IALA

IALA GUIDELINE

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APPLICATION OF RETROREFLECTING MATERIAL ON AtoN

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1. INTRODUCTION

Retroreflective material has in general widespread use in many types of applications, including safe driving, safe navigation, safety of workers, industrial/technical automatization and for many other purposes.

The most commonly and well-known use is in enhancing the light returned from vehicle headlights to enable the drivers to detect warnings, impart information and aid the driver through the necessary manoeuvres. For this reason, road traffic signs and vehicles in general are equipped with retroreflective material.

Other applications are high-visibility clothing for workers, authority personnel, etc. to be safely and effectively visible and further for equipment for life rafts/boats and life vests according to SOLAS regulations.

Retroreflective material on Marine Aids to Navigation (AtoN) has also significance. Retroreflective material has a widespread use in narrow and complicated waters and fairways for the marking at nighttime when a marine signal light is not suitable due to cost or size. However, retroreflective material has also importance on lighted fairways in case of the failure of a light.

The IALA Recommendation *R0106 (E- 106)* [1] describes the codes for use of retroreflective material on floating AtoN according to the *IALA Maritime Buoyage System (MBS)* [5].

This guideline will give more detailed information on what retroreflectivity is and how retroreflective material can be applied.

2. AIMS AND OBJECTIVES

The guideline provides a general informative overview for AtoN authorities and suppliers of retroreflective material, including terminology, design, characterising, classification and guidance on its use for AtoN purposes.

3. HISTORY

The earliest recorded information of spherical shapes made of glass dates back to early Chinese history. Observation of light reflected back towards the light source from these spheres was used to intensify the brightness or brilliance of art objects. Glass spheres of different coloured glasses can be found in ancient jewellery. Many of the cuts of the facets of diamonds are made to retroreflect the incident light, resulting in the brilliance of the diamond.

The first use of retroreflective material for purpose of enhancing the conspicuity of objects was probably created in Great Britain around the turn of the 20th century. Observation of light reflected from animal's eyes, especially those of cats, started the thought of using this technique to enhance the brightness of objects.

The explanation of the glowing nature of cat's eyes stems from the highly reflective nature of their retinas. These animals are primarily nocturnal and rely on making the most use of the available low light level. The tissue (tapetum lucidum) immediately behind the retina is coated with material which reflects over 80 % of the incident light, and reflects visible light back through the retina, increasing the light available to the photoreceptors and then increase the detectability of objects.

Figure 1 Cat's "glowing eyes" (https://en.wikipedia.org/wiki/Retroreflector)

The first use of the "cat eye" principle was for the safety of drivers in road traffic application; therefore investigations were made resulting in the production of glass spheres with retroreflective features.

Figure 2 Cat's eye for a bicycle (photo DMA)

Retroreflective material is available today in arrays in different sizes and colours, sheeting of plastic and metal, adhesive tape, etc. Numerous manufacturers for various applications provide many different colours and degrees of reflection intensity.

As with any retroreflector, sheeting glows brightly when there is a small angle between the observer's eye and the light source directed toward the sheeting but appears non-reflective when viewed from other directions.

4. RETROREFLECTIVE MATERIAL FOR MARINE AIDS TO NAVIGATION PURPOSES

For floating AtoN retroreflective materials should be used according to the codes in IALA *R0106 (E-106)* [1].

Further there are many applications for fixed AtoN, e.g.:

- Day boards for leading lines
- Beacons and lighthouse structures
- Signs for waterways
- Lettering and numbering
- Marking of obstacles and piers

4.1. FLOATING MARINE AIDS TO NAVIGATION

Retroreflective material is usually used as an alternative to lights on buoys on less important fairways and fairways for leisure crafts; however, they also have importance on lighted fairways in case of the failure of a light.

The shape of the buoy provides the daymark according to the *IALA MBS* [5]. The retroreflective material has a lower conspicuity at daytime compared to an ordinary or fluorescent surface colour. In addition, retroreflective material is much more expensive than a traditional surface colour and cannot be fixed to some curved surfaces. Therefore, it is not recommended to use retroreflective material for the whole shape of a buoy. Instead, it should be applied as small sheets to the buoys and it should not interfere with the daymark. As a result, retroreflective material is for short range navigation (typically less than 1 NM for floating aids).

The codes of retroreflective material on floating AtoN are specified by IALA Recommendation *R0106 (E-106) Use of Retro-reflective Materials on Aids to Navigation Marks within the IALA Maritime Buoyage System*. There are two types of codes for floating AtoN – the Standard Code and the Comprehensive code which are defined.

The Standard Code provides only the identification of lateral and special marks. Safe water, cardinal and isolated danger marks have a white retroreflective sheet, which provides detection of the buoy only.

In the Comprehensive Code all types of marks of IALA MBS are individually translated into a code for the retroreflective material. As black cannot be translated to retroreflective material, the colour blue replaces black.

4.2. FIXED MARINE AIDS TO NAVIGATION

Retroreflective material is used for different types of fixed AtoN to navigation and for purposes related to safe navigation or warning of obstructions close to navigational water and fairways. Applications where retroreflective materials are used can be for day boards of leading lines, lettering and numbering, signs for waterways, marking of edges, jetties, piers, etc.

In contrast to the application on buoys, the retroreflective material may be used for both the daymark and the marking at night. This means that the day board may be completely covered with retroreflective material.

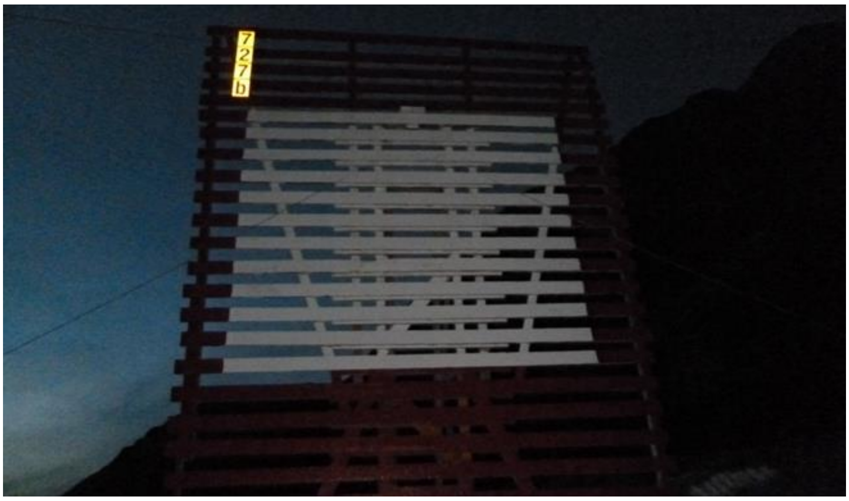

Figure 3 Illuminated retroreflected ID number on a day board (DMA Greenland)

5. TERMINOLOGY, PRINCIPLE, BASIC TECHNOLOGY AND DESIGN

The Commission Internationale De L'éclairage/International Commission on Illumination (CIE), the international standardizing body responsible for light and colour measurement, defines retroreflection as follows:

> "Reflection in which the reflected rays are preferentially returned in direction close to the opposite of the direction of the incident rays, this property being maintained over wide variation of direction of the incident rays"

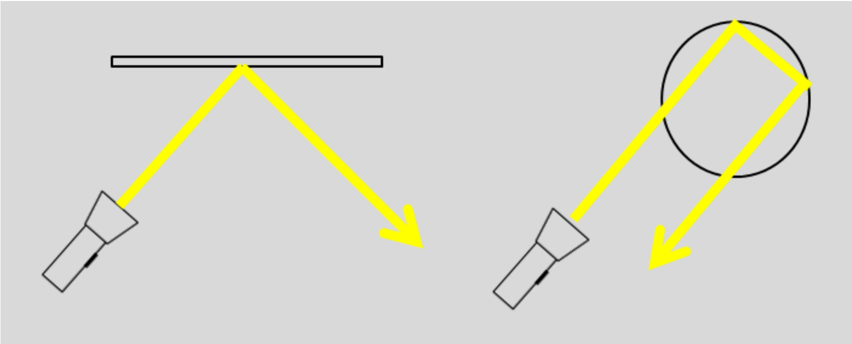

Figure 4 Reflection and Retroreflection (DMA)

5.1. REFLECTION AND RETROREFLECTION

The reflection of light depends on the surface. When the surface is very rough the light will be reflected diffused. A smooth surface (e.g., mirror) produce direct reflection and that means the optical path of the reflected rays are parallel, see Figure 5.

