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IALA

MARITIME BUOYAGE SYSTEM

GUIDELINES

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SECTION 1. GENERAL PRINCIPLES OF THE IALA MARITIME BUOYAGE SYSTEM

1.1 INTRODUCTION

The IALA Maritime Buoyage System provides a single set of rules which apply world-wide to all fixed and floating marks, other than lighthouses, sector lights, leading lights and marks, lightships and large navigational buoys (reference 6.1).

The rules provide for the world to be divided into two buoyage regions: Region A where the surface and light colours of lateral marks are green to starboard and red to port, and Region B where red colour is to starboard and green colour is to port according to the conventional direction of buoyage (see para. 1.3). In all other respects the rules are identical for both regions. The two regions are very well defined in Section 8 of the buoyage rules.

1.2 CHOICE OF MARKS AND LIGHT CHARACTERS

Within the IALA Buoyage System there are 5 types of marks which may be used in any combination. The mariner can readily distinguish between these marks by shape and surface colour or at night by the colour and rhythm of the light.

An administration can choose whether it wishes to make use of all or only some of the 5 types available. The choice will depend upon the configuration of the coastline, the type of sea bed, depth of water and type of traffic.

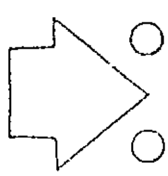
When selecting light characters, careful attention should be paid to the appropriate IALA Recommendations (reference 6.2).

1.3 CONVENTIONAL DIRECTION OF BUOYAGE

Lateral marks are laid out according to a conventional direction of buoyage which can be either :

the general direction taken by the mariner when approaching a harbour, river, estuary or other waterway from seaward, or;

the direction determined by the appropriate local or national authority in consultation with neighbouring countries or administrations. In principle it should follow a clockwise direction around continental land masses. Where the mariner can be in doubt about the conventional direction of buoyage, hydrographic services should be asked to include the internationally agreed buoyage direction symbol on the appropriate charts, viz:



1.4 LATERAL MARKS

When deciding the distance of one lighted mark from the next in laterally marked channels, account should be taken of the range achieved from the red or green lights.

Where lateral marks are used to mark a channel of considerable length, some additional assistance may be given to the mariner from any or all of the practices described in the following paragraphs.

1.4.1 STANDARD CHARACTERS

The practice of having standard periods for group flashing lights, for example: all Fl (2) lights to have a period of 5s, all Fl (3) lights to have a period of 10s may be worth considering in the interests of standardisation of equipment.

1.4.2 SYSTEMATIC CHARACTERS

Introducing a systematic approach to lateral light characters along a channel, e.g. :

- the mark at the outer end of a channel to have a single flashing character, the next Fl(2), the next Fl(3) and so on, the mark following Fl(4) reverting to single flashing and the sequence repeated, (see also the case of cardinal marks in lateral channels, para. 1.5.2).

- to have one character only for all lights in a channel. This can be particularly useful where a number of channels are closely adjacent to one another.

1.4.3 MODIFIED LATERAL MARKS

The IALA rules also provide for a modified lateral mark to be used at the point where a channel divides, to distinguish the preferred channel, that is to say the primary route or channel which is so designated by an appropriate authority. This modified lateral mark with its distinctive Fl (2+1) rhythm may be particularly useful by helping small coasters, fishing boats or pleasure craft to avoid main deep draught routes. A point where there is a bifurcation in the channel can also be marked by using an appropriate cardinal mark (see para. 1.5.2).

1.5 CARDINAL MARKS

1.5.1 PURPOSE

Cardinal marks are particularly useful for marking offshore dangers or dangerous obstructions of significant size, e.g. sandbanks, rocks, or wrecks. They are also very useful for marking the route in areas where the direction of buoyage cannot easily be defined (see para. 1.3).

1.5.2 USE IN CHANNELS

The use of cardinal marks is also recommended in laterally marked channels :

- to indicate the point at which channels divide or join;
- to show course alteration points;
- to mark important positions in the channel;
- to break up the pattern of red or green lights or surface colours;
- to provide for the mariner at night, a white light with which he may verify his position from a greater distance;
- to provide for the mariner by day, a different distinctive shape.

Where lighted cardinal marks are interspersed with lateral buoys using the progressive system of light characters described in paragraph 1.4.2, it is preferable for the lateral buoy following such a cardinal mark to revert to single flashing and thus to start the sequence anew.

1.5.3 TOPMARKS

Every effort should be made, consistent with the stability of the mark, to provide for the superstructure, and also the topmarks of cardinal marks to be as large as possible, (see paras. 2.3.4 and 2.4). Experience of using cardinal marks indicates that the colour configuration on the superstructure and buoy body may be apparent to the mariner at a greater distance than that at which the form of the topmarks can be identified.

1.5.4 CHARACTERS

Lighted cardinal marks should, where practicable, make use of very quick flashing lights as such lights are very distinctive and easily seen. Quick flashing lights can be used where it is necessary to distinguish between two similar lights in the same area. However it must be recognised that to achieve the same light intensity, the very quick flashing lights will consume more energy than the quick flashing lights.

1.6 ISOLATED DANGER MARKS

1.6.1 POSITIONING

The isolated danger mark is only used for a danger of small area which otherwise has navigable water all around it.

It is therefore important that this mark should be placed on or over the danger it is marking. In the case of a buoy, this will mean placing the mooring on or very near to the danger.

1.6.2 SHAPE

Wherever possible, the isolated danger mark should be in the form of a pillar or spar to help with its identification. However, it may be necessary to use other shapes in some circumstances.

For dangers of large area it is safer to use one or more of the appropriate cardinal or lateral marks.

The isolated danger mark with its double topmark and group flashing white light is allied to marks of the cardinal group.

1.7 SAFE WATER MARKS

These marks are not used for indicating a danger but to mark areas where there is navigable water, such as landfall marks, or mid channel marks.

The availability of four light characters and two day shapes permits several of these marks to be used adjacent to one another to mark the centre line of a channel.

The safe water mark with its single topmark has a white light with a slow rhythm, and is allied to marks of the lateral group.

1.8 SPECIAL MARKS

1.8.1 PURPOSE

Special marks are primarily intended for purposes other than to assist the navigator to determine his position and their use should, whenever possible, be confined to situations where their purpose can be ascertained by reference to charts or other nautical documents. Their surface colour is always yellow, and any light they exhibit is also yellow.

1.8.2 LIGHT CHARACTERS

To avoid the possibility of confusion between yellow and white lights particularly in poor visibility, the use of any light character reserved for cardinal, isolated danger or safe water marks is precluded. This therefore limits the characters available for special marks to the following:-

- Group occulting light
- Single flashing light, but not a long flashing light with a period of 10s
- Group flashing light with a group of four, five or (exceptionally) six flashes (see para. 1.8.3)
- Composite group flashing light
- Morse code light, but not with the single characters "A" or "U".

1.8.3 ODAS

It is recommended that ODAS Buoys have the yellow light character of group flashing (5) every 20 seconds, but due to the limitation on character availability, it is not considered that other special marks should be precluded from using this light character if absolutely necessary.

1.8.4 OUTFALLS

An example of the use of special marks is in the marking of outfall pipelines. When, as is the case with many outfalls constructed in recent years, the pipeline is buried over its entire length with the exception of a short section at the outer end, there may well be no reason to discourage navigation by small craft between the outer end of the outfall and the shore. In such cases it is felt that the appropriate marking for the outer end of the outfall (where marking is required) will be by a special mark. In cases where a continuous obstruction to navigation exists over the whole length of the pipeline and the requirement is to indicate that vessels should pass to seaward of its outer extremity, a lateral or cardinal mark would be appropriate.

1.8.5 SPECIAL CHANNELS

An important application for special marks is to mark a channel of interest to a particular class of vessel, for example, a specially dredged channel for deep draught vessels in an area where there already is adequate depth of water for most vessels. In such a case the limit of safe navigation for vessels generally will continue to be marked by lateral (or cardinal) marks but the channel of special interest will be indicated by special marks with the appropriate daymark shape.

1.8.6 SHAPE

Whilst the shape of a special mark is optional, care should be taken when using lateral shapes that the shape selected is appropriate to the position of the mark in relation to the navigable waterway and to the direction of buoyage.

1.9 NEW DANGERS

1.9.1 DUPLICATE MARKS

Where an authority decides that a new danger is sufficiently grave to warrant the duplication of one or more of the buoys by which it is marked, the duplicate mark must be of identical shape and must exhibit an identical light character to its partner.

1.9.2 DUPLICATE CARDINAL MARKS

Where a duplicate cardinal mark is used on a "new danger", it is better if both marks can be positioned on the same bearing from the "new danger".

1.9.3 DUPLICATE LATERAL MARKS

Where a duplicate lateral mark is used on a "new danger" its position will have to depend upon the configuration of the route to be followed.

1.9.4 RECOGNITION BY RADAR

Whilst two identical buoys marking a "new danger" should be placed close to one another, due regard should be paid to the desirability of having sufficient separation between them to ensure that they show up as two separate targets on a ship's radar display.

A new danger may be marked by a Racon coded Morse D (- ··). This distinctive Racon character is reserved only for this purpose.

1.9.5 REMOVAL

When the Authority is satisfied that the existence of the new danger has been sufficiently promulgated, the duplicate mark may be withdrawn.

SECTION 2. THE RECOGNITION OF MARKS BY DAY

2.1 GENERAL

The IALA Maritime Buoyage System (rule 1.3) states that the significance of a mark by day depends upon one or more of the following features :

- Colour, Shape, Topmark.

These features which are all equally important are discussed below, together with details about size and proportion.

2.2 COLOURS

2.2.1 GENERAL

The purposes of surface colours are :

- to render a buoy or seamark conspicuous
- to convey a simple navigational message or information.

The rules of the IALA Maritime Buoyage System provide for the use of the colours black, white, red, green and yellow. In the selection of the shades of these colours a comprise has to be reached between high conspicuity at long range and clear message recognition at close range. The recognition ranges that are possible for various colours under the wide variety of conditions of incident light and background experienced at sea, may be found in an IALA Bulletin article entitled "Daymarks as aids to marine navigation" by P. Blaise in issue n° 47 (see reference 6.3). Although even under favourable conditions of light there are severe limitations to the recognition of colour at a distance, particularly if the surface area concerned is small, the use of good colour shades can greatly assist in the recognition of a mark.

2.2.2 METHODS OF COLOURATION

The surface colours of marks required by the IALA system may be provided in various ways. The most common is that of paint, which should be of a high quality and resistant to the effects of water, ultra-violet radiation, temperature variations, marine growth, etc. Paint has the advantages of permitting an easy colour change if necessary, and of being quickly renewed or retouched.

Through-coloured plastic materials and fibreglass (GRP) may give resistance to damage and weathering and reduce the need for regular repainting, but they do not lend themselves to easy colour change.

For certain parts of a seamark, coloured adhesive sheeting may be convenient, but it can be difficult to apply to some shapes and surfaces, and may tend to peel at the edges. There can be some difficulty in removing it when a change or renewal is required. (See also Section 5).

2.2.3 SELECTION AND TESTING OF COLOUR SHADES

The colours used on an aid to navigation must be clearly recognised at close range. This requires that they should remain throughout their service life within certain colour chromaticity regions. The graph showing these chromaticity regions may be found in the "IALA recommendations for the surface colours used as visual signals on aids to navigation" (reference 6.4). The degree of lightness or darkness of a colour also has a significant effect on its recognisability.

The science of surface colours is extremely complex. An introduction to this subject and an explanation of the terminology can however be found in references 6.5, 6.6, 6.7 and 6.8.

