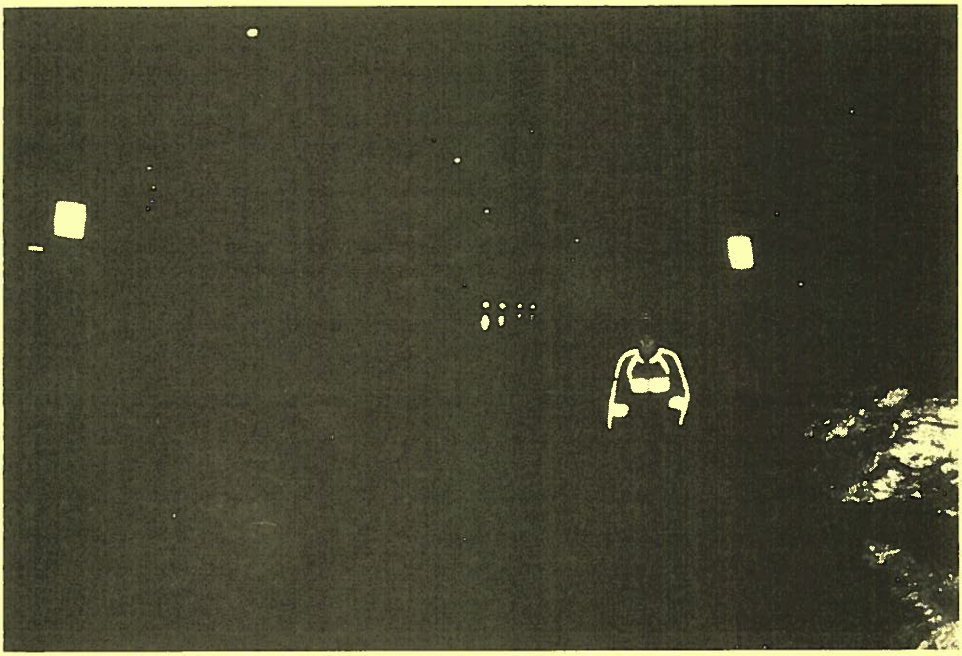
MÖRKERTRAFIK
NIGHT TRAFFIC
RAPPORT NR. 5 1982



PEDESTRIAN RETROREFLECTORS
FUNCTIONAL AND TECHNICAL REQUIREMENTS

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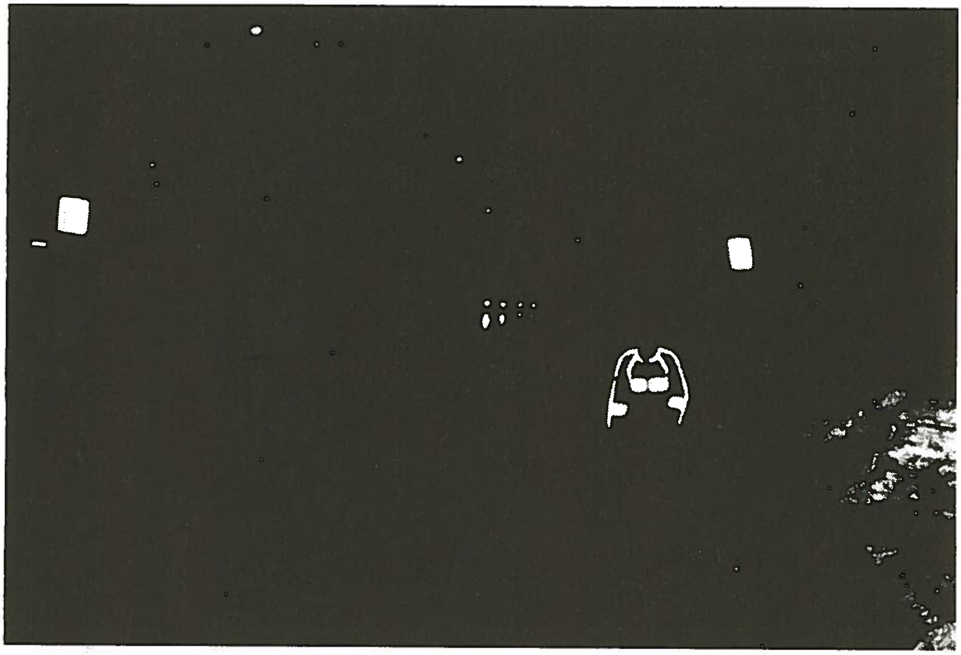

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PREFACE

The objective of this work is to provide an assembled presentation of today's knowledge concerning the use of pedestrian retroreflectors as aids to improve traffic safety. One also wishes to unify the various technical specifications for pedestrian retroreflectors existing in the Nordic countries.