Most practical surfaces have mixed reflection, which is a mixture of diffuse reflection and mirror reflection. A particular kind of reflection is retroreflection, where most of the light is reflected back to the light source

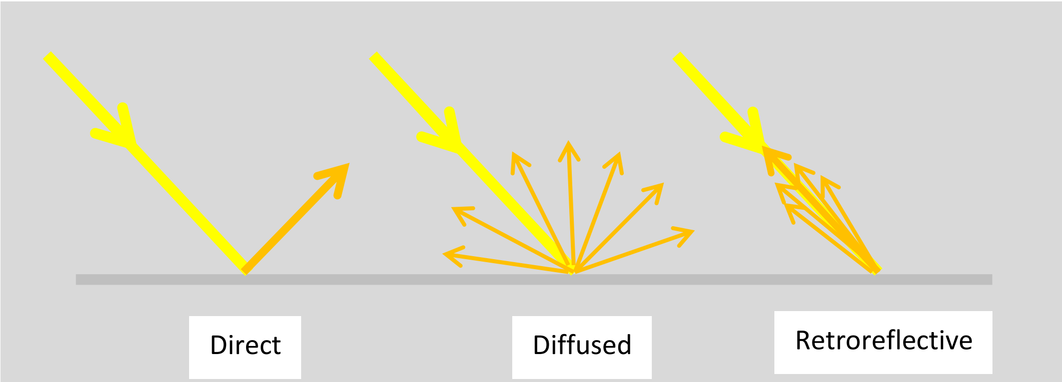

Figure 5 Retroreflection compared with other reflection patterns (DMA)

5.2. OPTICAL PRINCIPLES

There are two basic optical systems for obtaining retroreflection: -

- The Glass Sphere or Bead, see Figure 6.
- The Prismatic or Cube Corner Reflector, see Figure 7

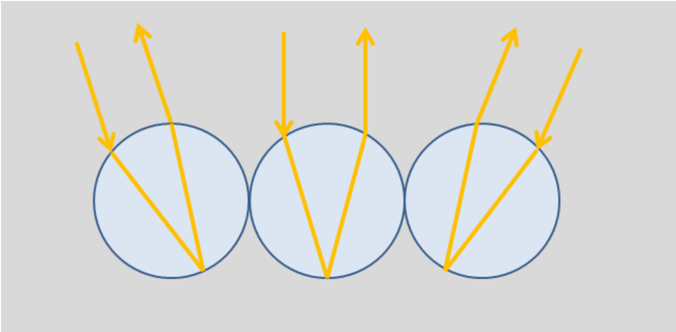

Figure 6 Glass Bead Retroreflectors (DMA)

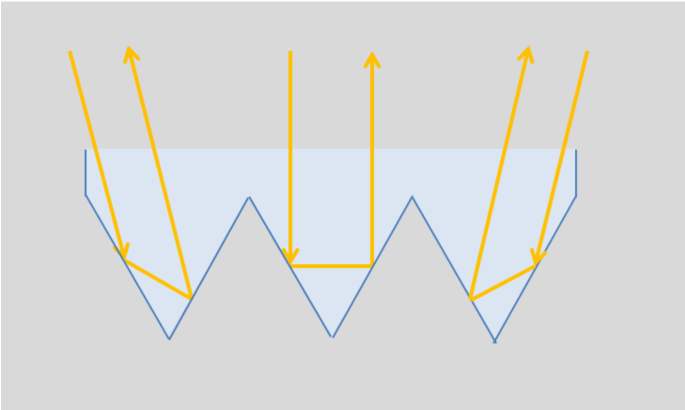

Figure 7 Prismatic Retroreflectors (DMA)

5.3. THE GLASS SPHERE OR BEAD

The simplest retroreflector is a glass sphere or bead and this type was the first retroreflective element used for the so-called “Cat’s Eye”.

The incident light will be refracted at the front surface of the sphere and is focused towards the centre of the rear surface of the sphere. From there the light is reflected and refracted at the front surface again onto a course parallel to the direction from which it came.

To improve the reflectivity the rear surface should have a reflector coating.

Only 28 % of the area of the sphere is at a sufficiently favourable angle to return the light beam. To enhance the reflectivity, the prismatic reflector can be used as an alternative.

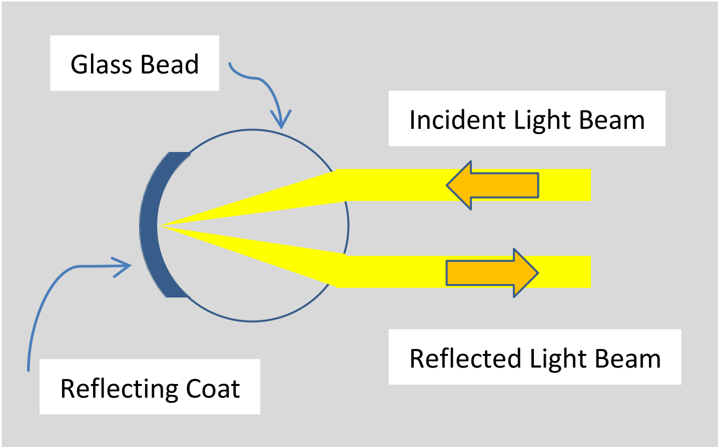

Figure 8 Glass Sphere or Glass Bead (DMA)

Depending on the construction, the glass sphere/bead can be divided in three different types in respective order according to improvement

- Exposed glass bead
- Enclosed glass bead
- Encapsulated glass bead

5.4. PRISMATIC OR CUBE CORNER REFLECTOR

The prismatic or cube-corner is the more efficient reflector.

If you take a solid glass cube and slice off one corner with a cut that passes along the diagonals of three adjoining faces you have the basic cube-corner unit which is a squat triangular pyramid shaped prism. When the pyramid is set up with the triangular base directed towards a beam of light, the light passes through the base with very little loss. Once inside the pyramid the light is internally reflected off each of the three side faces in turn, before being directed back through the base, exiting parallel to the incoming light beam. Reflected light is still parallel to the incoming beam as the light is equally refracted when entering and leaving the prism, see Figure 9

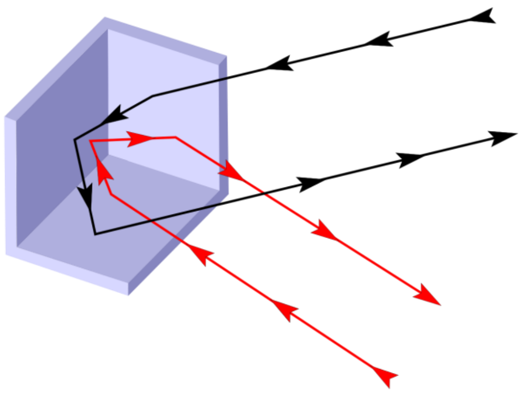

Figure 9 Principle of Prismatic/Cube Corner Reflector (https://en.wikipedia.org/wiki/Corner_reflector)

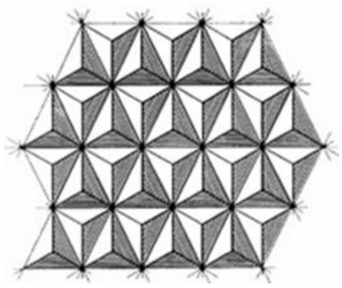

Figure 10 Prismatic Tape Overhead View (ifloortape.com)

5.5. COMPARISON

The prismatic retroreflector generally produces a very small cone of reflective light. In situations, where the observer is not exactly in the position of the light source, a broader returning angle may be preferred. Many glass bead sheets are more flexible and can be attached to curved surfaces more easily.

Figure 11 shows the difference in the reflected light between glass bead and prismatic tape.

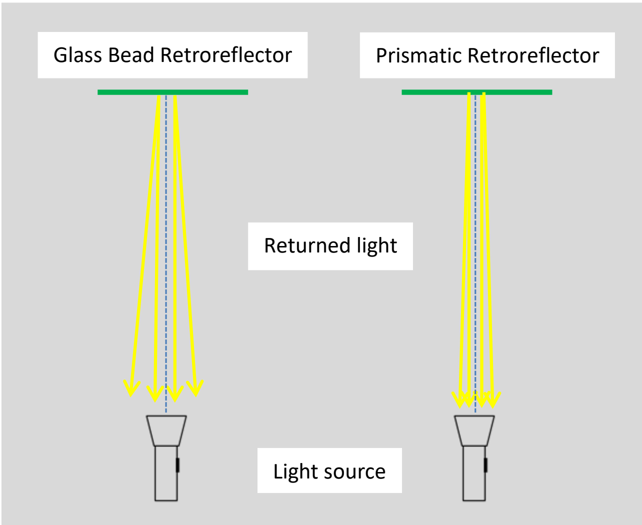

Figure 11 Dispersion path from Glass Bead and Prismatic Retroreflectors (DMA)

6. CHARACTERISING AND MEASUREMENT OF RETROREFLECTING MATERIAL

The retroreflective material is mainly characterized by two properties: -

- the coefficient of retroreflection R_A (CIE 54.2-2001) [6]; and
- the colour chromaticity co-ordinates x, y and the luminance factor (CIE 1931).

Performance values for retroreflective sheeting are expressed with its efficiency in reflecting the incident light at a particular geometry.

The reflectivity is the ratio between the reflected light and the incident light.

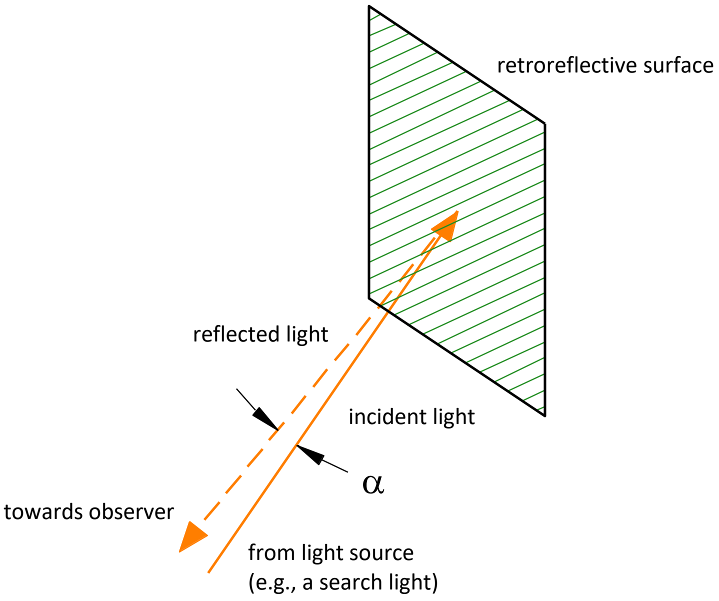

Figure 12 Coefficient of Retroreflection (Ra)

The incident light is described by the illuminance $E_\perp$ the light source produces at the surface.

