchor/sinker.

If the anchor/sinker is allowed to free-fall, its final resting position will depend on the prevailing current, water depth, shape of the anchor/sinker and the nature of the seabed. Controlling the decent of the anchor/sinker may serve to improve the positional accuracy of the buoy.

Markings and Topmarks

Markings

Floating aids to navigation are often identified by names, abbreviations of names, letters and/or numbers. Authorities should ensure that the actual marking is identical to the List of Lights reference and the charted marking.

Topmarks

The type, colour and arrangement of topmarks on a buoy are shown in the IALA Maritime Buoyage System, extracts of which are shown in Annex D. Topmarks should conform to Guideline 1094 on Daymarks for Aids to Navigation.

Refer to IALA publications:

- Guideline 1094 on Daymarks for Aids to Navigation.

3.4.7.5 Auxiliary Marks

This section to be developed

Notes

[1] CIE S 004/E2001 replaces CIE 2.2 - 1975, "Colours of Light Signals"

[2] Blue surface colours may be used in inland waterways. estuaries and harbours where the colour may be seen at close range. see IALA recommendation E108. in addition, blue lights are being tested for use on emergency wreck marking buoys - IALA Recommendation O-133 refers

[3] CIE website address: www.cie.co.at/cie

[4] A single fixed light shall not be used on a mark within the scope of the IALA Maritime Buoyage System because it may not be recognized as an aid to navigation light.

[5] A Morse Code white light with the single character “U” is assigned to offshore structures.

[6] Lateral marks differ between buoyage regions A and B.

[7] For example, in waterways where the aid may be drifting or destroyed due to ice conditions.

[8] Also known by the trade name of PEL light.

[9] In these situations the beacon will generally show a colour scheme and topmarks in accordance with the IALA Maritime Buoyage System.

[10] As adapted from the IALA Guidelines on Availability and Reliability of Aids to Navigation, Theory and Examples (Edition 2, December 2004).

[11] This is defined as the maximum depth of water and includes the highest tide level and half the maximum wave height at the particular site.

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