The work has been conducted as a part of the Nordic cooperation on night time traffic research. In this cooperation the following institutions are involved:

- The Danish Illuminating Engineering Laboratory (LTL), Denmark
- The Road Directorate (VD-DK), Denmark
- Roads and Waterways Administration (VVS), Finland
- Norwegian Research Institute of Electricity Supply (EFI), Norway
- The Public Roads Administration (VD-N), Norway
- National Swedish Road and Traffic Research Institute (VTI), Sweden
- National Road Administration (VV), Sweden

The work is directed by a coordinating group, presently consisting of the following persons:

Kai Sørensen (LTL)
Jørgen Haugaard (VD-DK)
Pentti Hautala (VVS)
Hans-Henrik Bjørset (NTH/EFI)
Torkild Thurmann-Moe (VD-N)
Kåre Rumar (VTI), chairman
Karl-Olov Hedman (VV).

This report has been prepared by a project group consisting of:

- Birger Nygaard,
  Ministry of Justice, Denmark
- Matti Koivurova,
  Central Organization for Traffic Safety, Finland
- Kåre Rumar,
  VTI, Sweden
- Bjørn Brekke, project coordinator and report editor
  EFI, Norway

In addition, the following persons have contributed directly to the work of the project group, including the studies and experimental investigations which have been performed:

- Harald Lund-Jessen,
  LTL, Denmark
- Olli Halonen,
  Finnish Organization for Standardization, Finland
- Tapani Timonen,
  Technical Research Centre of Finland
- Sven-Olof Lundkvist,
  VTI, Sweden
- Bjørn Eide-Olsen
  EFI, Norway

The coordinating group has examined and accepted the report, and has at an earlier stage forwarded the proposals of the project group of technical requirements for pedestrian retroreflectors, to the road and traffic authorities of all the four countries.

CONTENTS

SUMMARY

Title : Pedestrian retroreflectors. Functional and technical requirements.

Publisher: Nordic Research Cooperation for Night Traffic.
Report No. 5, 1982
(The report may be obtained from: EFI, N-7034 TRONDHEIM-NTH, Norway)

Pedestrians are subjected to high accidental risks in night time traffic, a problem which is closely related to the poor visibility conditions generally present, especially on roads without permanent lighting installations. Presently, the only means for improving pedestrian visibility in a simple and efficient way is the retroreflector.

The importance of pedestrian retroreflectors as a traffic safety factor has been widely recognized for years in the Nordic countries. The problems remain, however, that

- Retroreflectors provide safety only as long as they are of a certain optical quality.
- The pedestrian himself is not able to decide whether his retroreflector is adequate for safe detection in traffic situations.
- The quality of retroreflectors on the market is highly variable.
- Retroreflectors deteriorate with time, due to environmental influences.
- The existing Nordic national regulations are rather incomplete, and although coequal, their requirements are somewhat different. Also, they deal with new (unused) materials only.

Recognizing the above problems, the project group has

initiated studies in order to determine what requirements should be put on retroreflectors when the aim is to ensure sufficient traffic safety value over a reasonable life time.

A safety distance of 140 m was adopted as the basis of technical requirements. This led to a corresponding minimum retroreflection requirement of about 300 mcd/lux for safe detection by car drivers on vehicle illuminated roads.

The optical and physical properties of retroreflectors have been reviewed. It turns out that the moulded prismatic (cube-corner) retroreflector is the most efficient type for dangling tags, while the glass bead retroreflector has properties that makes it advantageous for permanent mounting on garments (retroreflective fabric).

Comprehensive investigations of retroreflector qualities have been performed. New (unused) materials have been measured, and the processes of wear and tear during use have been studied, both by simulated strain in the laboratory and by actual use over time. These results show that polystyrene tags have a life time not much longer than one winter season (5 months), while the life time of retroreflective fabrics depends greatly upon the garment treatment, especially washing. Most high-quality materials of today will loose almost half of their initial retroreflection after 10 washings. Also, the washing deterioration may be partly compensated by applying larger retroreflector areas on the particular garment.