The reflected light is described by the luminous intensity *I* emitted towards the direction to the observer.

The ratio *R* between them is called the 'coefficient of luminous intensity of a retroreflector' [6].

Equation 1 Coefficient of luminous intensity of a retroreflector

$$R = \frac{reflected\ light}{incident\ light} = \frac{I}{E_\perp}$$

Unit: $\left[\frac{cd}{lx}\right]$

This ratio still depends on the size A of the retroreflective sheet. To get a specification for the sheet independent of its size, the 'coefficient of retroreflection of a plane retroreflective surface' is defined as [6]:

Equation 2 Coefficient of retroreflection of a plane retroreflective surface

$$R_A = \frac{R}{A} = \frac{I}{E_\perp * A}$$

Unit: $\left[\frac{cd}{lx * m^2}\right]$

Remark: The IEC Vocabulary uses the symbol R'. The relevant specification use R_A.

The important concept to understand is that the retroreflectivity value R_A is a ratio. It's similar to "percent" and does not tell how bright the sheeting will be on a given sign (even at the distance corresponding to the "geometry" for that particular value).

It is simply its "efficiency" at returning light to the source at that particular geometry (the set of observation and entrance angles).

The efficiency of a retroreflective material varies with different observation and entrance angles and the various materials vary in different ways.

These parameters influence the choice among different retroreflective materials for a particular application.

The following should be taken into account:

- geometry between light, AtoN and observer (angles and distance)
- type of light source
- practical viewing conditions and
- the viewing needs of the observer

The coefficient of retroreflection R_A depends on 4 different angles and is determined by a laboratory arrangement shown in Figure 13.

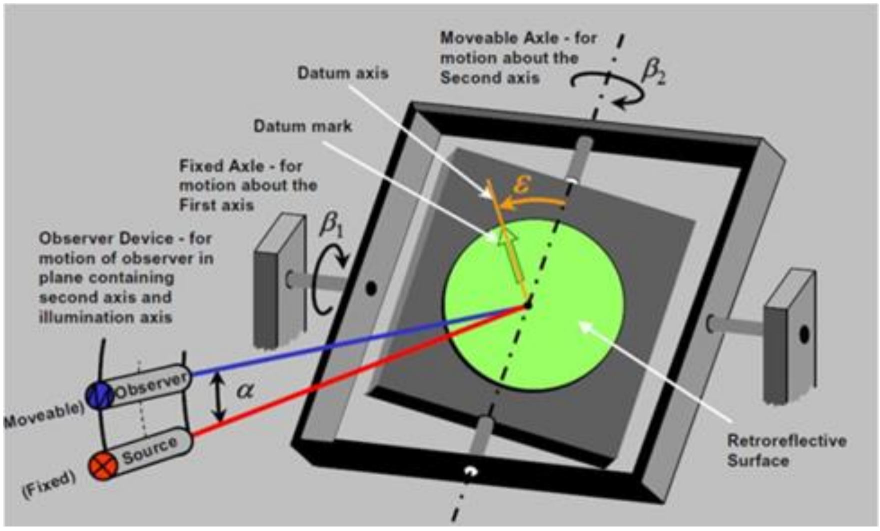

Figure 13 CIE Goniometer system for specifying and measuring retroreflectors (CIE)

The "observation angle'" α, is the angle between the light source and the observer, measured from the retroreflective sheet. In general, the light source and the observer are nearly in the same position and the angle α is small. Typical values chosen for technical specification are in the interval [0.1° ... 2.0°].

The "entrance angle" is the angle from the 'light source' axis to the 'retroreflector axis' and is characterized by two components, β_1 and β_2.

The retroreflection may depend on the rotation angle ε of the retroreflective surface around its perpendicular axis.

In consequence the coefficient of retroreflection is a set of numbers $R_A = R_A(\alpha, \beta_1, \beta_2, \varepsilon)$. The total sets of coefficients are very difficult to handle in practice. To simplify the specifications the angles β_2 and ε are set to zero, which means that the influence of these angles is ignored.

With this simplification the coefficient of retroreflection R_A becomes a matrix $R_A(\alpha, \beta_1)$.

Table 1 Matrix $\boldsymbol{R_A(\alpha, \beta_1)}$

R_A	$\beta_1(1)$	$\beta_1(2)$	$\beta_1(3)$
$\alpha(1)$	$R_A(1,1)$	$R_A(1,2)$	$R_A(1,3)$
$\alpha(2)$	$R_A(2,1)$	$R_A(2,2)$	$R_A(2,3)$
$\alpha(3)$	$R_A(3,1)$	$R_A(3,2)$	$R_A(3,3)$

Where R_A (i, j) is the coefficient for the angles α (i), β_1 (j) with i, j = 1, 2, 3. Because each colour has its own coefficient R_A the published matrices are rearranged.

Table 2 Matrix $\boldsymbol{R_A(\alpha, \beta_1)}$ with colour details

Geometry		Colour		
α	β_1	White	Yellow	...
$\alpha(1)$	$\beta_1(1)$	$R_{A,White}(1,1)$	$R_{A,Yellow}(1,1)$	$R_{A,\dots}(1,1)$
	$\beta_1(2)$	$R_{A,White}(1,2)$	$R_{A,Yellow}(1,2)$	$R_{A,\dots}(1,2)$
	$\beta_1(3)$	$R_{A,White}(1,3)$	$R_{A,Yellow}(1,3)$	$R_{A,\dots}(1,3)$
$\alpha(2)$	$\beta_1(1)$	$R_{A,White}(2,1)$	$R_{A,Yellow}(2,1)$	$R_{A,\dots}(2,1)$
	$\beta_1(2)$	$R_{A,White}(2,2)$	$R_{A,Yellow}(2,2)$	$R_{A,\dots}(2,2)$
	$\beta_1(3)$	$R_{A,White}(2,3)$	$R_{A,Yellow}(2,3)$	$R_{A,\dots}(2,3)$
$\alpha(3)$	$\beta_1(1)$	$R_{A,White}(3,1)$	$R_{A,Yellow}(3,1)$	$R_{A,\dots}(3,1)$
	$\beta_1(2)$	$R_{A,White}(3,2)$	$R_{A,Yellow}(3,2)$	$R_{A,\dots}(3,2)$
	$\beta_1(3)$	$R_{A,White}(3,3)$	$R_{A,Yellow}(3,3)$	$R_{A,\dots}(3,3)$

Where $R_{A,colour}$(i, j) is the coefficient for a specific colour and the angles α(i), β_1(j) with i, j = 1, 2, 3.

Most of the available retroreflective material is designed for road traffic signals and commonly, the applied 'observation angle' is for this purpose. In practice, the angle is given by the vertical distance between the head light (light source) of the car and the driver's position (observer) in the vehicle.

Traditionally the specifications of the coefficient of retroreflection are based on the illuminant A (2856 K), which is nearly the colour of the incandescent lamps of automobile head light. However, vehicles and marine searchlights xenon arc and LEDs with high colour temperature (> 5000 K) are in use, which might give different values in practice.

Table 3 below shows typical datasheet values from a manufacture of retroreflective material.

The table shows the geometry of the measurements. Three sets of the 'observer angle α' and three sets of the "entrance angle β_1".

The actual retroreflective material is available in six different colours and the value of R_a [cd/ (lx*m^2)] respectively of each colour is displayed under different geometry.

Table 3 An example of data sheet for retroreflective film (Coefficient of Retroreflectivity)

Minimum Coefficient of Retroreflection [cd/(lx * m²)]							
Geometry of measurements		Colour					
α	β_1, (β_2 = 0)	White	Yellow	Red	Green	Blue	Orange
0,2°	+ 5°	250	170	45	45	20	100
	+ 30°	150	100	25	25	11	60
	+ 40°	110	70	15	12	8	29
0,33°	+ 5°	180	120	25	21	14	65
	+ 30°	100	70	14	12	8	40
	+ 40°	95	60	13	11	7	20
2°	+ 5°	5	3	1	0,5	0,2	1,5
	+ 30°	2,5	1,5	0,4	0,3	-	1
	+ 40°	1,5	1,0	0,3	0,2	-	-
”-” indicates ”Value greater than zero but not significant or applicable”							

6.1. COLOURS

Retroreflective material is typically available in white, yellow, red, green, blue and orange.

For buoys, orange may not be used because it is not in the codes of the MBS and may cause confusion with yellow and red.

For fixed AtoN or other marks orange may be used according to the assessment of the competent authority.

The surface colour is described by a luminance factor β and two chromaticity co-ordinates x, y (see IALA Recommendation *R0108 (E-108)* [2]

Measurement of the colour of retroreflective material is carried out by same method as for other surfaces colours and in accordance with IALA Guideline *G1134* [3]

Table 4 below shows an example of a specification for colours of a retroreflective material.

The specified chromaticity regions for retroreflective material is often much smaller than for surface colours.

The standard specifications are for daytime observations only. So, for the coefficient of retroreflection illuminant A (2856 K) is used and for the colour illuminant D65.