To help in a practical way with the selection of colour shades and materials to be used for any particular application, they should, if possible, be subjected to a period of practical assessment by direct observation at sea under a variety of visibility conditions. The choice of colour shades and material can be modified if necessary in relation to the local conditions of ambient light and colour, types of background, climatic conditions and deterioration due to sea, sun, and marine growth (references 6.9 and 6.10). Authorities would be well advised to require the regular checking of service paints and other colour material against standard paint colour samples that have been properly protected against deterioration.

2.2.4 COMBINATIONS OF COLOURS

To provide sufficient navigational messages, combinations of colour are necessary. The use of more than one colour on a seamark has the effect of breaking up its outline and inevitably reduces to some extent the long distance conspicuity of the mark. Where coloured bands or stripes are used, care should be taken to keep the area of each colour as large as possible consistent with the construction of the mark.

2.2.5 INTERNATIONAL RECOMMENDATIONS

Apart from IALA recommendations for the surface colours to be used on aids to navigation (reference 6.4), the International Commission on Illumination (CIE) has also prepared official recommendations of "Surface colours for visual signalling", but these have a more general application.

2.2.6 FLUORESCENT PAINTS AND FILMS

Signal colours, particularly red and green, may be greatly improved by the use of fluorescent paints or films. Red can be made to have a brighter appearance, even in regions of shadow, and more saturated greens may be obtainable without loss of brightness. Hitherto, the use of such materials has been limited in practice by their short service life and the difficulties of application and retouching. Fluorescent materials degrade rapidly under the influence of sunlight, due to ultra violet radiation, unless they are protected by special varnishes, however excessive varnish will reduce the fluorescent effect. Even with this protection, effective service life at sea is commonly limited to about one year. Fluorescent paint is applied as a system requiring several special undercoats and topcoats, and the protective varnish which cannot be satisfactorily applied at low temperatures. Fluorescent sheeting is subject to similar difficulties to those of ordinary coloured adhesive sheeting.

For the reasons given above, in spite of their great advantages in respect of colour, fluorescent materials have not yet received universal application on aids to navigation, although technical progress may be expected to effect substantial improvements in the future.

Reference 6.4. includes limits of chromaticity and luminance factor to be applied to fluorescent colour materials (see also Section 5 concerning retroreflecting materials).

2.2.7 LETTERS, NUMBERS OR SYMBOLS

If lettering, numbers or other symbols are to be read on seamarks, even at close range, apart from being of sufficient size, adequate contrast must be provided betweeen symbol and background. Black symbols may be used on yellow and white backgrounds and also on bright fluorescent red or green. White or yellow symbols may be used on black, or ordinary red or green backgrounds.

2.2.8 COLOURED HORIZONTAL BANDS

A particular problem with the use of horizontal bands, particularly on buoys, is that false "black" bands may be formed by marine growth and the navigator may be misled. Anti-fouling yellow paints is particularly recommended for the west and north cardinal and special buoys.

The false "black" band creates a special problem for fixed beacons, especially where there is a large range of tide. At low water, the false band can appear very large, and at times of exceptionally high tide, the lower band can disappear. In these cases the topmark is of particular value.

2.3 SHAPE

2.3.1 SHAPES OF LATERAL AND SAFE WATER MARKS

Although the rules of the IALA System permit the use of spar or pillar buoys in any lateral or safe water situation, the use of more specific shapes clearly gives the mariner great advantages in recognising the significance of a buoy.

This is particularly true where the colour of the buoy has deteriorated, or when a buoy is observed against the light, preventing its colour from being determined.

In addition, the significance of any specific shape is common to both Regions A and B.

The specific shapes for lateral and safe water marks laid down in the IALA rules are:

Conical	: Starboard hand marks
Cylindrical (Can)	: Port hand marks
Spherical	: Safe water marks

2.3.2 DIMENSIONS FOR LATERAL AND SAFE WATER MARKS

To ensure that the shape of a mark is clearly identifiable it is advisable that its visible dimensions comply with the proportions below.

- Conical : A cone with a height between 0.75 and 1.5 times its base diameter
- Cynlindrical (Can): A cylinder with a height between 0.75 and 1.5 times its diameter
- Spherical : A sphere whose apparent height above the water line is more than 2/3 of its diameter.

2.3.3 RECOGNITION RANGE OF LATERAL AND SAFE WATER MARKS

The recognition range of a shape depends upon its dimensions, the eyesight of the observer, the contrast between the shape and its background, and the geometry of the shape.

In the case of a mark of spherical, conical or cylindrical shape, with height equal to diameter, the recognition range with the naked eye may be roughly estimated as being 500 times the height of the shape.

2.3.4 SPAR AND PILLAR BUOYS

When using spar or pillar buoys it must be remembered that the visible surface area is sometimes quite small and thus the recognition range can be low. A low recognition range can be enhanced by the use of topmarks (see § 2.4) as is the case with cardinal marks and isolated danger marks.

Topmarks can also be helpful when such buoys are used in lateral situations.

The recognition range of spar or pillar buoys cannot in fact be even approximated here, due to the large variety of different pillar and spar buoys in use.

2.3.5 DIMENSIONS FOR SPAR AND PILLAR BUOYS

Due to the large variety of shapes currently in use, it is not possible to lay down specific dimensions for these marks. However the following definitions may be of assistance.

2.3.6 DEFINITION OF A SPAR BUOY

A buoy whose visible part generally has a small cross section with a height of more than 5 times its width.

2.3.7 DEFINITION OF A PILLAR BUOY

A buoy which normally has its flotation body surmounted by a lattice or solid tower carrying the light and/or topmark.

2.4 TOPMARKS

2.4.1 GENERAL

The use of topmarks in the IALA System is to assist the mariner in recognising marks and identifying their purpose and the rules provide for six types :

Double Cone topmarks for Cardinal Marks

Single Cone topmarks for Starboard Hand Marks

Single Cylinder (Can) topmarks for Port Hand Marks

Double Spherical topmarks for Isolated Danger Marks

Single Spherical topmarks for Safe Water Marks

Single X topmarks for Special Marks.

On lateral marks and safe water marks, topmarks are of particular use when the mark itself does not have a specific shape.

For cardinal marks and isolated danger marks, the topmark is a very important feature of the mark, and should be used wherever practicable. (See reference 6.9).

Special marks have their own particular "X" shape indicating that their prime purpose is not that of an aid to navigation.

2.4.2 POSITION AND DIMENSIONS OF TOPMARKS

To fulfil its purpose, the topmark should be situated at a height clearly above all other parts of the mark and its associated structures and be as large as practicable. However, the problems presented by having a large structure high above the water line on a buoy must be taken into consideration. (See 2.4.9).

2.4.3 CONICAL TOPMARKS (SINGLE OR DOUBLE) (See figure 1)

The vertical height of a cone from base to apex should be about 90% of the base diameter (i.e. nearly equilateral).

For cardinal marks, the separation distance between cones should be about 50% of the base diameter.

The vertical clear space between the lowest point of the topmark and all other parts of the mark should be at least 35% of the base diameter of the cone.

POSITIONS AND DIMENSIONS OF TOPMARKS

FIG. 1.
(para 2·4·3)

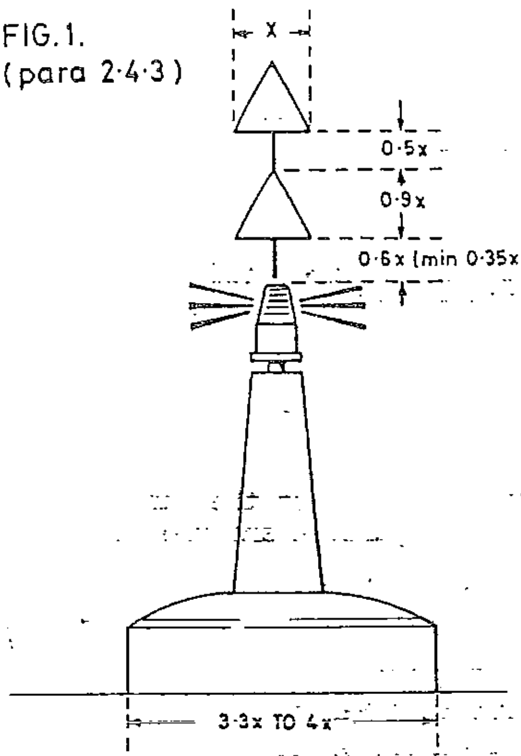


FIG. 2.
(para 2·4·4)

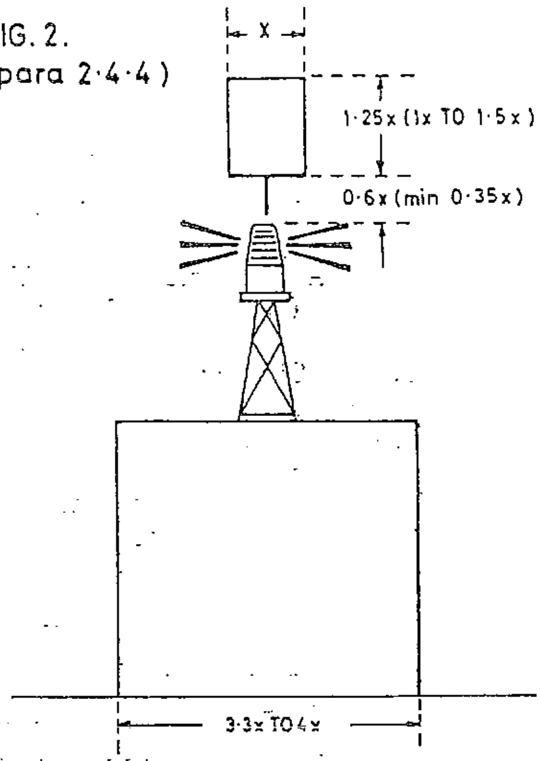


FIG. 3.
(para 2·4·5)

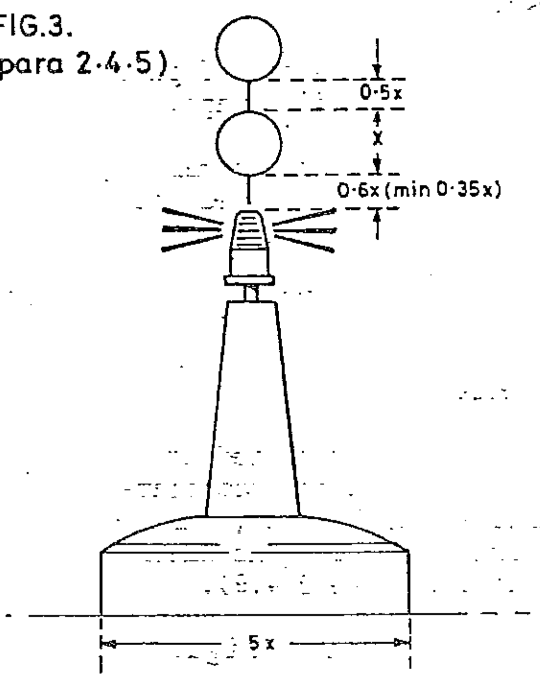
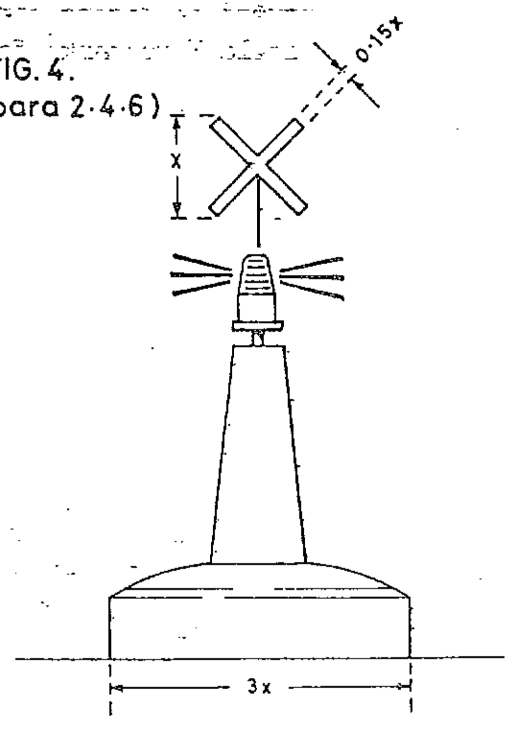
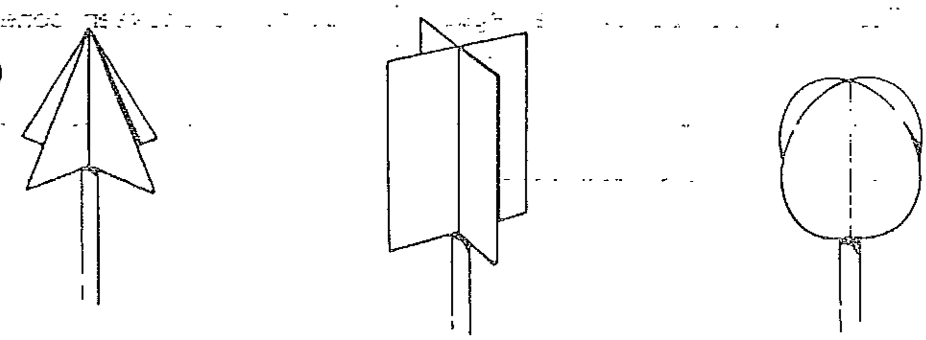


FIG. 4.
(para 2·4·6)



CONSTRUCTION OF TOPMARKS USING PLANE SECTIONS

FIG. 5.
(para 2·4·8)



In the case of a buoy, the base diameter should be 25%-30% of the diameter of the buoy at waterline.