The main conclusion of the present work is a set of specifications for each main type of retroreflectors: Tags and retroreflective fabrics. The specifications state the functional requirements and describe relevant laboratory tests designed to ensure fulfilment of the functional requirements throughout a reasonable life time.

The specifications have already been forwarded to the traffic authorities of all the four participating countries for consideration.

Also retroreflector manufacturers, traffic organizations, consumers' organizations, clothes manufacturers and others see major benefits in common Nordic requirements for pedestrian retroreflectors. It is the hope of the Nordic Research Cooperation that the proposed specifications shall reach international acceptance also outside the Nordic countries.

SAMMENDRAG

Tittel : Fotgjengerreflekser. Funksjonelle og tekniske krav.

Utgivere: Nordisk forskningssamarbeid om mørketrafikk.
Rapport nr. 5, 1982.
(Rapporten kan bestilles hos EFI,
N-7034 TRONDHEIM-NTH).

Fotgjengere er utsatt for høy ulykkesrisiko i mørketrafikken, et problem som vesentlig skyldes den reduserte synligheten som normalt opptrer i mørke, spesielt på veger uten fast lysanlegg. Den mest effektive kjente metoden for å øke synligheten av fotgjengere er bruk av retroreflektorer.

Betydningen av fotgjengerreflekser som trafikksikkerhetsfaktor har vært bredt anerkjent i mange år i de nordiske landene. Likevel er følgende problemer fortsatt til stede:

- Reflekser gir sikkerhet bare så lenge de har en viss optisk kvalitet.
- Fotgjengeren selv kan ikke avgjøre om hans refleks er tilstrekkelig for sikker oppdagelse i trafikksituasjoner.
- Kvaliteten av reflekser på markedet er svært variabel.
- Reflekser ødelegges over tid på grunn av påvirkninger fra omgivelsene.
- De eksisterende nordiske nasjonale spesifikasjoner er forholdsvis ufullstendige, og selv om de er likeverdige, er de tekniske kravene noe ulike. Dessuten gjelder de kun for nye (ubrukte) materialer.

Under erkjennelse av disse problemene har prosjektgruppen satt i gang undersøkelser med sikte på å

avgjøre hvilke krav som må stilles til retroreflektorer når målet er å sikre tilstrekkelig trafikksikkerhetsverdi over en rimelig levetid.

De optiske og fysikalske egenskapene hos retroreflektorer er gjennomgått. Det viser seg at støpte prismereflekser (cube-corner-reflekser) er de mest effektive som brikker, mens glassperle-reflekser har egenskaper som gjør dem fordelaktige til permanent montering på plagg (tekstilrefleks).

Omfattende undersøkelser av reflekskvaliteter er blitt gjennomført. Nye (ubrukte) materialer er målt, og slitasjeprosessene ved bruk er blitt studert. Det gjelder både simulerte påkjenninger i laboratoriet, og virkelig bruk over tid. Disse resultatene viser at polystyrene-brikker har en levetid som ikke er mye lenger enn en vintersesong (5 måneder), mens levetiden for tekstil-reflekser avhenger sterkt av plaggbehandlingen, særlig vasking. De fleste materialene av høy kvalitet pr. idag mister mindre enn halvparten av retrorefleksjonen etter 10 vaskinger. Dessuten kan vaskeslitasjen delvis kompenseres ved å bruke større refleksarealer på det enkelte plagget.

Hovedkonklusjonen på det foreliggende arbeidet er et sett spesifikasjoner for hver hovedtype retroreflektorer: Brikker og tekstilreflekser. Spesifikasjonene angir de funksjonelle kravene og beskriver relevante laboratorietester som er laget for å sikre at de funksjonelle kravene er oppfylt over en rimelig levetid.

Spesifikasjonene er allerede blitt overlevert til trafikkmyndighetene i alle de fire deltakerlandene for vurdering. Også refleksprodusenter, trafikkorganisasjoner, forbrukerorganisasjoner og andre ser vesentlige fordeler ved felles nordiske bestemmelser for fotgjengerreflekser.