Table 4 An example of data sheet for retroreflective film (Chromaticity and Luminance factor)

Chromaticity and Luminance factor									
Colour	1		2		3		4		Luminance factor
	x	y	x	Y	x	y	x	y	β
White	0,305	0,315	0,335	0,345	0,325	0,355	0,295	0,325	≥ 0,40
Yellow	0,494	0,505	0,470	0,480	0,513	0,437	0,545	0,454	≥ 0,24
Red	0,735	0,265	0,700	0,250	0,610	0,340	0,660	0,340	≥ 0,03
Blue	0,130	0,090	0,160	0,090	0,160	0,140	0,130	0,140	≥ 0,01
Green	0,110	0,415	0,170	0,415	0,170	0,500	0,110	0,500	≥ 0,03
Orange	0,631	0,369	0,560	0,360	0,506	0,404	0,570	0,429	≥ 0,14

7. CLASSIFICATION AND STANDARDS OF RETROREFLECTIVE MATERIAL

Standardization of retroreflective material is related to the increase in use of automobiles and historically the first specification on the topic for safe driving was probably formulated in the United States in the 1930s.

The start of the international standardization on retroreflective materials began in Vienna in 1968 with the Convention of Road Signs and Signals by the CIE. Today CIE is the international organization for the standards in light and colour. Many technical reports and documents of the CIE are dealing with light signals, surface colours, illumination and light measurement. These are the basis for international agreements or national specifications.

For retroreflective material the most important international document is the CIE Technical Report 54.2 on Retroreflection, Definition and Measurement [6].

From this document all other international and national specifications are derived. The geometry of measurement differs somewhat among these specifications; however, today's international trend is to specify the characteristics of retroreflectors for road traffic applications.

Important standards on retroreflective materials are:

- European Standard *EN 12899-1 (Fixed, vertical road traffic signs)*
- US American Standard *ASTM D 4956-04 Standard Specification for Reflective Sheeting for Traffic Control*
- German Standard *DIN 67520 (Retro-reflecting materials for traffic safety)*

8. CONSIDERATIONS WHEN APPLYING RETROREFLECTIVE MATERIAL

Applying retroreflective materials for AtoN the type to use must be considered. In general, the application for floating AtoN and fixed AtoN differs. For example, floating AtoN are dynamic objects with limited size and fixed AtoN are static objects that may be very large.

8.1. GENERAL CONSIDERATIONS FRO FLOATING AND FIXED MARINE AIDS TO NAVIGATION

8.1.1. COLOURS

The retroreflective principle works only when the surface is illuminated at night with a search light near the observer. In daylight the retroreflective colours show low luminance and are not very conspicuous. Therefore, retroreflective materials should not be used to entirely cover a daymark.

Manufacturers of retroreflective material have introduced retroreflective-fluorescent films. However, the colours available are made for road traffic signals and there is not a complete set of films for the IALA MBS colours.

Care should be taken that the amount of white retroreflecting material used on an AtoN does not detract from its daytime appearance.

Figure 14   Spar buoy with green retroreflective band (DMA)

It may be difficult for the observer to discriminate between yellow and white retroreflecting materials, particularly where only one of these colours is being observed on its own. Thus, only one yellow band may be used on a special mark to avoid confusion with a West Cardinal mark in the comprehensive code (two yellow bands).

It may also be difficult for the observer to discriminate between green and blue retroreflecting materials, particularly where only one of these colours is being observed on its own. In principle, green buoys should carry only one green band, whereas blue is always used in combination with another colour, except in the case of East Cardinal marks which have two blue bands according to IALA *R0106 (E – 106)*. However, this principle may be violated if one of the bands has become damaged.

The coefficient of retroreflection of blue and red is much lower than white or yellow, and to ensure proper recognition the following must be observed:

- Safe water marks:

  The red bands or stripes must be at least twice the width of the white bands or stripes. The separation distance between the colours must be at least twice the width of the white bands or stripes.

- North and South Cardinal Marks:

  The blue bands must be at least twice the width of the yellow bands. The separation distance must be at least twice the width of the yellow bands.

- Isolated Danger Marks:

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

Figure 15 South Cardinal, Comprehensive Code, double blue band and single yellow band (DMA)

8.1.2. PHOTOMETRIC PERFORMANCE WHEN WET

The photometric performance of the retroreflective material can change under wet conditions. Particularly a glass bead retroreflector can have decreased performance under wet conditions. Tests have shown that micro prismatic retroreflectors, compared to glass beads, performs better under wet conditions.

8.1.3. TEMPERATURE

High and low temperatures can cause deformation of the retroreflective material and the deformation can cause the loss of coefficient of retroreflection, cracking, distortion and reduced lifetime.

When specifying retroreflective materials, it is important to select materials with technical temperature specifications at least equal to or better than the local annual temperature variation.

8.1.4. FLEXIBILITY

Buoys can have curved and sharp edges and it is necessary to select the retroreflective materials that can be bent as necessary.

If the flexibility is not adequate for the actual use, the retroreflective material will crack and there will be a loss in retroreflectivity.

8.1.5. CLEANABILITY

To obtain high performance retroreflectivity and long lifetime of the material, it is important that the retroreflective material has good self-cleaning characteristics. Gloss and uniform surfaces are recommended.

8.1.6. APPLICATION OF RETROREFLECTIVE MATERIAL

Proper application techniques are very important to obtain optimal retroreflective performance and to ensure long lifetime of the retroreflective material. The manufacture's instruction for applying retroreflective material must be followed. A data sheet of the product will have detailed information.

Read all health hazard, precautionary and first aid statements before handling the material.

The corners of a rectangular sheet may become undone by weathering. To improve the stability these can be rounded.

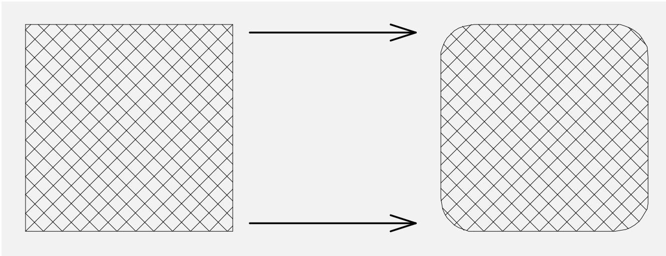

Figure 16 Rounding off corners to improve stability

On some plastic material the retroreflective material will not adhere very reliable. For cylindrical buoys it is advised to have an overlap, so the material can adhere to itself.

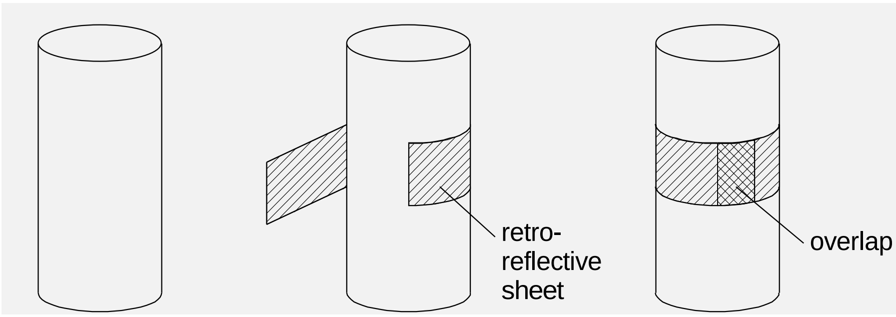

Figure 17 Use overlap on cylindrical buoy where possible

8.1.7. DEGRADATION OF RETROREFLECTIVE MATERIALS

The deterioration rate or service lifetime of retroreflective material depends of many factors and their influence is type dependent.

Plastic cube-corner prismatic materials are the most common type applied as retroreflective material on AtoN.

The colour may change due to pigment fading and loss of transparency caused by ultraviolet (UV) exposure. The material for unbending cube corners may crack allowing moisture to penetrate and destroy the sheet. Due to the harsh environment the retroreflective materials are often exposed to mechanical injury caused by the scratching from the too close passing vessels, ice scratching, change in temperature and humidity, etc.

Microprismatic materials that are used in flexible materials will deform, changing the shape of faces and spreading the returned light, thus lowering the value of retroreflectivity at the same geometry.

The data sheets of retroreflection are for new material only. In practice because of weathering the coefficient of retroreflection will decrease. This degradation depends on many factors and in the absence of data a value of 0.75 can be used as the service condition factor k_{scf}. That means over the lifetime of the retroreflective material the coefficient should be at least 75% of new material. If degradation data is available then this should be substituted into k_{scf}.

For Adhesiveness and mechanical durability see Finnish Report in annex A.

8.1.8. PRECAUTION WHEN USING RADAR REFLECTOR IN COMBINATION WITH RETROREFLECTING MATERIALS

Experiences have shown that retroreflective material consisting of metal film can cause a lower Radar Cross Section (RCS) value. It is recommended not to apply the retroreflective material on the buoy surface where the surface is covering a radar reflector.

8.2. FLOATING MARINE AIDS TO NAVIGATION

Floating AtoN are typically buoys, used for short range navigation. Buoys can have different designs and sizes. The hydrostatic properties of the buoy have great influence on how the buoy performs with the retroreflectors during different sea conditions, including wind, current, waves, etc.