2.4.4 CYLINDRICAL (CAN) TOPMARKS (see figure 2)

The vertical height of a cylinder should be 1-1.5 times the base diameter.

The vertical clear space between the lowest part of the cylinder and all other parts of the mark should be at least 35% of the diameter of the cylinder.

In the case of a buoy, the base diameter of the cylinder should be 25%-30% of the diameter of the buoy at the waterline.

2.4.5 SPHERICAL TOPMARKS (see figure 3)

For isolated danger marks the separation distance between spheres should be about 50% of their diameter.

The vertical space between the lowest part of the sphere(s) and all other parts of the mark should be at least 35% of the diameter of the sphere(s).

In the case of a buoy, the diameter of the sphere(s) should be at least 20% of the diameter of the buoy at the waterline.

2.4.6 "X" (DIAGONAL CROSS) TOPMARKS (see figure 4)

In the case of a buoy, the arms of the "X" should be diagonally contained within a square with length of side of about 33% of the buoy diameter at the waterline. The width of the arms of the "X" to be about 15% of the length of side of the square.

2.4.7 RECOGNITION RANGE OF TOPMARKS

The recognition range of a shape depends upon a number of factors (see 2.3.3).

In the case of a topmark of spherical, conical or cylindrical shape with height equal to diameter, the recognition range with the naked eye may be roughly estimated as being 500 times the height of the sphere, cone or cylinder.

In the case of an "X" topmark the recognition range will be very low due to its lack of surface area. Such a topmark is however useful for close quarters identification.

2.4.8 MATERIALS AND CONSTRUCTION METHODS

Because topmarks are high above the waterline, these assemblies should be as light as possible, but of adequate strength to prevent them from being damaged by natural forces. They are also liable to damage when a buoy is being placed on, or removed from, station. They should be easy to renew and cheap to manufacture. Topmarks can cover a large storage area, a factor which must be taken into account when considering their construction.

Topmarks may be manufactured from a number of materials, e.g. :

Plastic, using medium density polythene and moulded to shape using a rotational moulding process

Glass reinforced plastic (GRP) moulded to required shape

Light metal frame infilled with marine plywood battens and formed to required shape

Perforated aluminium alloy formed to required shape.

Topmarks may also be manufactured from the above materials but made from plane sections assembled in such a way as to give the appearance of a solid body, e.g. 2 triangles, 2 rectangles or 2 circles at right angles to one another (figure 5).

2.4.9 EFFECT OF TOPMARKS ON BUOY BEHAVIOUR

A very large topmark has the advantage of being readily indentified. Its disadvantages are the increased weight and wind resistance. With the centre of gravity of this assembly well above the waterline, these two factors combining will alter the stability of the buoy causing it to ride at an angle.

A small topmark cannot be so easily identified and its physical dimensions are unlikely to have any great effect upon the buoy's stability.

Therefore, when designing a new buoy or adapting an existing buoy, it will be necessary to reach a compromise between the two extremes.

2.4.10 COLOURS AND PAINTS

The surface colours of black, red, green and yellow used on topmarks should conform to the recommendations laid down in paragraph 2.2.

SECTION 3. THE RECOGNITION OF MARKS BY NIGHT

3.1 GENERAL

The IALA Maritime Buoyage System (rule 1.3) states that the significance of a mark by night depends upon the colour and rhythm of the light. This section discusses these features and the means of achieving them.

3.2 COLOURS OF LIGHTS

3.2.1 COLOURS IN USE

The colours of lights provided in the IALA System are red, green, white and yellow. The colours red and green for lights are reserved exclusively for lateral marks; white lights are used for cardinal, safe water and isolated danger marks; yellow lights are used solely for special marks.

All colours of lights should conform to the "IALA Recommendations for the colours of light signals on aids to navigation, December 1977" (reference 6.11).

3.2.2 COLOUR FILTERS

The normal way of producing red, green and yellow lights is by the introduction of glass or plastics colour filters over the light source, or by the use of self-coloured plastics lenses. Great care must be exercised over the choice of material for colour filters. It must be borne in mind that colour filters can reduce the luminous intensity of a white light to about 20-25% of its original value in the case of red, 20-30% in the case of green, and 60-75% in the case of yellow. However, the consequent reduction in the range of the light does not follow the decrease of intensity in a linear way. A graph showing the relationship between intensity and range can be found in the "IALA Recommendations on the determination of the luminous intensity of a marine aid-to-navigation light, December 1977" (reference 6.12).

3.2.3 COLOURED DISCHARGE TUBES

These tubes can be used for red, green and white lights. Their light intensity when no optic is used is limited to about 25 candelas corresponding to a nominal range of 3.5 nautical miles. However, they have outstanding vertical divergence which makes them suitable for use on buoys.

3.2.4 CAPACITOR DISCHARGE FLASH LAMPS

Capacitor discharge flash lamps, or flashtubes, create a flash of very high instantaneous intensity by discharging a capacitor to produce a controlled spark. The duration of the flash is generally around a millisecond, which creates problems reported as "lack of depth perception" under many viewing conditions.

However, if a signal red light is required, the bluish white light normally emitted requires special filters which results in a light of extremely reduced intensity.

For these reasons, they have not received widespread use as aid to navigation signal light sources.

3.3 RHYTHMIC CHARACTERS OF LIGHTS

3.3.1 SELECTION OF RHYTHMIC CHARACTERS OF LIGHTS

Although the IALA System lays down the basic rhythmic characters of lights to be used, there is still a wide range of choice left to the Lighthouse Authority in assigning a specific character to each lighted aid.

Light characters must be selected in strict conformity with the "IALA Recommendations for the rhythmic charracters of lights on aids to navigation, April 1982" (reference 6.2). This publication devotes an appendix to the rhythmic characters of lights used in the Maritime Buoyage System.

3.3.2 STANDARDISATION OF CHARACTERS

Authorities should bear in mind the need to limit the number of light characters used in their Service to an extent compatible with the need for reliable identification of a mark by the mariner. The use of an unlimited number of characters will lead to spares and maintenance problems (see also paras. 1.4.1 and 1.4.2).

Special attention is drawn to the undesirability of using fixed lights on aids to navigation. Such lights are very easily confused with those carried by vessels in accordance with the International Regulations for the Prevention of Collisions at Sea. Furthermore, fixed lights are very difficult to distinguish against background lights along a coast or in a port area.

3.4 LIGHTED BUOYS

3.4.1 GAS BUOY LIGHTS

The gases in use today are acetylene, propane, butane or a mixture of propane and butane.

Although flammable and explosive, acetylene, propane and butane can be handled safely provided that appropriate safety precautions are followed. Personnel engaged on servicing gas lights must have suitable training.

Care should be taken to ensure that the pilot flame adjustment is correct and that the lantern design will accommodate high wind or sea conditions likely to cause extinguishing of the pilot flame.

Acetylene Gas

Acetylene generates a white light with an open flame burner, the light intensity can be increased by the use of a cluster of burners or by a mantle. However, mantles are shock sensitive and liable to fracture due to the motion of the buoy.

The acetylene is dissolved in acetone diffused within a porous silicate mass under high pressure. Acetylene, having a much higher storage pressure than propane or butane, needs much stronger and heavier containers than other gases, and thus the energy per unit gross weight is lower for acetylene bottles than for those of other gases.

The acetylene gas used in aid to navigation lights must be of a high degree of purity, otherwise the jets will tend to clog up and extinguish the flame.

Propane and Butane

Propane and butane use a mantle burner to generate a bright white light. These mantles are, however, sensitive to shock.

The storage of propane and butane is easier than acetylene. They can be contained in bottles and can even be contained within the buoy body itself without the need for separate containers.

The properties of propane and butane are very similar to one another, except that the pressure of propane is higher for a given temperature, and that butane condenses when used in ambient temperatures near to freezing and can be used only in tropical or subtropical zones.

Sometimes a mixture of two gases may be used in certain lighting applications.

Gas Flashers

Traditionally gas lights have produced their rhythmic light characters with mechanical flashers activated pneumatically by the gas and these have been found to be very reliable.

Means have been introduced recently whereby the gas valve is operated from a small battery using an electronic flasher which has the facility of offering a change to any rhythmic character whilst utilising the one basic mechanism.

Similarly the gas light can now be initiated according to conditions of daylight by photoelectric means.

3.4.2 ELECTRIC BUOY LIGHTS

For some years electric buoy lights have been powered by primary cells and rechargeable type cells but means are now available for the battery to be recharged aboard the buoy using solar cells, wind and wave, or tidal current energy conversion.

Low voltage electric operation requires few safety precautions. The weak points in electric lanterns are the service life of lamps and sensitivity of all electric contacts to corrosion.

These weaknesses can be countered by the use of double filament lamps or lamp changers and extensive sealing of all parts of the equipment. However, the sealing can limit the ventilation which may be necessary for batteries.

- Primary Batteries

Without doubt, primary batteries are raliable and are the most simple to use. However, they are expensive, and new environmental laws in most countries insist the used primary batteries be disposed of in a specified way. The spent batteries have to be brought ashore and the cost arising from battery disposal must be taken into account.

- Rechargeable Batteries

These batteries can only be used on buoys where they can be easily exchanged or where there is a reliable method of recharging them on site. New methods of recharging batteries on buoys are being developed in many countries. Proper ventilation must be arranged to prevent an accumulation of hydrogen gas generated during the charging process, however, very great care is needed to exclude water and excessive moisture from battery compartments.

- Renewable Sources of Energy

Batteries can be recharged by the use of renewable sources of energy, and some wind generators and wave generators are in operational use on buoys.

Solar cells are successful as a source of power for aids to navigation. However, there can be a drop of efficiency due to pollution of solar panels by salt, guano or wind drifted particles. Abrasion by sandstorms and corrosion can also be troublesome.

With regard to the use of solar cells on buoys, care must be taken to avoid damaging them during handling operations, and there are additional special problems in latitutes greater than 45° North or South.

3.4.3 VERTICAL DIVERGENCE OF BUOYS LANTERNS

Adequate vertical divergence of lighting apparatus on buoys is particularly important to compensate the movement of the buoy and to ensure observation over a varying angle of observation according to the size of the vessel and its proximity to the buoy.