INTRODUCTORY COMMENTS
by Bjørn Brekke

Pedestrian retroreflectors have been in common use for many years, especially in the Nordic countries. Investigations have so far also shown a steadily increasing use, and the latest Finnish report (Oranen, 1980) indicated that in rural areas in Finland as much as 60% of all pedestrians wear retroreflectors when being on the roads during the dark hours, while 50% wear retroreflectors in towns.

Bearing in mind that the acquirement and application of a retroreflector requires some action on the part of the user, in some cases even monetary expences, the findings of the Finnish investigation are quite impressive. The reason for the active interest shown by pedestrians, is no doubt to be found in a general need for safety. Information campaigns which are run regularly by traffic organizations and road authorities have made retroreflectors into the most widely recognized traffic safety factor for pedestrians.

However, retroreflectors provide safety only as long as they are detected at a certain minimum distance by oncoming car drivers. This implies that the retroreflectors must have a certain optical quality in order to be effective.

A major problem is that the wearer himself is unable to decide whether his own retroreflector is sufficiently bright to be detected. Therefore traffic situations may frequently occur where pedestrians think themselves safe, while in reality the quality of their retroreflectors is far inferior to what is required for safe detection.

This problem immediately calls for some sort of regulations defining what should be accepted as a pedestrian retroreflector.

A report concerning the use of pedestrian retroreflectors was made by The Nordic Road Safety Council in 1975 (NTR 1975). In connection with this work the possibility of making the use of retroreflectors compulsory was discussed. During the years 1978-1979 Finland, Sweden and Norway adopted standards and regulations for the quality of retroreflective tags (SFS,1979, Konsumentverket,1978, Samferdselsdepartementet,1978). Finland established at the same time a standard for retroreflective fabrics.

During the work with the Norwegian regulations, measurements confirmed that a number of the retroreflective tags on the Norwegian market at that time had a very low quality. Some of them could hardly be called retroreflectors at all (Brekke, 1980).

The regulations of 1979 led to a marked improvement of the quality of tags on the market. Therefore, one might also expect a similar effect from the introduction of specifications for retroreflective fabrics. However, the situation for fabrics is somewhat more complicated. Not only is it important to make the manufacturers improve the quality of their products, but in this case it is also important that designers and manufacturers of clothes become more interested in equipping their products with retroreflectors which will give the wearer a satisfactory degree of safety. This requires at least some knowledge about

- The technical properties of the retroreflector material
- How the retroreflector is supposed to function in a traffic situation.

The present work is meant to give some of this knowledge.

The technical specifications proposal, which is the main conclusion of the report, has already been forwarded to the traffic authorities of our four countries. It is hoped that this report will contribute to an increased general understanding of the potential traffic safety benefits lying in the regulated distribution and use of pedestrian retroreflectors.

1 VISIBILITY AND SAFETY OF PEDESTRIANS IN NIGHT TRAFFIC

by Kåre Rumar.

It is generally accepted that night driving is two - three times more hazardous than daylight driving per driven km. However, since most of the traffic is carried out during daylight hours the absolute accident figures are generally higher for daylight illumination. But some accident types - such as pedestrians being hit by cars are in many countries even in absolute figures more frequent in night driving than in daylight. These types of accidents are normally very severe since the speed of the car is high and since the pedestrian is completely unprotected.

Not only does accident statistics show very bad figures for night driving but basic research concerning vision under low levels of illumination also indicates that night driving is a situation for which man is not constructed and in which man's visual system proves inefficient.

The visual system is developed to function in good lighting conditions and has its highest performance characteristics at normal daylight conditions. In night driving conditions on the other hand, the visual situation is radically worsened. The illumination levels under which night traffic is carried out are in the lower region of photopic vision where the receptor sensitivity is considerably decreased. But it is important to stress that although it is called night traffic the illumination levels are so high that it is not scoptic vision that is used in night traffic. We normally refer to the night traffic illumination levels as photopic or mesopic.

Contrast sensitivity is drastically lowered at levels of night traffic illumination. While contrasts in day traffic are normally very high and not critical, they are of primary and vital importance in night traffic. The task of the driver in vehicle lighting is to distinguish between a somewhat brighter surface (e.g. a pedestrian) and a somewhat darker surface (the background). The task is often very close to the visual threshold.