When approaching and passing a buoy the observer sees the buoy from very different positions. In addition, the buoy may move vertically and may heel, see Figure 18

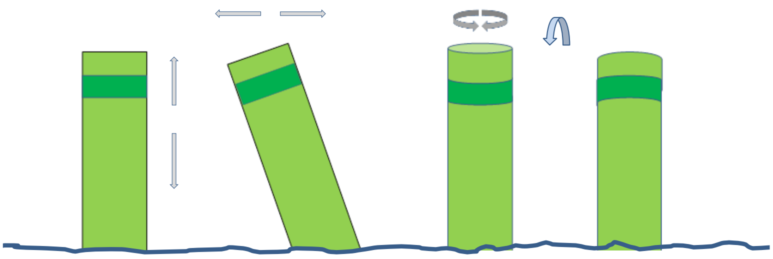

Figure 18 Movement pattern of a buoy (spar buoy)

8.2.1. SMALL BUOYS

On small buoys and spar buoys, the retroreflective material is commonly applied as a band on the full circumference of the buoy – the retroreflector is therefore omnidirectional, see Figure 19

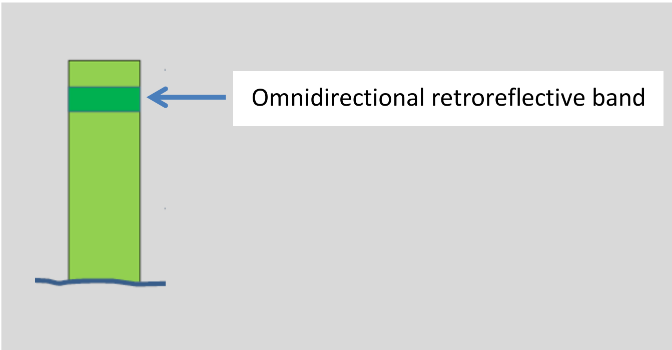

Figure 19 Band on the full circumference on small buoys

8.2.2. LARGE BUOYS

On larger buoys the shape, size and the structure of the buoy do not allow for the use of a band on the full circumference of the body of the buoy. In this case the retroreflective sheets are applied to the buoy body at specific suitable positions on the circumference.

There are two commonly used arrangements shown in figures below.

In each figure, the positions of the retroreflective sheets are shown and in addition the figures also show how they are seen from the observer's position.

The retroreflective coverage is best at 90°or 120°, respectively.

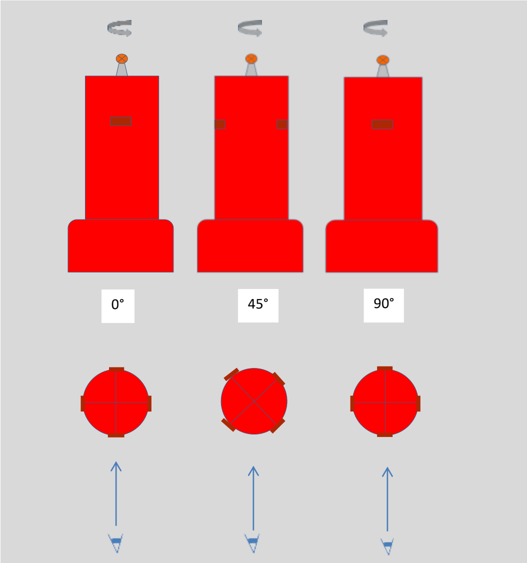

Figure 20 Retroreflector applied at every 90 Degrees

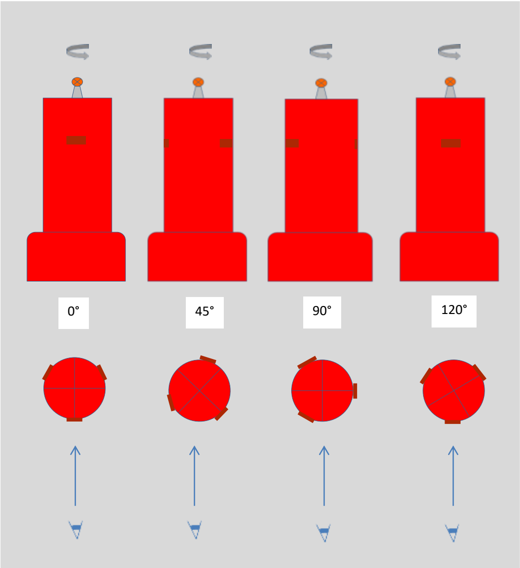

Figure 21 Retroreflector applied at every 120 Degree

Care should be taken with safe water marks and emergency wreck marking buoys when using a comprehensive code with vertical stripes. In this case an arrangement with an angle of 90° is preferred.

The shape of the buoy has influence on the retroreflectivity. As illustrated at figure 22, the entrance angle for the can buoy is better than for the cone buoy and a heeling of the buoy due to wind and current can have excessive influence on the retroreflectivity.

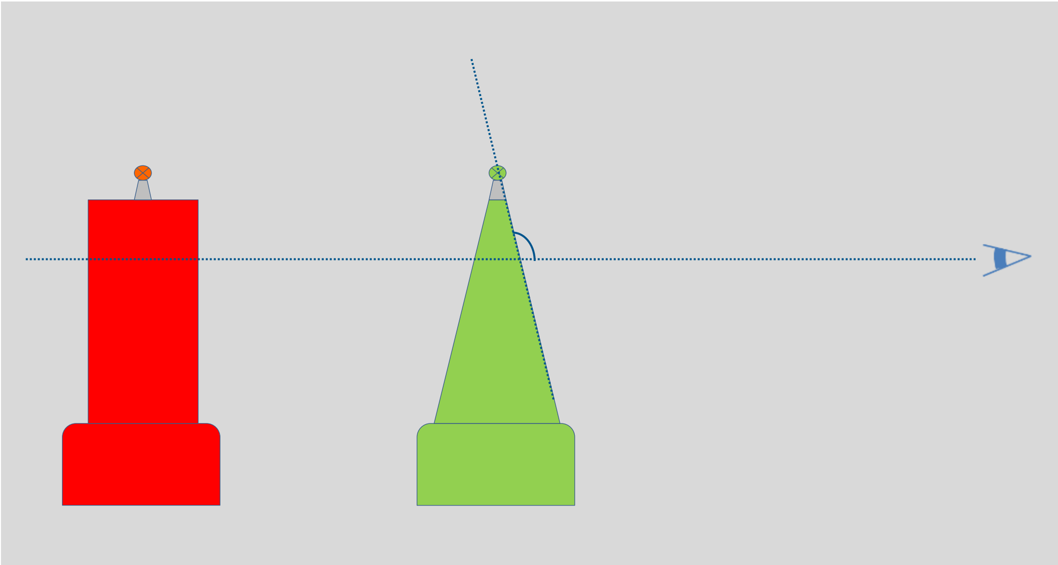

Figure 22 Buoys shape compared with the viewing angle

Figure 23 shows a spar buoy with an excessive heeling of approx. 45° and compared to data sheets of commonly used retroreflective material, the reduction in retroreflectivity is significant and this can be compensated by increasing the vertical size of the sheet.

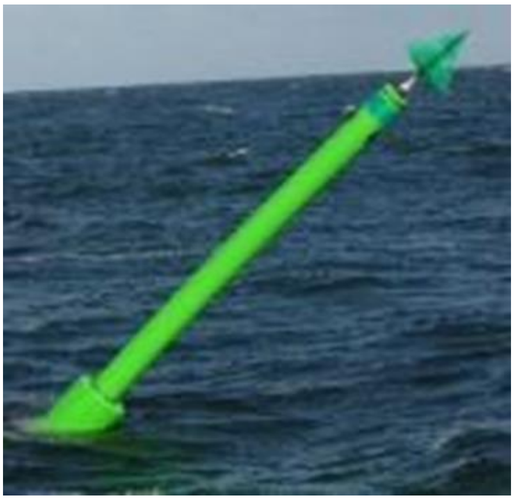

Figure 23 Spar buoy heeling approx. 45 degrees caused by wind and current

Movement of the buoy and movement of the observing vessel, including the eye height of the observer, should also be considered when selecting and specifying retroreflecting material for floating AtoN, see Figure 244.

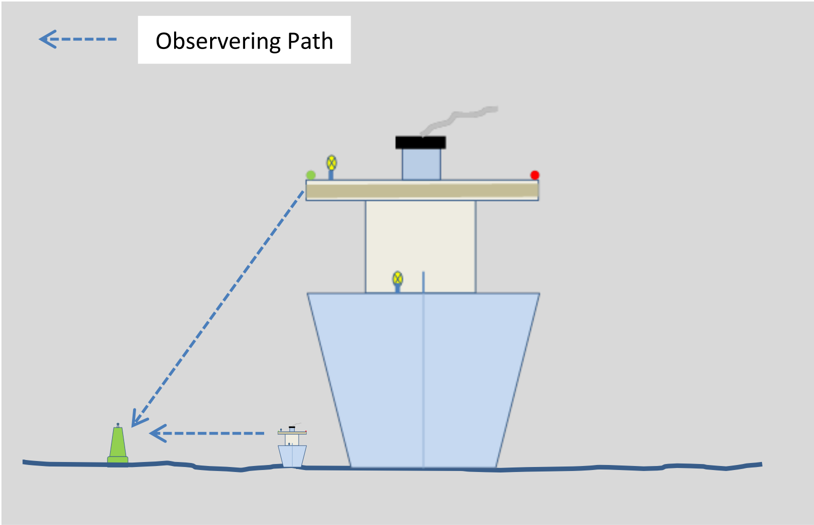

Figure 24 Eye height compared for a small and a large vessel

The 'observation angle' α is the angle between the light source and the observer, measured from the retroreflective sheet. In general, the light source and the observer are nearly in the same position and the angle α is small and typical in the interval [0.1° ... 2.0°], see Table 3. If the angle is greater than this then the observed retroreflectivity is significantly reduced. For example, this situation can occur when close to the AtoN and a searchlight is mounted on the bow of the ship and the observer is on the bridge wing as shown in Figure 255.