In general, gas lanterns provide an acceptably wide vertical divergence, because this divergence is a function of height of light source and focal distance, and with the relatively large burner mantle or flame this is readily achievable. Conversely, some electric buoy lanterns provide inadequate vertical divergence due to the relatively compact light source. Care should be taken to ensure that this divergence is adequate either by limiting the lens focus or by selecting equipment in which artificial vertical divergence is built into the lens design itself. However, at a given lamp power, and thus energy consumption, this inevitably leads to a reduction in maximum light intensity.

In assessing the vertical divergence required, care should also be given to choosing a buoy design which has good floating stability and riding qualities compatible with its location.

3.4.4 DEGRADING OR LANTERN GLAZING

One should consider to what degree ageing and pollution of the lantern glazing reduce the light intensity given in the original specification. This phenomenon should be taken into account when calculating luminous ranges. Some authorities use a reduction factor of 0.75 in the light intensity to allow for ageing or pollution.

3.4.5 RELIABILITY OF LIGHTING EQUIPMENT

It is rather difficult to compare the reliabilities of different lights on buoys. The reason for this is that most lighthouse authorities restrict the possible methods of light operation to one or two, because of standardisation, tradition or the special circumstances within each country.

In recent years, the IALA Technical Committee on the Reliability and Availability of Aids to Navigation started investigations into this problem. One of the first steps has been to analyse failure data from lighted buoys in the approaches to six major ports in Europe and the USA. This analysis showed that acetylene-operated buoys with open flame burners had the highest reliability, followed by electric operation and then propane.

However, it can be said that acetylene, propane and electric lights are all capable of a high standard of reliability. The reliability of any light probably depends as much on the quality of its design, manufacture, installation and maintenance as on its energy source.

3.4.6 COMPARATIVE COST OF OPERATION

Before carrying out any comparison of cost between gas and primary battery operation, several assumptions have to be made.

a) That the "bare body" costs of the buoy are the same for each type and that the relevant equipment fits within it.

b) That the normal maintenance and repair costs are of the same order and do not play a decisive role.

If the above assumptions are accepted, the comparison cost of operation can be confined to comparing :

- the capital expenditure on the lighting equipment;
- the annual energy costs;
- the cost of replenishing the energy source at sea.

With regard to capital expenditure, electric lanterns using primary batteries have considerable cost advantages over gas lanterns, especially when short range equipment is required. However, if the capital expenditure for the lantern is amortized over a number of years, and the annual energy costs are included in the calculation, gas operation tends to be cheaper than electric in the long term. This is particularly true where lights of higher intensity and high light/dark ratios are required. The reason is that gas is cheap compared to batteries.

If only short luminous ranges are required and rhythmic characters of a low light/dark ratio can be used, the cost of the energy does not play a decisive role. In this case the initial capital cost advantages lead to electric operation being more advantageous.

With regard to the replenishment of the energy source, modern anticorrosion techniques permit buoys to be left on station for periods of up to 4 years depending on the environmental conditions. However, other important considerations such as fading of surface colours, ice flow, mooring wear, overhaul of lighting equipment, etc... lead many lighthouse authorities to limit the service period to 1-2 years.

The most efficient operation would be to match the period for the necessary replenishment of the energy source with the normal service period that the buoy remains on station.

An alternative to replenishing gas containers or batteries at sea is the installation of more energy in the buoy. However, more energy installed inevitably leads to larger buoys and to higher initial and maintenance costs. When one considers the total cost of running a Lighthouse Service, the cost of the energy consumed by the lights represents only a very small fraction of the total.

3.5 LIGHTED BEACONS

Although many of the problems relating to maintaining lighted buoys on station are applicable to lighted beacons, in most cases they are generally much easier to solve.

The choice of energy source can be much wider, gas can easily be used with mantle burners, mains electricity may be avalaible or locally generated on site.

With the availability of a fixed structure, the use of wind generator, or solar panels becomes much easier and effective.

Very often plenty of space is avalaible and more energy in the form of gas bottle or batteries can be stored.

The need for wide vertical divergence with consequent loss of intensity is largely overcome, as the light can be aligned as required.

3.6 CONCLUSION

An authority contemplating the introduction of new lighted buoys has many factors to take into consideration. In particular, the choice of energy source depends on many features: technical, financial and availability of personnel capable of carrying out the necessary maintenance.

However, it is essential that the navigator must be satisfied with the end result. His requirements for lights are :

- absolute reliability;
- adequate range, particularly in restricted visibility;
- positive identification of light character even under heavy movement due to wave action;
- rhythmic light characters that are conspicuous and easy to recognise.

Reliability depends on high quality equipment carefully and regularly maintained.

Normally the navigator requires long luminous ranges so that he may locate the course of the waterway ahead and, in particular, to observe dangerous areas in good time. Exceptions exist in areas where several channels are closely adjacent to one another and in narrow and frequently curving channels, which require short distances from buoy to buoy. In these cases, long luminous ranges in extremely clear weather conditions can lead to confusion.

Adequate vertical divergence of the light is essential for positive identification of the light character, particularly if the buoy is heeled by wind and sea. Buoy lanterns with narrow beams cause problems in this way.

Difficulty in storing sufficient energy in a buoy tends to lead an authority into restricting itself to energy-saving rhythmic light characters, requiring greater concentration on the part of the navigator. However, in the interests of traffic safety, characters with a high repetition rate and good light/dark ratio should be offered to the navigator wherever appropriate.

SECTION 4. THE RECOGNITION OF NAVIGATION MARKS BY RADAR

4.1 INTRODUCTION

Safe radar navigation in coastal waters depends not only on a powerful shipborne radar but also requires radar aids that clearly mark the waterway or channel on the radar display. Buoys or beacons usually constitute poorly reflecting targets. To enhance their radar function these aids have to carry a radar "payload" in the form of either a radar reflector or a radar beacon (racon).

A radar reflector is a passive device which enhances the echo of a target by increasing its radar cross section (also called echoing or backscatter area). The main objectives of its use are

- improved target detection at long ranges (for example landfall navigation)
- improved target detection in areas of sea or rain clutter.
- As a by-product, improved protection of these aids against damage by collisions.

On the other hand, a radar beacon is an active (i.e. electronic) device. It also provides an enhanced target signal but its prime function is target identification. A radar beacon is a much more expensive device than even the best radar reflector and it requires a power supply. Furthermore, the benefit of target identification and possible longer ranges are reduced to some extent by drawbacks like interference and clutter.

The use of radar beacons is therefore restricted to locations where a particular operational need exists. Thus, both the radar reflector and radar beacon have their own specific field of application.

The following sections deal with the main technical and operational features of both devices. Further information on this subject can also be found in the IALA Manual on Radio Aids to Navigation (reference 6.13).

4.2 RADAR REFLECTORS

Basically three parameters determine the radar performance of a target equipped with a radar reflector:

- the type of the reflector
- its size and
- its height above water level.

For an effective use of a radar reflector, minimum requirements have to be established for these parameters.

4.2.1 TYPES OF RADAR REFLECTORS

From a radar point of view a radar reflector is sufficiently characterized by its radar cross section (RCS), for a given size or diameter, and by the angular coverage depicted by its backscatter diagram.

Since the radar reflector should give a strong return regardless of the target's attitude at sea, the required angular coverage is closely related to the floating stability of the target. Consider a buoy rolling at sea with a maximum heeling angle of ± 20°, for example. Then, the backscatter should not only have a total coverage in the horizontal plane (omniazimuthal characteristic) but should also extend up to at least ± 20° in the vertical plane (omnidirectional or three dimensional characteristic).

A vertical coverage of approximately ± 15° is sufficient for targets of high floating stability, whereas a coverage of ± 30° or even more is required for targets of poor stability.

The choice of radar reflectors is between two entirely different types of reflectors. One type is the Luneberg lens, the other the corner cluster.

A Luneberg lens is basically a spherical lens made up of a number of concentric shells of foam material and covered by a thin layer of glass reinforced plastic (GRP) for protection. Luneberg lenses have an equatorial ribbon of aluminium as a reflecting element.

On the other hand, a corner cluster is a metallic reflector comprising up to 20 or more corner reflectors in various configurations.

The fundamental property of either reflector type is its ability to concentrate the incident radar energy back in the direction of the interrogating radar rather than to scatter it in a broad solid angle.

A prominent feature of the Luneberg lens is its uniform omnidirectional backscatter characteristic up to a tilt angle of approximately ± 15° (reference 6.14).

The phenomenon of multipath propagation can be very pronounced across the sea and can affect the reflections from radar reflectors. If it did not occur, a Luneberg lens would provide a constant non-fading echo. However, the Luneberg lens has some major drawbacks which have to be taken into consideration when using it:

- it is less rugged than corner clusters. Humidity may penetrate into the foam body and reduce its effectiveness.
- the RCS of commercially available Luneberg lenses are limited to rather small values (in the order of $10m^2$) not sufficient for applications under heavy sea conditions or at long ranges.
- the price of the lens per square meter RCS is comparatively high due to the delicate fabrication process.

For these reasons, the vast majority of radar reflectors used in the maritime field are corner clusters.

Three examples of corner clusters are illustrated in Figs. 6 to 8. Their backscatter diagrams show the variations of the RCS vs. azimuthal angle in a logarithmic scale. To give an indication how the RCS varies in the vertical plane, two backscatter diagrams are presented for each reflector with tilt angles of 0° and 15° respectively.

The simplest of all corner clusters is the octahedron, an 8-corner cluster. It is made up of three metal plates all intersecting at right angles. In Fig. 6a one of several possible mounting attitudes is shown. The backscatter diagram exhibits broad gaps ("hollows") of low reflectivity in the horizontal plane (Fig 6b) as well as in the vertical plane, resulting in a small mean value of the RCS.

A more sophisticated cluster is the 10-corner cluster shown in Fig. 7a. There are no broad gaps in the backscatter diagram of this type but the diagram has a spikey nature due to interference effects between the main lobes of adjacent corner reflectors. The average RCS of the 10-corner cluster is also quite low since it is composed of relatively small corner reflectors.

The 6-corner cluster, shown in Fig. 8a (references 6.15 and 6.16) in two different versions, yields the best results with respect to angular coverage and RCS but its construction is somewhat more complicated and expensive than those discussed before.

This corner cluster comprises 6 asymmetrically enlarged corner reflectors in a specific configuration. It can be effectively used on targets with a maximum heeling angle of approximately ± 30°. Beyond the value the RCS drops off rapidly. This also applies to the 10-corner cluster of Fig. 7a.

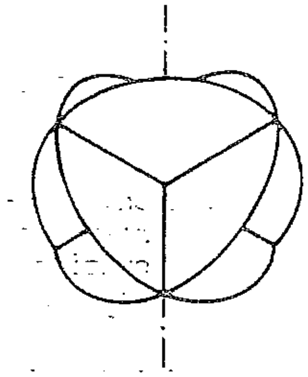
For applications requiring a broader vertical coverage as, for example, with spar buoys under conditions of strong currents and heavy seas, the octahedron should be chosen (more information about the performance of various types of reflectors is given in references 6.15 and 6.16).

4.2.2 REFLECTOR SIZE

The next parameter which needs careful consideration is the size of the reflector. The size, in conjunction with the type of the reflector, determines the RCS, which in turn determines the maximum possible range and target visibility in clutter.

The RCS is extremely sensitive to changes in the size of the reflector. Theory shows that the RCS increases with the fourth power of the reflector diameter, no matter what reflector type - corner cluster or Luneberg lens - is used. For example, doubling the diameter yields a 16 times larger RCS but the increase in range is not linear as can be seen in table 2. From this relation between RCS and diameter conclusions of practical importance can be drawn:

Firstly, the largest possible reflector diameter should be used. Small units are ineffective.