On top of this basic visual deficiency come other properties of the eye especially important and critical in night traffic - glare sensitivity and night myopia. The main causes to glare in road traffic are the optical deficiencies of the eye that cause the veiling stray light. Other glare causes are adaption and neural interaction. On broad terms the so-called Holladay's law is valid and makes it possible to calculate the visual degradation caused by glare. The main cause for night myopia is probably the regression of the accomodation of the eye in night traffic towards the resting point. This is probably due to difficulties in adequate fixation and accomodation in the improperly illuminated visual field.

The effects of both glare and night myopia could be expressed in terms of decreased contrast sensitivity. Consequently, the inadequacy of the human eye in night traffic could be expressed in three words bad contrast sensitivity.

The low visual contrast sensitivity is most probably the basic reason for the high accident rate in night traffic. What would then be effective countermeasures? Very low contrast sensitivity could be translated into short visibility distances. Which visibility distance do drivers need from safety point of view?

According to the Nordic Association for Road Technique (NVF 1976) the shortest safe visibility distance at a normal rural road speed of 90 kmph is 140 m.

The various efforts to aid the visual system presented and tested so far (optical filters, glare shield glasses, special adaptation lamps, drugs, etc.) have been unsuccessful in improving vision in real night driving situations. On the other hand every effort should be taken to correct visual deficiencies of the eye - e.g. myopia, astigmatism.

The possibilities to improve visual performance by training are very limited. The contrast thresholds are of a physiological-optical nature rather than psychological. On the other hand it is quite possible to train drivers what to look for, where to look for it and when to look for it. Together with having drivers experience how bad their visibility level really is such a training would probably have favourable effects on the accident situation. The comparatively good night driving statistics for professional drivers gives some hope for the effect of training.

In order to make the traffic conditions during night driving correspond to daylight driving two different principles of light sources have been introduced - road and vehicle lighting. Road lighting is solved in principle but is a very expensive method in sparsely populated areas - such as the Nordic countries. In vehicle lighting the problem is the meeting phase - both the initial part on high beam and the final part on low beam. In this phase visibility distances to dark objects (pedestrians) on the road are normally around 50 metres and very seldom above 100 metres (Johansson et al 1963, Johansson & Rumar 1968, Rumar 1974, Helmers & Rumar 1975, Helmers & Ytterbom 1980). The only possibility to increase visibility above 140 m by changing vehicle illumination seems to be the polarized headlights (Johansson & Rumar 1970, OECD 1971, Helmers 1981).

What remains then is to change the appearance of the objects (pedestrians). Theoretically three possibilities seem available:

- to equip the pedestrians with lighting,
- to equip the pedestrians with retroreflective material,
- to have the pedestrians dress in bright clothes.

The first alternative is too complicated and will never work with present battery - technology. Several studies (Johansson et al 1963, Helmers & Ytterbom 1980) have shown that bright clothes is no solution. The visibility distances will not pass the limit 140 m.

The effect of retroreflective material has been shown in series of studies (Johansson et al 1963, Rumar 1974, Rumar 1976). The technical principles used (spheric or prismatic retroreflection) mean that the contrast against the dark background as seen by the driver from behind the headlights is several hundred times higher than that of white cloth. In consequence with that visibility distances to dark clothed pedestrians equipped with retroreflective material during vehicle meetings both in the high and low beam phases may well exceed the mentioned 140 meters. In order for that to happen it is however necessary that the retroreflection exceeds certain limits.

One commonly accepted way to express retroreflection is by the coefficient of luminous intensity (CIL), denoted millicandela/lux (mcd/lux). An effort to relate the CIL-values to visibility distances to pedestrians in low beam - low beam situations (the most difficult situation) is given in Figure 1. This curve is based on the unpublished measurements obtained by Berggrund & Rumar (1975). As can be seen from this curve <u>a visibility distance of 140 metres roughly requires a CIL-value of 300 mcd/lux</u>.

Pedestrians could be wearing retroreflective material in the form of special auxiliary retroreflectors such as dangling tags or as retroreflectors fixed to the normal clothing. The dangling tag has been shown to have a higher attention value when it is rotating (blinking) as compared to the fixed retroreflector (Berggrund & Rumar 1975). But the fixed retroreflectors improve the driver probability to identify the pedestrian as being a pedestrian (pattern recognition) and not something else. The identification of objects is an important but overlooked function. The more common retroreflectors become along our roads, the more important becomes a special way to identify pedestrian retroreflection pattern. Furthermore, the standard flat hanging tag always runs the risk of not showing any of its retroreflective surfaces. Therefore in a longer perspective the fixed retroreflective materials seem more promising. They do not demand anything from the wearer, they are always there and they always function - that is under two conditions:

- that they are so placed that they are effective in all horizontal directions,

- that they can endure normal wear and washing.