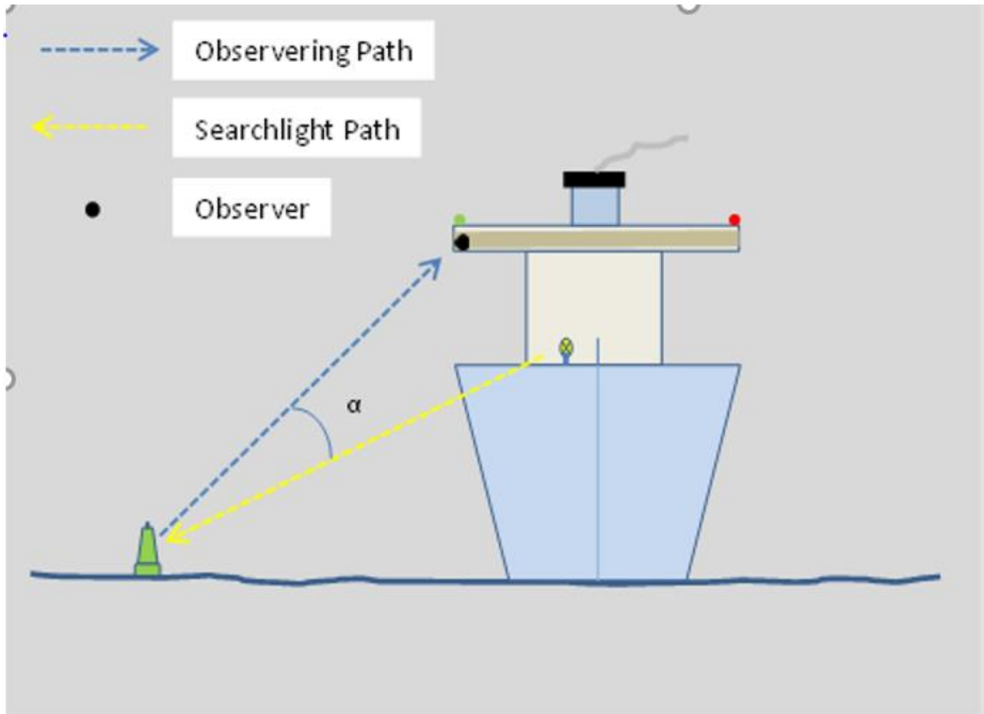

Figure 25 Searchlight Path and Observing Path

The curvature of the buoy has influence on the retroreflectivity as illustrated at Figure 266. A searchlight illuminating two buoy body structures and lengths of the dotted lines present the retroreflected intensity. In the left illustration, the curvature of the buoy causes a lower retroreflectivity than the flat structure of the buoy illustrated to the right. The reason is that the entrance angle of the light is increased and a large entrance angle causes less retroreflectivity. In fact, a curved retroreflective band can have a very small 'active' area and consequently a very limited retroreflectivity. The reflectivity of a spar buoy, with a limited diameter, can be increased with a broader retroreflective band (vertical) causing a larger 'active' area in the observer's direction.

For floating AtoN, it is preferable to choose retroreflective material with large entrance angle (β).

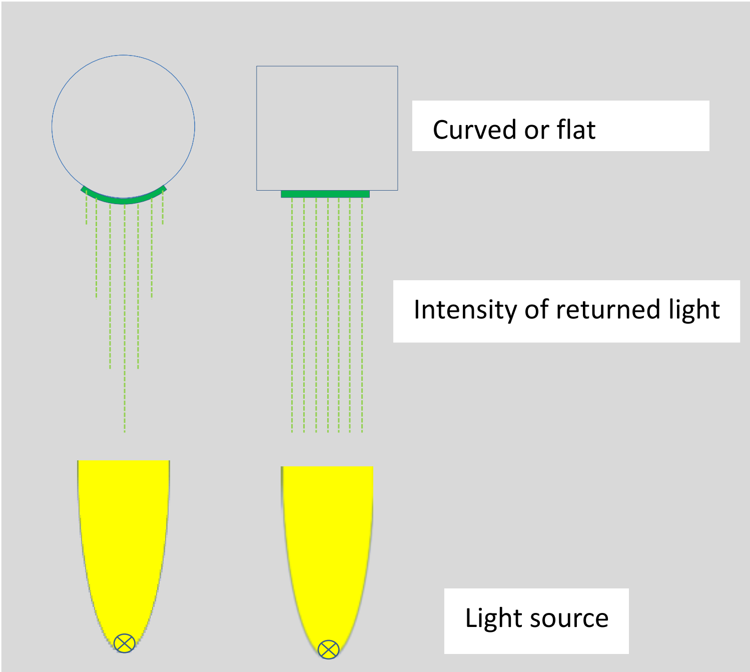

Figure 26 Retroreflectivity depending on the curvature shape of the buoy

8.3. FIXED MARINE AIDS TO NAVIGATION

Fixed AtoNs are static and their use is closely comparable with the use of retroreflective materials for road signs and markings for traffic.

Therefore, the use of retroreflective material and estimation of range can be more detailed compared to floating AtoN.

Fixed AtoN with retroreflectors are commonly for longer distance navigation compared to retroreflector applied on floating AtoN.

Day boards in leading line can be of a size of several square meters as shown in Figure 27. On leading marks, retroreflector of the front mark should be placed on the lower end of the daymark and reflector of the rear mark on the upper end of the daymark to ensure largest possible separation of the reflectors (see Figure 37).

Figure 27 Large day board of a leading line (DMA Greenland)

8.4. CALCULATION OF SIZE OF RETROFLECTORS FOR FIXED ATON

For the calculation of the approximately size of a retroreflector, the following quantities must be known:

- the intensity of the searchlight, I_s [cd]
- the distance between the searchlight and the retroreflector, d [m]
- the retroreflectivity (datasheet from supplier), R_a [cd/lx/m^2]
- the meteorological visibility, V [m]

Allard's law allows the calculation of the illuminance as a function of distance, luminous intensity and the meteorological visibility [9]:

Equation 3 Calculation of the incident illuminance at the retroreflector

$$E_s(d) = I_{ls} \frac{0.05^{\frac{d}{V}}}{d^2}$$

where:

E_s	is the illuminance at the surface [lx]
I_{ls}	is the luminous intensity of the light source [cd]
d	is the distance between the light and the surface [m]
V	is the meteorological visibility ($V = V_{0,05}$) [m]

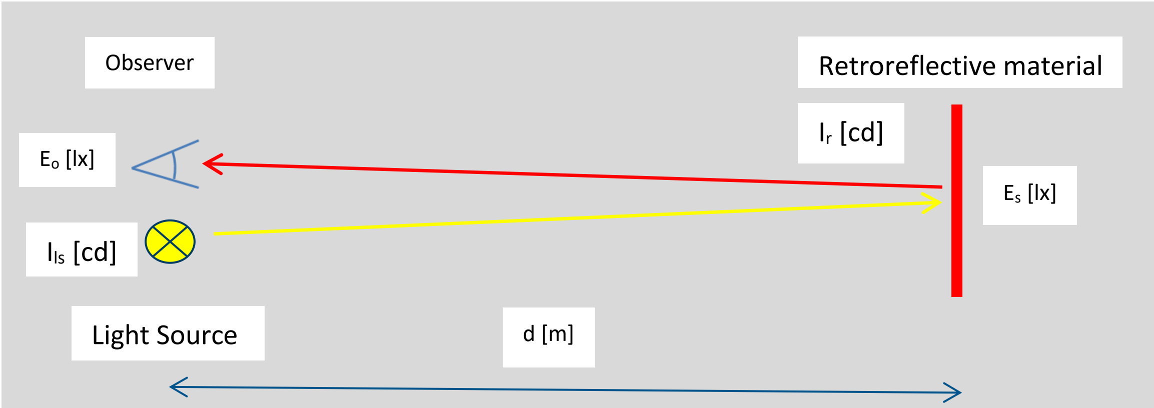

Figure 28 Quantities of Allard's Law

Equation 4 Calculation of illuminance (E) at the eye of the observer

$$E_o = I_r \frac{0.05^{\frac{d}{V}}}{d^2}$$

where:

E_o is the illuminance at the eye of the observer [lx]

I_r is the luminous intensity of the retroreflective material [cd]

d is the distance between the light and the observer [m]

V is the meteorological visibility ($V = V_{0,05}$) [m]

Equation 5 Calculation of the luminous intensity of the retroreflector

$$I_r = k_{scf} * R_a * E_s * A$$

where:

I_r is the luminous intensity of retroreflective material [cd]

R_a is the retroreflectivity of the reflector [cd/lx/m^2]

E_s is the incident illuminance at the retroreflector surface [lx]

A is the size of the retroreflector [m^2]

k_{scf} is the service condition factor

Equation 6 Calculation of the size of a retroreflector

$$A = \frac{I_r}{k_{scf} * R_a * E_s}$$

The luminous intensity, I_r must be equal to or greater than the intensity required to meet the intended distance.