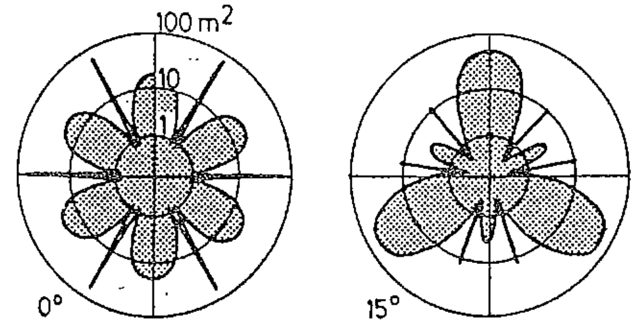
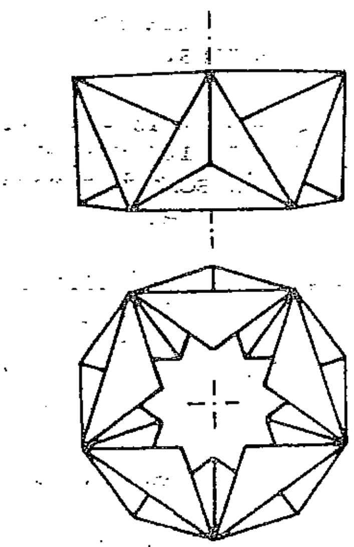


Fig. 6 a) Octahedral reflector

b) Backscatter diagrams at heeling angles of 0^{0} and 15^{0}



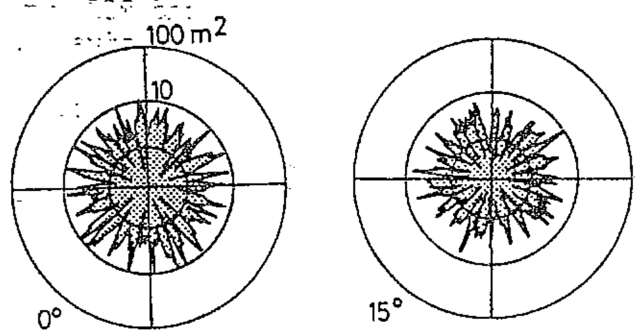
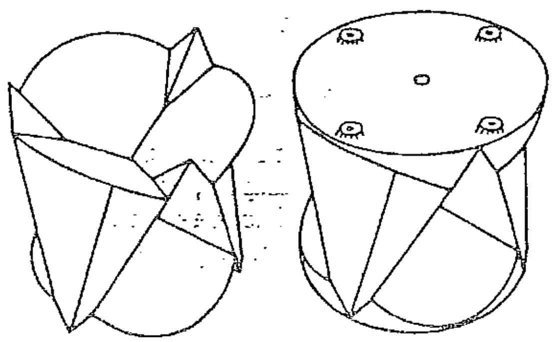


Fig. 7 a) 10-Corner cluster

b) Backscatter diagrams at heeling angles of 0^{0} and 15^{0}



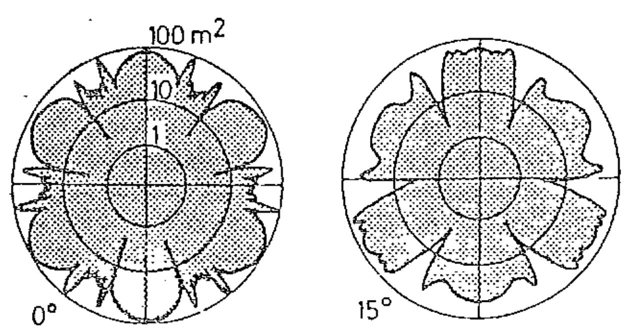


Fig. 8 a) 6-Corner cluster

b) Backscatter diagrams at heeling angles of 0^{0} and 15^{0}

Secondly, a corner cluster comprising a large number of small corner reflectors is substantially inferior to a cluster of the same diameter made up of a smaller number of larger corner reflectors. This is clearly demonstrated by the two corner clusters of Figs. 7a and 8a. Their backscatter diagrams are based on identical diameters of 0.5 m to allow a direct comparison.

When small targets like buoys are fitted with radar reflectors, practical considerations limit the extent to which the reflector can be enlarged. Design parameters like shape of the target, floating stability, maximum top load, buoyancy and windage have to be taken into account for an optimum overall design. To give an indication of what reflector diameter is required from a radar point of view, some data are compiled in Tables 1 and 2. For example, for a long range of 10 nautical miles or when severe sea clutter prevails a reflector diameter of approximately 1 m is recommended.

Table 1

sea clutter	required RCS at X-band	required diameter of reflector
low	$\geq 10\ m^2$	0,3 - 0,4 m
moderate	$\geq 100\ m^2$	0,5 - 0,7 m
severe	$\geq 1000\ m^2$	0,9 - 1,2 m

Table 2

radar range (nautical miles)	required RCS at X-band	required diameter of reflector	required height of reflector †)
3	$\geq 10\ m^2$	0,3 - 0,4 m	1 - 2 m
5,5	$\geq 100\ m^2$	0,5 - 0,7 m	2 - 4 m
10	$\geq 1000\ m^2$	0,9 - 1,2 m	4 - 8 m

†) ship's antenna height assumed to be between 10 and 20 m

The figures of Tables 1 and 2 apply to X-band radars (λ = 3,2 cm) only. For S-band radars (λ = 10 cm) the RCS of corner clusters or Luneberg lenses drops by a factor of 10. This reduction in performance is not as serious a problem as one might expect, since S-band radars are usually more powerful than X-band radars and less affected by sea clutter.

A more critical loss in performance occurs when circular polarisation is employed instead of horizontal or vertical polarisation in order to reduce rain clutter. Only a weak signal is received, if any. This is a further reason to specify the largest possible reflector size.

4.2.3 REFLECTOR HEIGHT

The final parameter to be considered is the reflector height above sea level. As is well known from visual target detection at long ranges, the target and/or observer heights have to be increased with increasing range due to the curvature of the earth. The range in nautical miles of the optical horizon is given by the formula:

$$R_{opt} \approx 2.1\ (\sqrt{H_t} + \sqrt{H_o})$$

where H_t = target height and

H_o = observer height, both in meters

This formula can also be used for a rough estimation of the radar horizon. The observer and target heights have to be substituted by the reflector and antenna heights respectively.

It should be noted that this formula results in values for the radar range that are too optimistic under normal atmospheric conditions. For a conservative range estimation only 60 to 90% of the optical range should be used.

Hence $R_{radar} \approx 0{,}6 \ldots 0.9\ R_{opt}$

This considerable reduction in range is caused by the strong interference effect of the multipath propagation across the sea.

Under the assumption of a ship's antenna height between 10 and 20 m, the reflector heights necessary to obtain specified ranges have been listed in Table 2. Again, these figures apply to X-band radar only. S-band radars are far less capable of detecting targets near the water surface owing to their longer wave length. This fact has one important advantage, but at the same time it also has an important disadvantage. The waves of a rough sea cause less sea clutter but, on the other hand, the reflector height has to be increased by a factor of 2 to 3 for an equal probability of detection. Such a substantial increase in reflector height cannot be implemented in most cases, especially when small targets like buoys are involved.

4.2.4 INSTALLATION OF RADAR REFLECTORS

Problems of design and installation of radar reflectors usually emerge if restrictions exist with respect to weight, size, shape, etc. A typical example of this situation is the incorporation of a radar reflector into the superstructure of a light buoy. Two alternative solutions are possible: installation of the radar reflector above or below the lantern.

If the radar reflector is mounted on top of the lantern it must be integrated into the topmark in order to avoid any confusion with the topmark itself. This results in a small reflector size and subsequently in a very small radar cross section as has been stated in para. 4.2.2. Therefore this solution is not recommended.

A much better solution is to install the radar reflector below the lantern though the reflector height above waterlevel is somewhat lower. A considerably larger and more effective reflector can be used. In addition, the reflector can be designed as an integral part of the superstructure so that the shape and the floating stability of the buoy are not adversely affected and the radar reflector is protected from damage.

4.2.5 SOME REMARKS OF PRACTICAL IMPORTANCE

To avoid problems in the design and application of radar reflectors (corner clusters) some additional remarks of practical importance are given in paras. 4.2.6 to 4.2.9.

4.2.6 REFLECTOR MATERIAL

Usually corner culsters are manufactured from plates of steel or aluminium. But any other material of high electrical conductivity can be employed as well. From a radar point of view only a thin metallic layer is required for a perfect reflection. Thus, a plastic material like GRP with a metallized surface or with a metallized nylon mesh embedded in it yields similar good results.

4.2.7 SURFACE PROTECTION

In a marine environment most metals require a surface protection against corrosion. Thin layers of paint which are directly applied for this purpose to the reflecting surface do not degrade the performance of the radar reflector. This situation is entirely different if a radome is used as a protective cover. A serious loss in performance occurs if the radome is not properly designed. Important design parameters of the radome are the radome material and its wall thickness with respect to the frequency band used.

4.2.8 TOLERANCE REQUIREMENTS

As with all types of cluster reflectors the individual reflecting elements (i.e. the corner reflectors) have to be manufactured to close tolerances, otherwise the reflected wave will diverge from the exact direction back to the illuminating radar. For best results all three plates of each corner reflector must be perfectly flat and the corner angles must be exactly at right angles. In a production process some deviations are unavoidable and result in a certain loss of performance. Unfortunately, the allowable angular tolerance and deviations from perfect flatness become smaller as the size of the reflector gets larger.

The following angular tolerances should not be exceeded

reflector diameter	maximum angular tolerance
0.5 m	± 1 to 2°
1	± 0.5 to 1°

Even under these conditions a noticeable loss of performance can occur if all tolerances of a corner reflector accumulate (all tolerances of the same sign).

4.2.9 APERTURE BLOCKING

If only one plate of a corner reflector is substantially masked by an obstacle, the total corner reflector is rendered ineffective (the radar wave "bounces" three times, once on each plate of the corner reflector, before returning back to the radar). Therefore care should be taken that constructional elements passing in front of the reflector do not cause a serious degradation of the performance. The projected area of these elements should be small compared with the size of corner reflector.

4.3 RADAR BEACONS

4.3.1 GENERAL

A radar beacon (racon) is a receiver-transmitter device which, when triggered by a marine radar automatically returns a distinctive signal which can appear on the display of the triggering radar. The beacon signal may provide range, bearing and identification information.

Though from a technical point of view a radar beacon is a transponder device, a clear distinction is made between the terms "radar beacon" and "transponder" with respect to their operational use. A radar beacon is a device which is exclusively used as an aid to navigation, whereas a transponder serves for ship to ship and ship to shore identification and information exchange. For shipborne transponders separate frequency bands have been allocated outside the two marine radar bands X- and S-band. At present most radar beacons operate in the X-band.

4.3.2 BASIC OPERATION

A radar beacon comprises three main components: a receiver, a transmitter and an antenna common to both the receiver and transmitter.

A radar within the range of the beacon interrogates the beacon during the recurrent time intervals the radar antenna points towards the beacon.

The beacon receiver amplifies the radar pulses up to a level that triggers the beacon transmitter. The transmitters might reply with a single pulse for each trigger but more usually the response consists of a series of coded pulses (Morse code) for beacon identification.

After triggering, a finite time must be allowed for the beacon to respond. This results in a transmission which is delayed in time (and range) with respect to the passive echo of the target on which the beacon is mounted.

The delay is generally equivalent to a range of less than 100 m and can therefore often be neglected at ranges greater than a few nautical miles.

The type of beacon in most common use today (1982) is the swept frequency beacon which has been available for some time, and is simple and rugged.

Its transmission frequency is periodically swept through the radar band in an adjustable time. Only when the frequency passes through the narrow bandwidth of the radar receiver is the beacon signal presented on the radar display, resulting in a short presentation time (1 to 3 antenna scans) and a long update time.