The large effect of pedestrian retroreflectorization is obtained on roads without stationary illumination. But tests (Berggrund & Rumar 1975) have shown that especially in wet conditions the effect is also substantial within street lighted areas - provided the vehicles are on low beam and not parking light. Furthermore, many cities presently switch off their street lighting part of the year or part of the night in order to save energy. In such situations pedestrian reflectorization would of course be very effective.

The conclusion is that pedestrian visibility in present night traffic is not acceptable. Normal detection distances in vehicle meeting situations on rural roads are around 50 m while about 140 m is required from safety point of view. The possibilities to improve visibility by changing human vision or vehicle lighting do not seem too promising - at least not in a shorter perspective. Retroreflective materials compensate the decreased contrast sensitivity of the eye in night traffic and is an effective, fast and inexpensive countermeasure. In order to reach a visibility of 140 m the pedestrian should be carrying retroreflective material with a retroreflection of about 300 mcd/lux. This value should be fulfilled also after some time of normal wearing and washing conditions. Specific requirements on pedestrian retroreflectorization are initially directed towards makers but are a prerequisite for as well effective information campaigns as for possible laws on compulsory wearing.

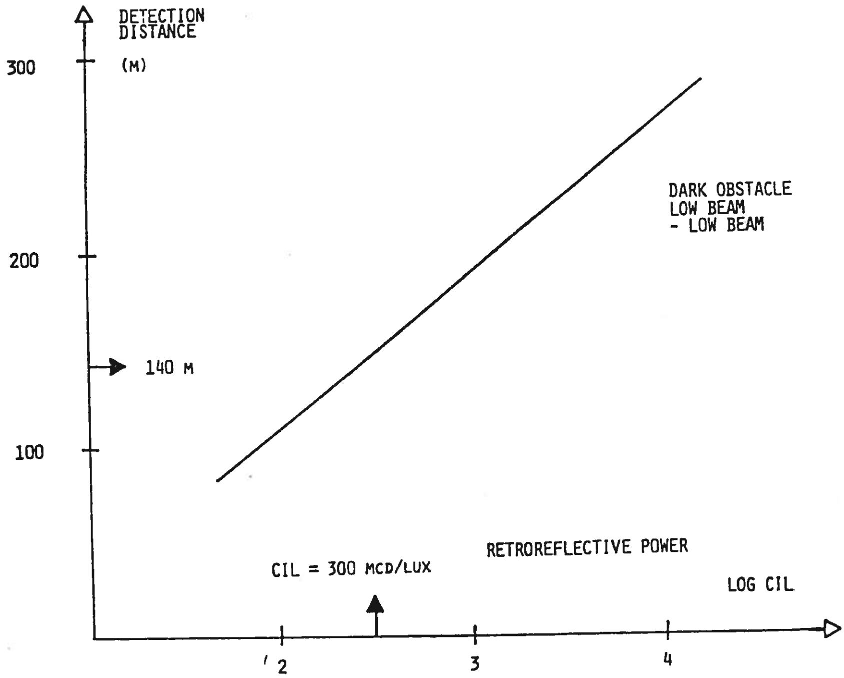


Figure 1. The relation between retroreflection and detection distance to a dark obstacle equipped with retroreflective material in a low beam - low beam situation.

2. RETROREFLECTORS

by Bjørn Brekke

2.1 Optical and physical characteristics

Although retroreflectors appear in a variety of shapes and sizes, depending on their use, they are all based on one of two optical principles, which may be called the cube-corner and the mirrored lens, respectively. Both types are used as pedestrian retroreflectors, and in this chapter their optical fundamentals are explained, and their individual characteristics as practical retroreflective aids are discussed. Also, the basic principles for measuring retroreflection are reviewed, and finally the problems of practical application of retroreflectors are discussed.