8.4.1. EXAMPLE OF CALCULATION SIZE OF RETROREFLECTOR IN A LEADING LINE

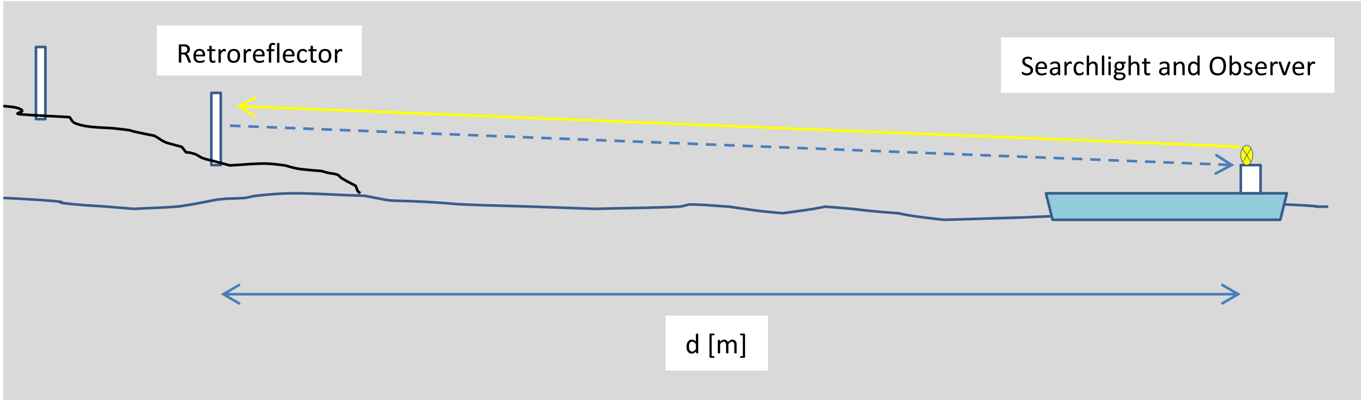

Figure 29 Leading line with retroreflectors (DMA)

Table 5 Data Sheet of retroreflective film used in the case story

Minimum Coefficient of Retroreflection [cd/(lx * m²)]							
Geometry of measurements		Colour					
α	β_1, (β_2 = 0)	White	Yellow	Red	Green	Blue	Orange
0,2°	+ 5°	250	170	45	45	20	100
	+ 30°	150	100	25	25	11	60
	+ 40°	110	70	15	12	8	29
0,33°	+ 5°	180	120	25	21	14	65
	+ 30°	100	70	14	12	8	40
	+ 40°	95	60	13	11	7	20
2°	+ 5°	5	3	1	0,5	0,2	1,5
	+ 30°	2,5	1,5	0,4	0,3	-	1
	+ 40°	1,5	1,0	0,3	0,2	-	-
”-” indicates ”Value greater than zero but not significant or applicable”							

Case Story Example:

A day board of a leading line is fitted with white retroreflective film. The retroreflective film conforms to EN 12899-1:2007 for class RA 2 and has a coefficient of retroreflection of 250 cd/ (lx*m^2) covering a viewing angle β of +5°. Due to the distance vessel/retroreflector and the site of the observer on the bridge just below the searchlight, the observation angle α is selected to be 0.2°

The maximum user distance is one nautical mile (1,852 m).

The visibility is 10 M (18,520 m). There is no background lighting. The vessel has a searchlight with a luminous intensity of 100,000 cd.

Calculate the minimum size of the retroreflector in m^2.

1. Calculate the incident illumination at retroreflector:

$$E_s = I_{ls}\frac{0.05^{\frac{d}{V}}}{d^2}$$

$$E_s = 100{,}000\frac{0.05^{\frac{1852}{18520}}}{1852^2}$$

$$\boldsymbol{E_s = 0.021608\ lx}$$

2. Calculate the minimum size of the retroreflector:

The observation distance in the example is 1 M, therefore I_r = 5 cd (for leading lines use 1 µlx for threshold of illuminance)

$$A = \frac{I_r}{k_{scf} * R_a * E_s}$$

$$A = \frac{5}{0.75 * 250 * 0.021608}$$

$$\boldsymbol{A = 1.234}\ \mathbf{m^2}$$

For practical purposes this is approximately equivalent to a retroreflective board of 1.50 x 1.0 m.

9. BEST PRACTICE AND TYPICAL APPLICATIONS

In this chapter, pictures show best practice methods on the application of retroreflective materials.

Figure 30 Green lateral light buoy with horizontal retroreflective sheets

Figure 31 Red lateral spar buoy with horizontal retroreflective band on full circumference of the buoy

Figure 32 Retroreflective band on a North Cardinal and a West Cardinal buoys (Comprehensive Code)

Figure 33 South Cardinal with vertical retroreflective sheets (Comprehensive code)

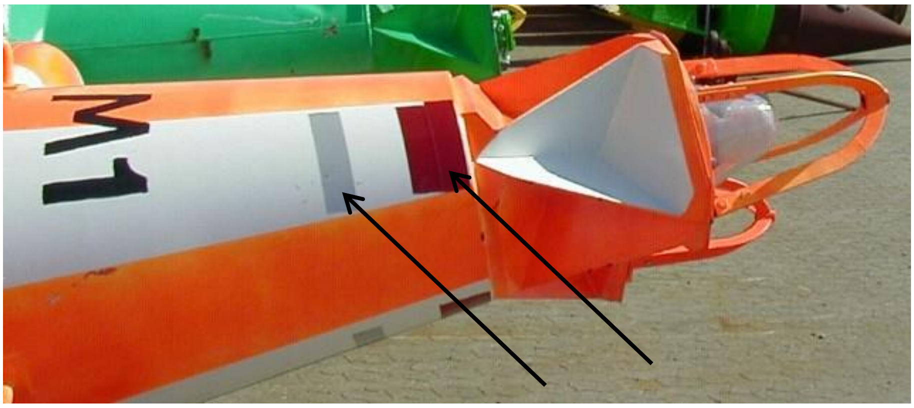

Figure 34 Safe Water light buoy with horizontal retroreflective sheets (Comprehensive Code)

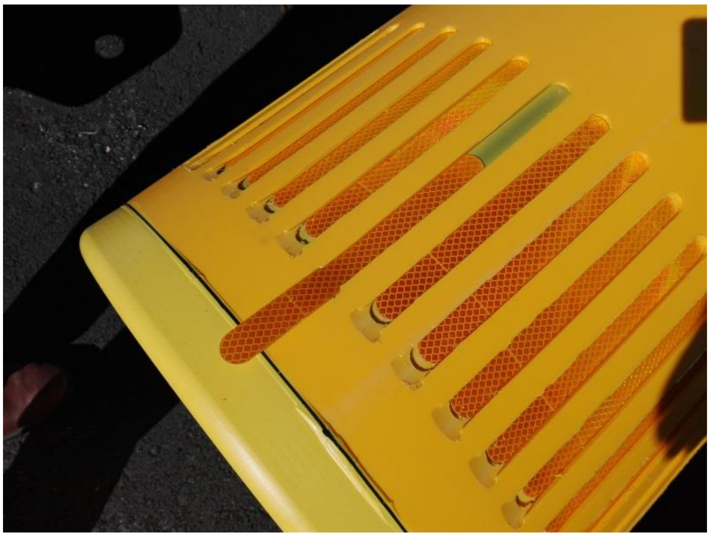

Figure 35 Example of a protective arrangement of retroreflective material

Figure 36 Offshore green lateral mark with horizontal retroreflective band on full circumference

Figure 37 Front day board with partly covering yellow retroreflective sheeting for night time use

Figure 38 Pier head attached with fluorescent yellow retroreflective material

Small waterways in tidal water may be marked with withies. The waterway is used at high water only. The withies are made of wood and have a bush as a top mark. Due to the high humidity the bush serves a low range radar reflector.

The withies are installed at low water. For night time use, a retroreflective band is attached.

Figure 39 Use of withies in tidal water

Figure 40 Retroreflective sheet fixed to a withy

Figure 41 Appearance of retroreflective sheets at day and at night with search light illumination

In Figure 42 a special mark with retroreflective material is shown. The buoy is for marking an anchoring position. It has two yellow retroreflective vertical stripes on the cylinder and some material at the radar reflector. The lettering is made of black retroreflective material which appears black at day and white illuminated by a search light.