4.3.3 OPERATIONAL USE

Though radar beacons offer a unique possibility of positive target identification, their use should be limited to those situations where a particular operational need has been established. An uncontrolled proliferation of radar beacons generally could lead to an unacceptable increase in responses being presented on a ship's radar display, thus degrading the usefulness of the display and causing confusion among multiple beacons and other responses.

Radar beacons may only be mounted on fixed structures or floating aids, anchored at fixed positions, to serve as aids to navigation. Under no circumstances should radar beacons be used to enhance the detection of marine craft.

The use of radar beacons is recommended for the following purposes (reference 6.17) :

1. ranging on and identification of positions on inconspicuous coastlines;
2. identification of positions on coastlines which permit good ranging but are featureless;
3. identification of selected aid to navigation marks both seaborne and land-based;
4. landfall identification;
5. as warning devices to identify temporary navigation hazards and to mark new and uncharted dangers.

If local conditions require, two further uses are possible :

6. to indicate navigable spans under bridges;
7. as leading beacons in narrow channels.

For the identification of offshore structures, special types of radar beacons should be used, for example fixed frequency beacons, which are now available to order. It must be said that the question of fitting radar beacons to offshore structures is still a matter of considerable discussion internationally.

4.3.4 LIMITATIONS OF RADAR BEACONS

The lighthouse engineer should be familiar with at least the major limitations of radar beacons to make effective use of them. A sufficient knowledge of the limitations also helps in selecting the type of beacon best suited to the application.

These limitations are caused by

- interference due to antenna side lobes
- interference caused by mutual masking of beacon signal and radar echos
- long update time

- occasional beacon overload.

4.3.5 SIDELOBE INTERFERENCE

A large portion of the interference problem is a result of the sidelobes of the radar antenna. Consider a radar beacon at such a range that its response is received only by the main beam of the radar antenna. As the distance lessens the intensity of the received beacon signal increases considerably. At short ranges the signal strength may be strong enough to be also received by many of the sidelobes of the radar antenna, thus widening the response on the radar display. In the event that a ship passes very close to a racon, the response on the display could appear as continuous circle. In this zone of interference it is almost impossible to detect other targets.

Some counter measures are generally available which help to overcome or at least reduce this kind of interference

- selection of a beacon site sufficiently far from the shipping route

- reduction of beacon sensitivity (and output power) at the expense of beacon range

- a non-continuity at the interrogating frequency operating radar beacon. A time modulation is automatically provided with a slow sweeping beacon due to its long update time

- use of sensitivity time control (anti clutter control) and Fast Time Constant (or differentiation) control on the radar set on board the ship. This will only give some relief of the interference problem since weakly reflecting targets are also adversely affected

- application of a sidelobe suppression technique to the radar beacon. An effective sidelobe suppression technique enables the beacon to respond only to interrogations which are radiated by the main beam of the radar antenna.

4.3.6 MUTUAL MASKING

It is obvious that the superposition of both the beacon and the radar signal on one display can cause considerable problems of mutual masking at certain times. On the one hand the beacon signal may mask radar echos of small targets especially when sidelobe triggering occurs (case 1). On the other hand strong radar echos, for example ground or sea clutter, may mask the beacon signal (case 2).

As mentioned before, a time modulated beacon operating at the interrogating frequency improves the situation in case 1. In case 2, the most common method currently being proposed to prevent masking is the use of a beacon operating on a frequency different from the interrogating frequency.

3.4.7 UPDATE TIME

A long update time is often acceptable for long range navigation since the navigator obtains sufficient information about the beacon position even when he is not watching the radar display continuously.

But under critical navigation circumstances, i.e. at short ranges, in congested areas and under conditions of heavy sea and rain clutter, an update time of the order of 1 min or more is considered too long. For this reason efforts have been made to develop radar beacons with significantly higher update rates (See para 4.3.5).

4.3.8 BEACON OVERLOAD

Beacon overload is normally of very little importance, but an overload or saturation condition may occur, if the radar beacon is interrogated by an excessively large number of radar pulses in a busy area. Under this condition the beacon is no longer able to respond to each interrogation because a number of radar pulses coincide with the time the beacon is in the transmission mode. This time consists of the transmission time and the blocking time (recovery or dead time after transmission). For operation in congested areas the radar beacon should no exceed a transmission time of about 25 μs (pulse length about 2 nautical miles) followed by a blocking time of 50 to 100 μs. A minimum blocking time of at least 10 μs is required to avoid triggering the beacon by near-by reflections of its own transmissions.

It is also possible for the interrogations from two ships to occur in such a manner that a reply is sent only to one ship because the interrogations from the second occur during the response time. This is known as capture and can occur when no other ships are present. It is not the same as overloading where a number of ships is concerned.

4.3.9 BEACON CATEGORIES

The majority of beacons presently in use employ broad band crystal video receivers covering the whole radar band. Some beacons under development however now use a superheterodyne receiver when an improved range is required. They are automatically triggered by pulses of any radar operating in the appropriate radar band. However, great differences among radar beacons exist with respect to their method of transmission. Current radar beacons can generally be categorized in two ways by their transmission modes:

- beacons responding on the radar frequency and
- beacons responsding on a frequency different from that of the interrogating radar.

Two beacon types belong to the first category:

- sweept frequency beacon type using a slow sweep, fast sweep and stepped sweep
- frequency agile beacon of the on-frequency type

and another two types belonging to the second category

- fixed frequency beacon
- frequency agile beacon using a fixed-offset-frequency mode.

A brief description of these beacons follows in paras. 4.3.11 to 4.3.15 Table 3 summarizes some operational and technical parameters of these beacons.

Table 3. Types of radar beacons currently available (1982)

	swept frequency beacon			frequency agile beacon		fixed frequency beacon
	slow sweep	fast sweep	stepped sweep	on-frequency response	fixed-offset frequency response	
state of implementation	in use	in use	in use	in use	now available	now available
update time of beacon signal	long	short	medium	short	short	short
modification of radar set required	no	no	no	no	yes	yes
signal presentation on radar display	automatically				only when switched to beacon mode	
(prospective) operational use	uncharted temporary hazards and new dangers				charted navigational marks	
signal coding possible	yes	coding by groups of dots	yes	yes	yes	yes
complexity of device / relative price level	low	low	low - medium	high	high	low
power consumption	low	low	low	medium	medium	low

4.3.10 OPERATIONAL BENEFITS AND USES

Radar beacons of the first category (with the exception of the slow sweeping beacon) have primarily been developed to obtain a more frequent update of the signal presentation. On the other hand, the main objective for the development of beacons of the second category is the elimination of interference. From the explanations given in earlier paras., it has become evident that the interference problem can be eliminated by using a radar beacon that responds on a separate frequency. Another method using time delay of the beacon signal is under consideration, and further information on this is contained in reference 6.22. Both methods offer the additional advantage that the radar operator can choose among several display modes, viz:

- display of the beacon signal alone
- display of the radar signal alone
- mixed display of both signals either superimposed or presented in consecutive antenna scans.

However, the implementation of such a beacon service requires an appropriate modification of the shipborne radar set, and this modification has to be agreed upon on an international basis.

If the new service is introduced those radar beacons already in operation do not become altogether obsolete. Both beacon categories will have their own specific fields of application.

Beacons responding on the radar frequency will continue to be used for marking uncharted navigational hazards and new dangers because only their signals are automatically presented on the radar display.

Beacons responding on a separate frequency could be effectively used for indication of those navigational marks for which a-priori information exists, i.e. on charted marks, with the radar operator selecting the display mode at his option.

4.3.11 SLOW SWEEP RADAR BEACON

This beacon has already been descrived in para 4.3.2. In general, modern slow sweep racons have a sweep time of between 1 and 2 minutes. The number having a sweep time longer than this is very small.

4.3.12 FAST SWEEP RADAR BEACON

The transmission frequency is swept through the radar band very rapidly in a time of between 1 and 12 µs. For each interrogation between 4 and 50 sweeps are generated. Thus, the response on the radar display appears as a characteristic line of between 8 and 50 dots, in a time of between 5 and 50 µs.

In addition a form of coding can be applied by arranging the dots to be in groups; though at present no such code is used.

4.3.13 STEPPED SWEEP RADAR BEACON

The radar band is divided into 4 sub-bands each 50 MHz wide. Each sub-band is rapidly swept during a time interval of 7.5s. This results in a signal presentation of 7.5s and an update time of 30s. No coding is applied to the beacon.

4.3.14 FIXED FREQUENCY RADAR BEACON

The beacon transmitter operates on a preset frequency at the lower edge of the radar band where a narrow frequency band is allocated for this service. A modification of the shipborne radar set is required for the reception of the beacon signal. The signal update occurs continuously, i.e. in each antenna scan.

4.3.15 FREQUENCY AGILE RADAR BEACON

The frequency agile radar beacon is the most advanced but also the most expensive radar beacon. Two versions of this type exist :

- the on-frequency type which has already been developed and tested, and

- the fixed-offset-frequency radar beacon.

The frequency agile beacon is instantaneously tuned (i.e. within a fraction of a microsecond) to either the interrogating frequency (on-frequency type) or to a frequency shifted apart from the interrogating frequency by a fixed amount of about 50 MHz (fixed-offset frequency type). Owing to this fast tuning method the beacon signal appears on the display in each antenna scan.

The on-frequency type of beacon requires either a sidelobe suppression technique or a recurrent time interval of no operation in order to reduce interference effects due to sidelobe triggering at close ranges (see para 4.3.5).

A separate beacon channel has to be added to the shipborne radar set for the reception of the fixed-offset frequency beacon.

4.3.16 BEACON RANGE

The maximum range of a radar beacon is determined by several factors

- output power and sensitivity of the beacon, including antenna gain
- heights of the beacon and ship's antenna above water level.

The physical background for range determination is similar to that of a radar reflector. In particular, the range is limited by the radar horizon and affected by the multipath propagation of the radar wave.

A longer range requires a more powerful and sensitive radar beacon and a greater beacon height. Output power and sensitivity have to be matched to each other, since a high output power is entirely useless if the beacon is not sensitive enough to be triggered by a radar at the maximum specified range.

To give some indication about power and height requirements some figures are presented in Table 4.

Table 4

radar range (nautical miles)	required radiated output power	required height of beacon antenna †)
5	0.2 W	2 m
10	0.8 W	8 m
20	3.2 W	50 m
30	7.0 W	150 m

†) ship's antenna height is assumed to be 20 m.

The figures in Table 4 apply to X-band beacons only. For S-band beacons greater outpower powers and antenna heights are necessary.

The power figures of Table 4 already include the antenna gain:

radiated output power = transmitter ouput power x antenna gain.

4.3.17 BEACON ANTENNAS

The range of a radar beacon can be extended if an antenna of higher gain is selected. However, the type (and gain) of an antenna is usually determined by the kind of target on which the beacon has to be mounted.

A floating target requires an omnidirectional antenna with a broad vertical beamwidth. This antenna is inevitably a low gain antenna. On fixed structures narrow beamwidth (high gain) antennas can also be installed.

Some data about antenna characteristics and antenna gains are presented in Table 5.

Table 5

type of target	antenna characteristic horizontal	vertical	antenna gain
floating	omnidirectional	approx. ± 25°	approx. 3 (5dB)
fixed	omnidirectional	approx. ± 8°	approx. 10 (10dB)
fixed	sector of approx. 90°	approx. ± 8°	approx. 30 (15dB)

Radar beacons have to be fitted with horizontally polarized antenna to conform with the polarization of merchant marine radars.

4.3.18 BEACON CODING

For beacon identification, the response of a beacon may be coded using a Morse code letter. The beacon code should meet the following requirements:

- the code should normally commence with a dash for better recognition of the beacon position under condition of clutter

- the design of the beacon should permit the use of an additional three dots or dashes

- the Morse code letter "D" (- . .) is exclusively reserved to indicate new dangers, for example, a wreck.