2.1.1 Cube-corner retroreflectors

The purpose of a retroreflector is to reflect incoming light back in the direction of the light source, and to achieve this within an appreciable range of the angle of incidence.

This may be obtained by means of a cube-corner as illustrated in figure 2.1a. The cube-corner consists of three mirrors mounted perpendicularly to each other, shaping a regular pyramid with the corner as the apex. The basis of the pyramid, the "entrance plane" of the retroreflector, is an equal-sided triangle defining the plane where the corner has been cut from the cube.

However, it is not very convenient to make retroreflectors by mounting three thin mirrors. An easier and more reliable method is to mould the pyramid in some transparent material (glass or plastic), and to mirror the outside of the three interperpendicular sides. This is how high-precision retroreflectors for optical purposes are constructed.

Cube-corners with mirrored surfaces will retroreflect light entering from any direction (within the cube-corner's own aperture limit). The process of mirroring, however, is expensive and not very realistic to use in mass production of low pedestrian retorereflectors.

The alternative is to use a solid pyramid without mirroring. For that case retroreflection will take place under certain conditions which may be illustrated by the two-dimensional situation of figure 2.1b. If the refractive index n_r of the material is sufficiently high, total reflection will take place at R_1 and R_2 simultaneously, and the incoming ray is thus turned 180^o before leaving the front surface again. If the angle v_i becomes too large the conditions for total reflection are eventually upset at R_1 or R_2 (or both), and the intensity of the retroreflected ray is strongly reduced, and more so the larger the entrance angle becomes.

It is possible to calculate the effective range of the entrance angle v_i when n_r is given (Brekke 1980). Using ordinary organic glass materials having

$$n_r \approx 1.55 - 1.60$$

the range of v_i giving total retroreflection is

$$v_i \approx \pm 5^o - \pm 10^o$$

which is still quite narrow.

As v_i increases beyond this limit, the amount of transmitted and absorbed light increases, with a corresponding decrease in retroreflected light. To extend the effective angularity, the apex angle of the pyramid may be varied. It can be demonstrated (Shreyer 1972) that a 1^o change of the apex angle

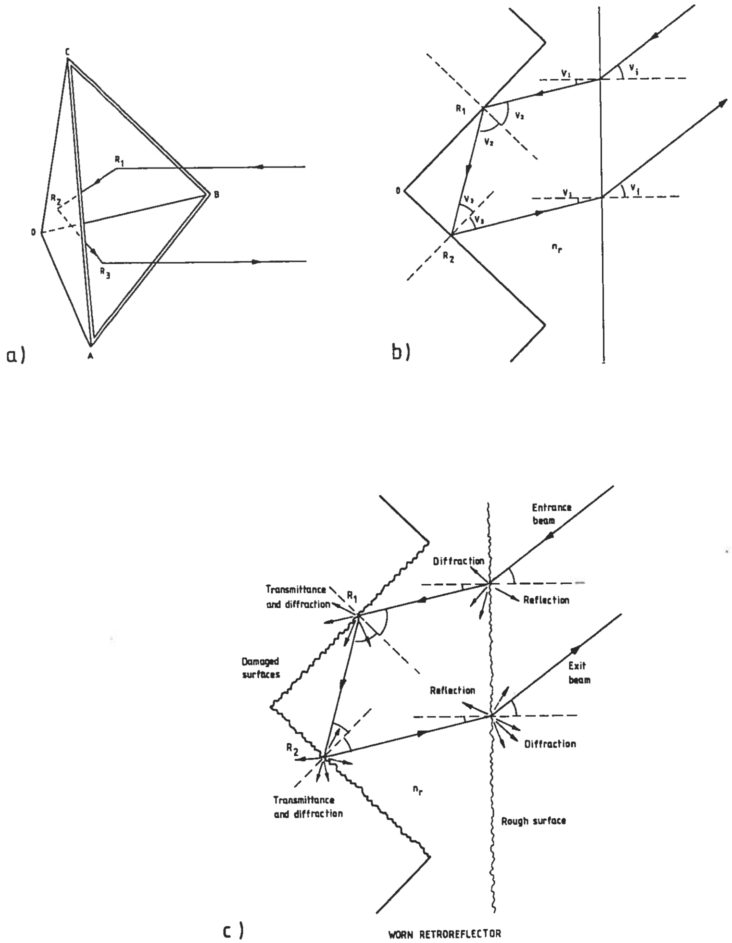


Figure 2.1 Optical principle of a cube-corner retroreflector. An entering ray is turned through 180° by three reflections on the sides of the regular pyramid (a). The two-dimensional case (b) illustrates retroreflection by simultaneous total reflection at R_1 and R_2. The maximum entrance angle v_i allowing total reflection, is determined by the index of refraction n_r for the cube-corner material. If the surfaces of the cube-corner are damaged by mechanical wear or moulding failure (c), the conditions for total reflection are partly upset, and the loss of light by diffraction is increased.

will diverge the retroreflected ray by approximately 6^{o}.