Figure 42 Special mark buoy

10. DEFINITIONS

The definitions of terms used in this IALA guideline can be found in the International Dictionary of Marine Aids to Navigation (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

11. ABBREVIATIONS

ASTM	American Society for Testing and Materials (today named ASTM International)
AtoN	Marine Aid(s) to Navigation
CIE	Commission Internationale de l'Eclairage / International Commission on Illumination
DIN	Deutsches Institut für Normung (German Institute of Standardization)
DMA	Danish Maritime Authority
EN	European Standards (translation from French/German as European Norms)
IMO	International Maritime Organization
MBS	IALA Maritime Buoyage System
Ra	Coefficient of Retroreflection
SOLAS	The International Convention for Safety of Life at Sea
UV	Ultraviolet (light) (10 – 380 nm)

12. REFERENCES

[1] IALA. Recommendation R0106(E – 106) Use of Retro-reflective Materials on Aids to Navigation Marks within the IALA Maritime Buoyage System

[2] IALA. Recommendation R0108(E-108) The Surface Colours used as Visual Signals on Aids to Navigation

[3] IALA. Guideline G1134 Surface Colours used as Visual Signals on AtoN

[4] IALA. Guideline G1094 Daymarks for Aids to Navigation

[5] IALA. Maritime Buoyage System (MBS)

[6] CIE 54.2-2001 Retroreflection: Definition and Measurement, ISBN 978 3 900734 99 2, CIE (Commission Internationale De L'éclairage/ International Commission on Illumination, www.cie.co.at)

[7] Handbook of Applied Photometry, Casmir DeCusitio

[8] Test methods for the coefficient of retroreflection of microprismatic sheeting materials, Kai Sørensen, DELTA, April 2004

[9] IALA. Recommendation R0202(E-200-2), Marine Signal Lights – Calculation, Definition and Notation of Luminous Range (or new guideline on calculation)

[10] IEC. 60050 International Electrotechnical Vocabulary, IEV ref 845-04-96, Symbol R

[11] IEC. 60050 International Electrotechnical Vocabulary, IEV ref 845-04-97, Symbol R'

ANNEX A SUMMARY OF REPORT ON ADHESIVENESS AND MECHANICAL DURABILITY OF RETROREFLECTIVE MATERIAL, SOLAR SIMULATOR FINLAND, 2017

Finnish Transport Infrastructure Agency (FTIA)

There are differences in adhesiveness, i.e., how well the sticker is adhered to the substrate under different conditions, resistance to abrasion and weather resistance of different retroreflective sheeting. These may be more important features in practice than optical performance, for example when used in ice buoys under harsh conditions.

Adhesion strength i.e., force needed to pull the sticker out of the substrate, may vary greatly depending type of the retroreflective sheeting, substrate, salt and other impurities on the surface and weather conditions during adhesion (temperature, humidity). In addition, the retention of adhesion after weather resistance and mechanical strain varies depending on the product.

Adhesion strength can be studied in a laboratory by evaluating or measuring the force needed to pull the sticker out of the substrate before and after cyclic weathering [Figure 43]. Abrasion resistance can be evaluated by abrasion tests (for example rotating wheel covered by sandpaper) and measuring residual gloss as a function of abrasion time [Figure 44].

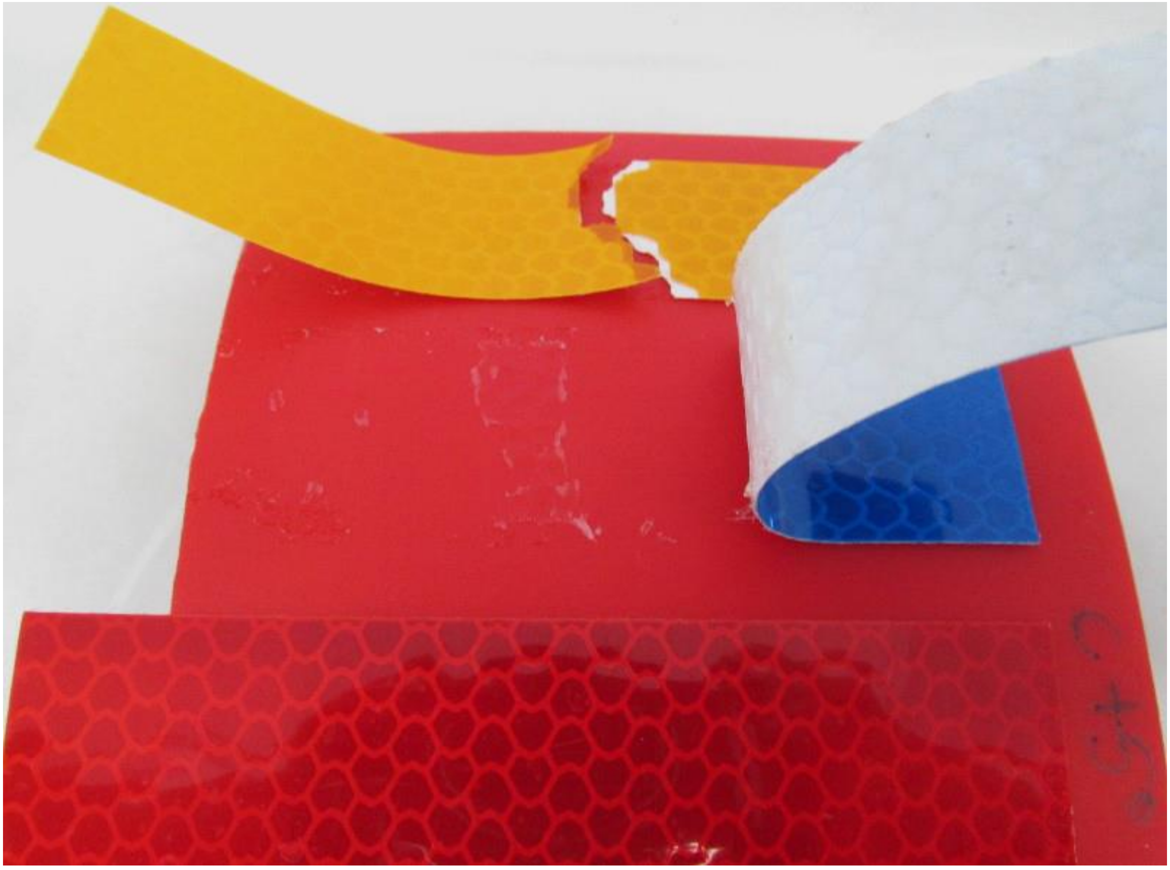

Figure 43 Comparative analysis of adhesiveness of retroreflective sheets applied to plastic buoy material [picture: Solar Simulator Finland Oy]

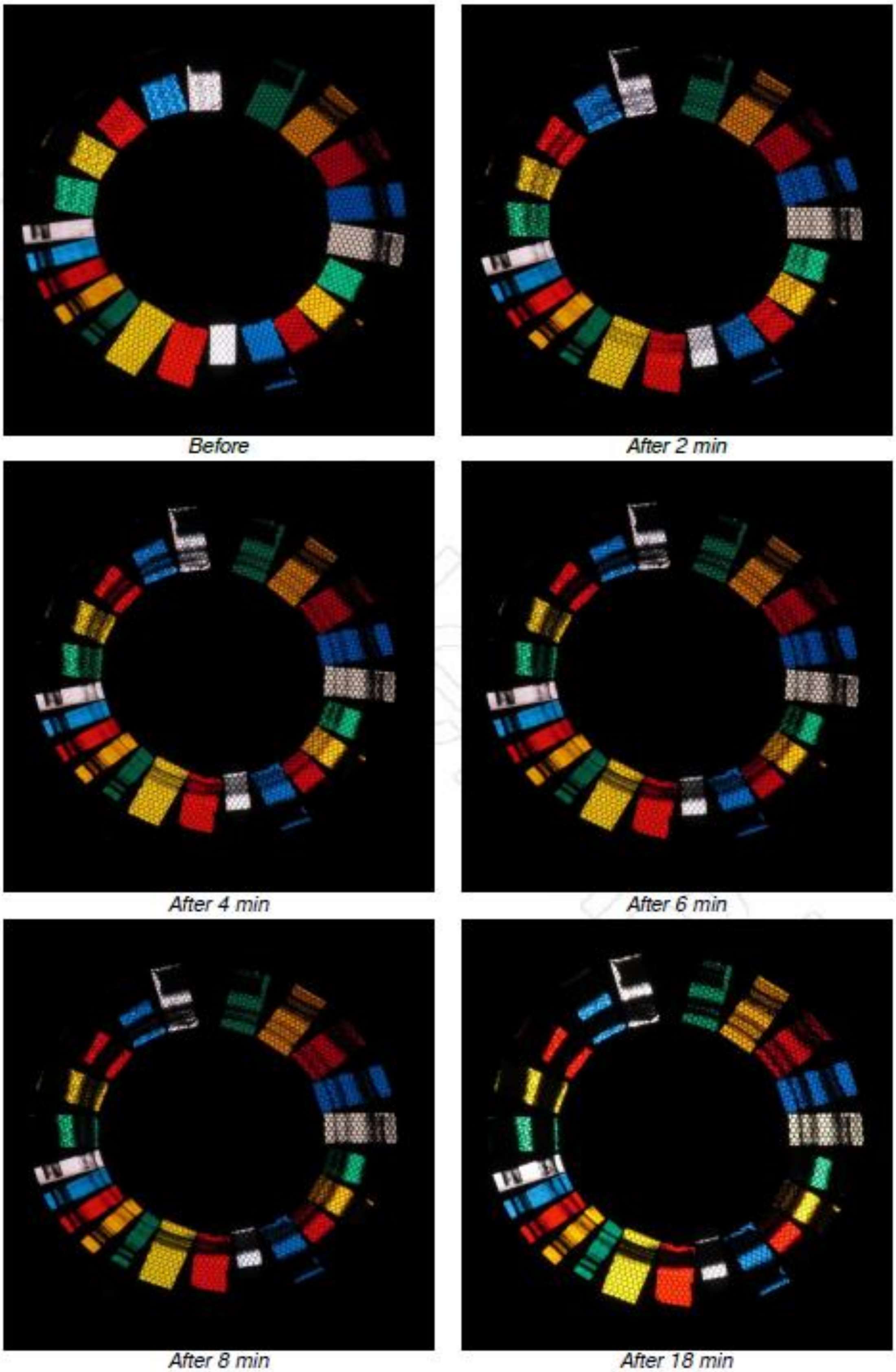

Figure 44 Comparative analysis of resistance to abrasion of retroreflective sheets [picture: Solar Simulator Finland Oy]