- the total length of the beacon code should not exceed 20% of the nominal range of the beacon. However, the code length of a particular beacon will sometimes be determined by the range to which the shipboard radars interrogating it are likely to be set.

4.3.19 BEACON INSTALLATION

In most cases the installation of a radar beacon raises no problems owing to their small size, low weight and ruggedness. An important requirement is a "free line of sight" to all radars in the service area of the beacon. This means a sufficient beacon height above water level and no obstacles in front of the beacon antenna.

For beacon installations on light buoys a position on top of the lantern is recommended. Since not all equipment can be mounted uppermost on the buoy, care must be taken to avoid confusion between the racon and the topmark (when used), realizing that the racon's response is sometimes masked by supporting structures when it is not the highest mounted equipment. The power supply (primary or rechargeable batteries) can be incorporated into the buoy body.

If the beacon is used on a position where a stationary radar is operated the beacon should be fitted with an "inhibit" input to prevent the beacon from being triggered by this radar.

4.3.20 LITERATURE ON RADAR BEACONS

Further useful information on Radar Beacons can be found in references 6.18 to 6.22.

SECTION 5, THE RECOGNITION OF MARKS BY THE USE OF RETROREFLECTING FILMS

5.1 GENERAL

Retroreflection may be described as "Reflection in which light is mostly returned along or close to the path of incidence". Commonly this property is maintained over a wide range of angles of incidence of the light on the surface of the retroreflector. Thus retroreflection can be used to produce a significant increase in the night-time visual range of unlighted aids to navigation and also to improve the probability of identifying the aid provided that the observer is situated close to the projected light beam.

The benefits of retroreflection are available to any vessel that has some form of light projector, which may range from a hand-held spotlight to a powerful searchlight, but authorities should take into account the obvious difficulties that may arise if a large number of vessels make use of light projectors within a limited region. A useful introduction on this subject can be found in "Introduction to Retroreflectors" (reference 6.23).

Retroreflection may be provided by a single device, such as the reflector fixed at the rear of a bicycle, but is often provided by retroreflecting film (sheeting), which is a flexible sheet material. This material may consist of a mass of extremely small spherical glass beads (lenses) that are tightly packed on an underlying reflecting layer and with perhaps an overlying transparent film, or minute trihedric prismatic reflectors (cube-corner reflectors). This latter kind (corner-cube sheeting) is not at present much used for marine purposes.

The three main types of retroreflecting films available for use are :

- Enclosed lens films in which the lens system is totally encased within a plastics material. This type is sometimes known as "engineer grade sheeting".
- Encapsulated lens films in which the lens system is sealed behind a transparent face which may be clear or coloured. This type is sometimes known as "high intensity sheeting".
- Exposed lens films in which the lens system is totally exposed to the atmosphere. Since this type, unlike the enclosed and encapsulated types, is ineffective when wet and is prone to rapid deterioration with the accumulation of dirt and salt, it is particularly unsuitable for maritime applications (retroreflecting devices formed by dispositing glass beads on a wet painted surface are also unsuitable for the same reason).

The selection of a retroreflecting film for any given application should take into account the following factors which are discussed below :

1) Performance as a retroreflecting device

2) Colour appearance by day and by night

3) Durability

4) Installation conditions.

5.2 PERFORMANCE AND VISUAL DETECTION RANGE OF RETROREFLECTING FILMS

A measure of retroreflecting performance is given by the coefficient of retroreflection of the film; this is equal to the ratio between the film luminance in the direction of observation and the illuminance received from the light source.

The coefficient of retroreflection depends on the type of film used, the direction of incidence of the light and the direction of observation.

White retroreflecting films have higher coefficients of reflection than yellow films, and both have higher coefficients than black, blue, green or red films.

The visual direction range of retroreflecting films increases with the coefficient of retroreflection, but as shown in Table 6 below the increase is not linear.

Table 6 gives the visual ranges obtained with typical retroreflecting films of 0.3 m2 when the meteorological visibility is 4 km and under the following conditions ;

- observer close to the light beam projected (within an angle of 0.2°)
- angle of incidence less than 4° from the normal to the film.

Table 6

Type of film	Coefficient of retroreflection ($cd/lx.m^2$)	Visual range in metres using 650 cd spotlight	Visual range in metres using 200,000 cd searchlight
Engineer grades or red, green or blue high intensity	25 - 100	350 - 470	1,100 - 1,400
Yellow high intensity	100 - 200	470 - 540	1,400 - 1,550
Silver-white high intensity	200 - 300	540 - 590	1,550 - 1,650

The visual range of a retroreflecting film can be determined by using the nomograms given in Figs. 8A and 8B.

The coefficient of retroreflection of a film with encapsulated lenses (high intensity) is generally double or triple that of a film with enclosed lenses (engineer grade). In addition the films with encapsulated lenses are less sensitive to the direction of incidence. The coefficient of retroreflection of films with enclosed lenses is approximately 6 times less for an angle of incidence of 40° than for an angle of incidence of 4°, whereas the reduction factor is approximately 2 for films with encapsulated lenses. However, the improved night-time performance is sometimes accompanied by a darkening of the daytime colour appearance.

5.3 RETROREFLECTING COLOUR BY DAY AND NIGHT

The number of colours and shades of retroreflecting films readily available is limited and in some cases the daytime colour of a film is significantly different from its reflected colour at night :

- films appearing black by day appear white by night,
- films with exposed lenses reflect white by night, regardless of their daytime colouring,
- silver (white) encapsulated lens films appear grey by day and reflect white at night.

It must also be emphasized that retroreflecting films appearing to be either yellow or black by day cannot in practice be distinguished by night as they both appear to be nearly white. Thus a system utilising yellow and black bands or retroreflecting material for Cardinal marks is impracticable by night.

The legibility of letters or numbers made of retroreflecting films depends on their size and shape, and on the ratio of the brightness of the legend to that of the background. Manufacturers have great experience in this field and may give useful advice.

5.4 DURABILITY OF RETROREFLECTING FILMS

Surface roughness encourages the deposition of salts and accelerates deterioration of the retroreflecting properties of a film. For this reason, preference should be given to retroreflecting films that have a smooth surface. Films with exposed lenses are therefore unsuitable for maritime applications.

Due to the hostile environment encountered at sea, the service life of retroreflecting films may be shorter than that given in a manufacturer's catalogue.

Experience has shown that films with a smooth surface correctly installed may have a service life from 1 to 3 years, depending on local conditions.

5.5 APPLICATION OF RETROREFLECTING FILMS

It is advisable, for optimum performance and durability of the retroreflecting film, to follow the supplier's (or manufacturer's) recommendations or to entrust the work to firms approved by the supplier.

5.5.1 SUPPORTING MATERIALS (SUBSTRATES)

General

It is very important to ensure proper adhesion between the substrate and the retroreflecting film, particularly at the edges, in order to prolong the useful life of the film.

The substrate must provide a smooth, clean and relatively non-porous surface which is weatherproof. If the substrate is not inherently of this type, its surface must be carefully prepared.

Care must be taken to avoid reactions between the substrate and the film which may alter the colour, the retroreflecting capability or the effective life of film.

Surface contamination by grease or oil

Since grease or oil on the substrate will cause poor adhesion and may stain the retroreflecting surface, any such contaminated substrate must be cleaned with a suitable solvent.

Painted surfaces

If a retroreflecting film is to be applied to a painted surface, care must be taken to ensure that the paint itself has good adhesion to the substrate. Painted surfaces which powder, peel or flake easily give poor adhesion to the retroreflecting film and must be avoided.

The constituents of some paints may migrate through and stain the retroreflecting film in the same manner as greasy contaminents. Before applying films to aids to navigation which have been painted, tests should be carried out on substrate samples which have been prepared in exactly the same way as the aids themselves and which have been left exposed to the elements for some time. A test period of one week will generally be sufficient to reveal any problems which may occur.

Metallic surfaces

Metallic surfaces should be protected from corrosion prior to the application of the film in order to ensure a good adhesive band.

Concrete surfaces

Concrete is too rough and porous for direct mounting of retroreflecting film; however, it may be made suitable by the application of a primer which is compatible with the film adhesive and recommended by the manufacturer. It may be necessary to apply several coats of primer to the concrete to obtain the smooth, sealed surface required.

Plastics surfaces

Not all plastics are compatible with retroreflecting film adhesives. Many plastics materials contain plasticizers, oils and colouring materials which may behave as migrating components, likely to modify the film. It is therefore necessary to request advice from the film and/or plastics manufacturer, and to carry out tests beforehand. One of the most common indicators of adhesive-substrate incompatibility is the occurrence of small bubbles appearing under the film 1 or 2 days after application.

5.5.2 APPLICATION TEMPERATURE

All the adhesives on films have an optimum temperature range outside of which they may not perform satisfactorily.

The manufacturer's recommendations for application temperatures must always be followed.

5.5.3 SURFACE CONFIGURATION

While most retroreflecting films can be applied successfully to surfaces which are flat or curved in two dimensions, they cannot be applied without buckling to surfaces curved in three dimensions. Such buckling may cause to contribute to physical damage to the films and shorten their useful lives.

5.5.4 RADAR REFLECTORS

Retroreflecting films must not be used where it would cover a radar reflector that is incorporated in the body of an aid to navigation, but the effectiveness of a trihedral external radar reflector would not be impaired if film is applied flat to the surfaces of the radar reflector.

5.6 NOMOGRAM FOR CALCULATING THE RANGE OF A RETROREFLECTING FILM

The visible distance or range of a retroreflecting film illuminated by a light projector is given by the following relationship which has been derived from the Allard formula :

$$E = \frac{R' A I (0.05)^{2d/V}}{d^4}$$

where E is the illumination threshold at the eye established at 0.2 microlux;

I is the light intensity of the light projector in the direction of the retroreflecting device in candelas;

R' is the coefficient of retroreflection of the retroreflecting film in candelas per lux per square metre;

A is the surface area of the retroreflecting film in square metres

d is the range of the retroreflecting film in metres;

V is the meteorological visibility in metres.

The nomogram (figures 8A and 8B) permits the range of a retroreflecting film to be determined as follows (care should be taken not to confuse the R' scale and the I scale, both of which appear on the vertical line at the extreme left-hand side of the nomogram) :

Step 1 - Run a straight line through scale A (surface area graduation expressed in square metres) and scale R' (coefficient of retroreflection graduation expressed in candelas per lux per square metre). Note where the line intersects scale R (coefficient of luminous intensity graduation expressed in candelas per lux).
NOTE : The symbol R was formerly known as CIL.

Step 2 - Run a straight line from the R value to scale I (luminous intensity graduation expressed in candelas). Note where this line intersects scale A.

Step 3 - Run a straight line from this intersection to scale V (meteorological visibility graduation expressed in kilometres). The range expressed in metres or kilometres is given by the point where this line intersects scale d .

An example is given in figure 9.

However, if retroreflection is provided by a single device, Step 1 can be omitted as the coefficient of luminous intensity R will already be known.

It must be borne in mind that the use of high-powered searchlight has advantages in good and moderate visibilities, but, in poor visibility, such a searchlight creates back-scattered light so that the target cannot be identified so easily.

Thus, whilst the threshold of 0.2 microlux used in the formula is satisfactory for meteorological visibilities exceeding 1 km, visibilities less than 1 km require an enhanced threshold of 5 microlux to take account of the effect on the observer of this back-scaterred light.

In this case, the nomogram in figs. 8A and 8B may still be used, provided that the luminous intensity entered on scale I is equal to the actual luminous intensity of the light projector divided by 25.

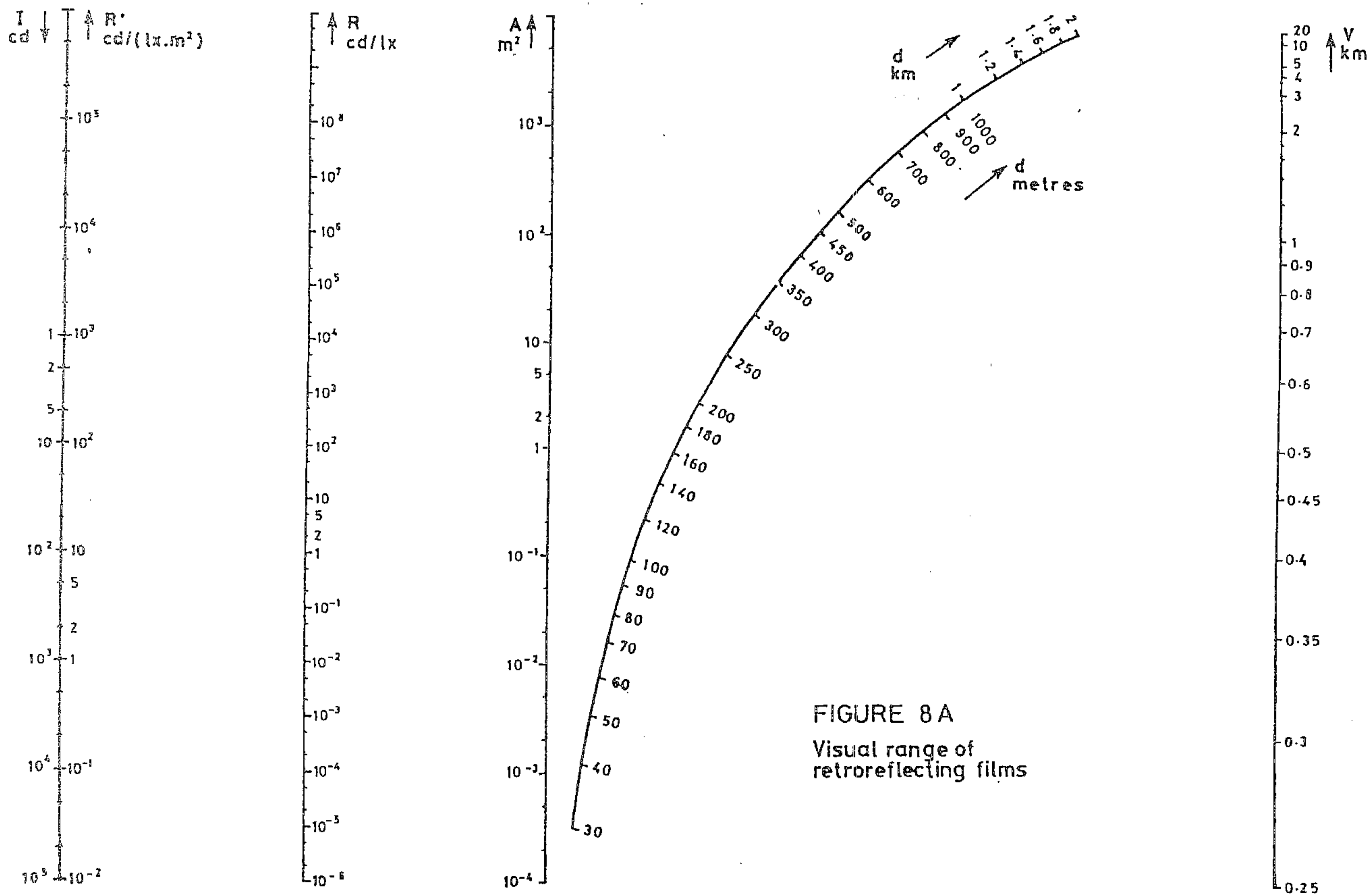


FIGURE 8 A

Visual range of retroreflecting films

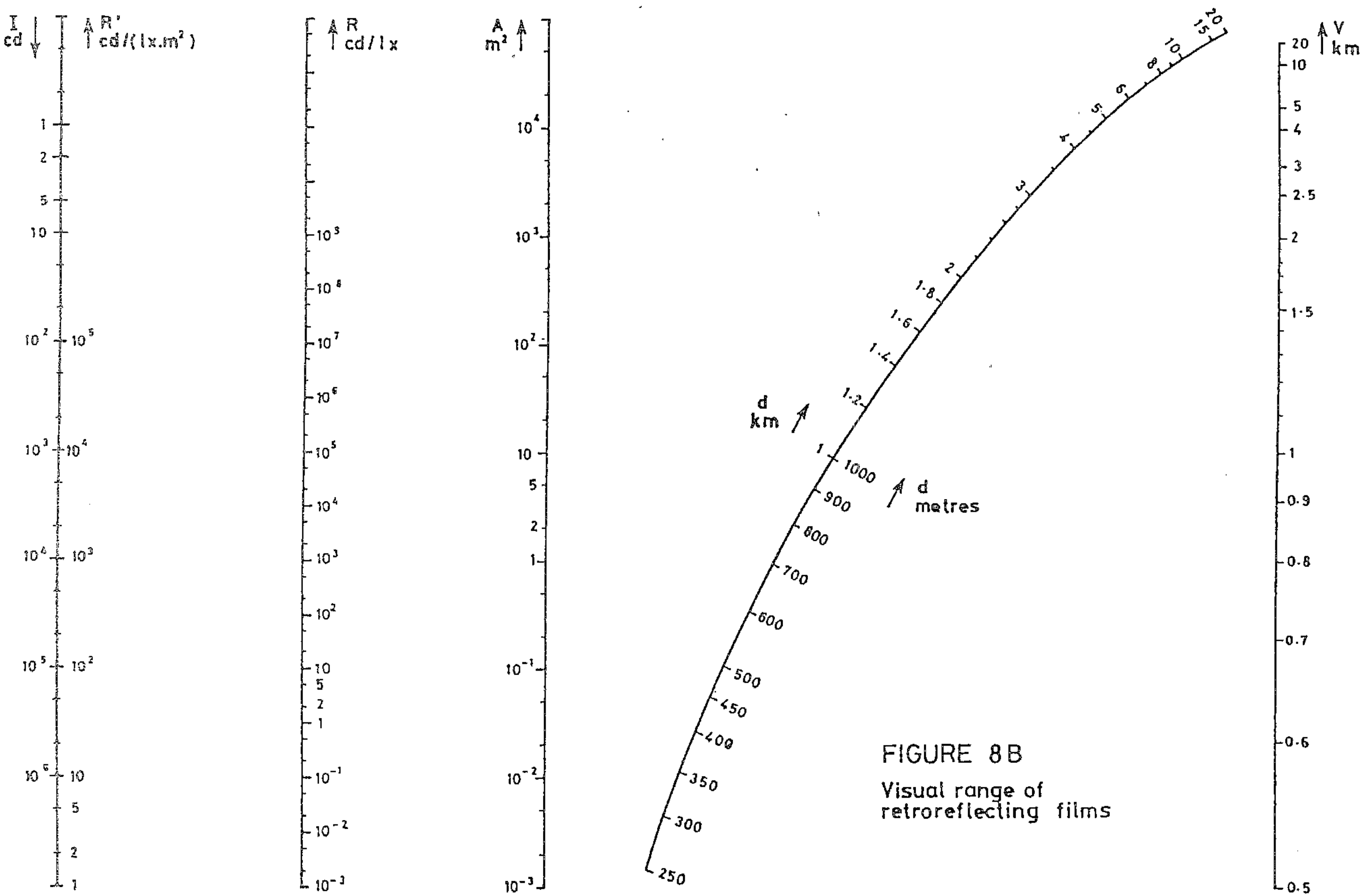


FIGURE 8B

Visual range of retroreflecting films

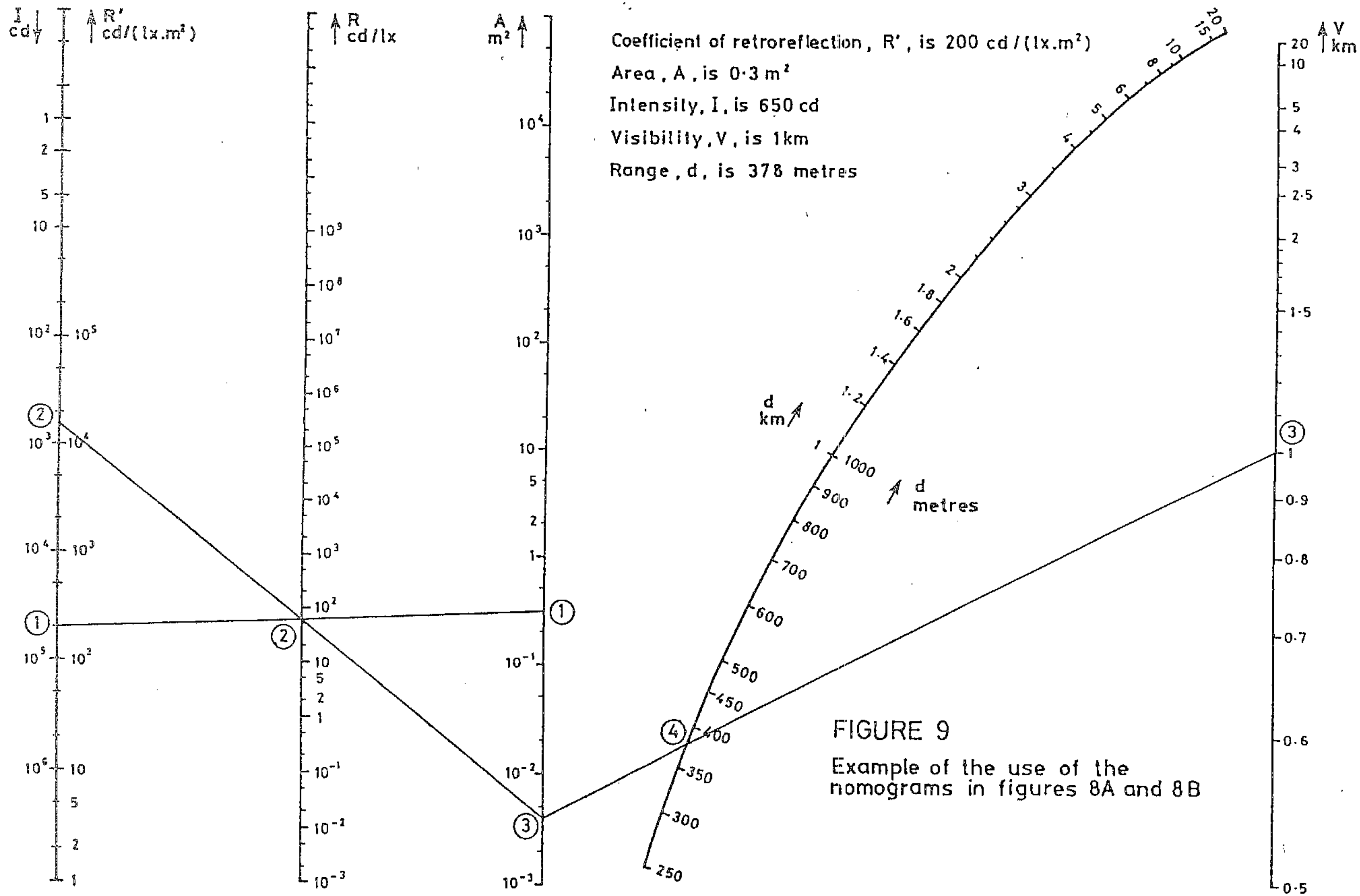


FIGURE 9

Example of the use of the nomograms in figures 8A and 8B

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Bureau Central
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75008 Paris, France

Reference 6.22 is obtainable from :

Telefonaktiebolaget LM Ericsson
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