Another way of changing the angularity is to tilt the pyramid as a whole with respect to the basis plane.

A practical cube-corner retroreflecting device intended for use by pedestrians, usually consists of a few hundreds of single cube-corner pyramids, each having an extension of approximately 1-3 mm. There are alternative methods for modifying and grouping the pyramids in order to maximize the effective area of the total retroreflector (Shreyer, 1972).

The most common type of retroreflector is moulded in polystyrene. Acrylic glass has better properties when considering durability and wearing effects, but polystyrene is preferred mainly due to the higher index of refraction (~ 1.59 compared to ~ 1.49 for acryle).

The retroreflective power of the retroreflector depends critically upon the optical quality of the surfaces of the prisms, which again is determined by

- the surface quality of the moulding equipment

- the degree of control of the moulding process (temperature, pressure)

Defective surfaces caused by scars and dust on the equipment, or wrinkles caused by improper cooling rates, will upset the reflections and increase the relative amount of transmitted, diffracted and absorbed light. This is illustrated in figure 2.1c. A similar effect is caused by the constant wearing of the front surface during use of the retroreflector, also indicated in the figure.

To ensure total reflection on the pyramid sides, it is important that these are kept clean, and they must not be in physical contact with other materials than air. It is therefore common practice to make pedestrian retroreflectors by welding together two identical reflector "halves", leaving a certain distance between the opposing pyramids.

2.1.2 Micro-prism retroreflectors

While most types of cube-corner retroreflectors for pedestrians are of the moulded type described above, at least one different class of materials is in practical use. In this case, the cube-corner prisms are impressed on one side of a thin, flexible vinyl type sheeting material. The "micro-prisms" thus obtained are much smaller than those of the moulded retroreflectors, typical size 0.1 mm.

The optical principle of this retroreflector is identical to that of all other cube-corner types. Also in this case the prisms have to be protected from contact with other media. By means of a backing material ensuring an air-filled space, total reflection in the prisms is permitted.

2.1.3 Mirrored lens retroreflectors

If a spherical mirror is placed in the focal plane of a positive lens, the system will act as a retroreflector (figure 2.2a).

A perfect, solid sphere with an index of refraction which is exactly twice that of its environment, will focus incoming light on its own back wall (Brekke 1980). To make it into a retroreflector, one simply has to mirror a portion of the sphere surface (exactly half of it to get maximum aperture angle). This situation is illustrated in figure 2.2b.

However, it is generally not realistic to design retroreflectors based on glass spheres with n_g=2. If $n_g < 2$ the focal surface of the sphere will be found at some distance beyond the back wall of the sphere, as indicated in figure 2.2c. (n_g=1.5 moves the focus to a distance d=R/2 from the wall).

A short inspection of the geometrical and optical properties of this retroreflector reveals that the mirrored lens avoids some of the problems encountered in the cube-corner. In particular, the ratio of retroreflected to incident light is less dependant upon the angle of incidence, since the amount of absorbed and transmitted light is roughly constant. This indicates that the lens retroreflector generally can be used for a wider range of the angle of incidence.

In practice, complete retroreflectors based on this principle consist of large numbers of near identical glass beads with diameters in the order of 0.05 mm, packed as tightly as possible to increase the effective area. Several techniques have been developed to solve the manufacturing problems of such devices, using glass beads floating in a transparent emulsion, and the retroreflection is achieved either by actual mirroring or by total reflection obtained after chemical processing (etching) of the outer part of the beads.

In some types of glass bead retroreflectors, especially the older ones, the beads are half immersed in a binder emulsion, while the upper parts are freely exposed. However, for reasons of mechanical protection, and in order to improve the optical quality of the device under

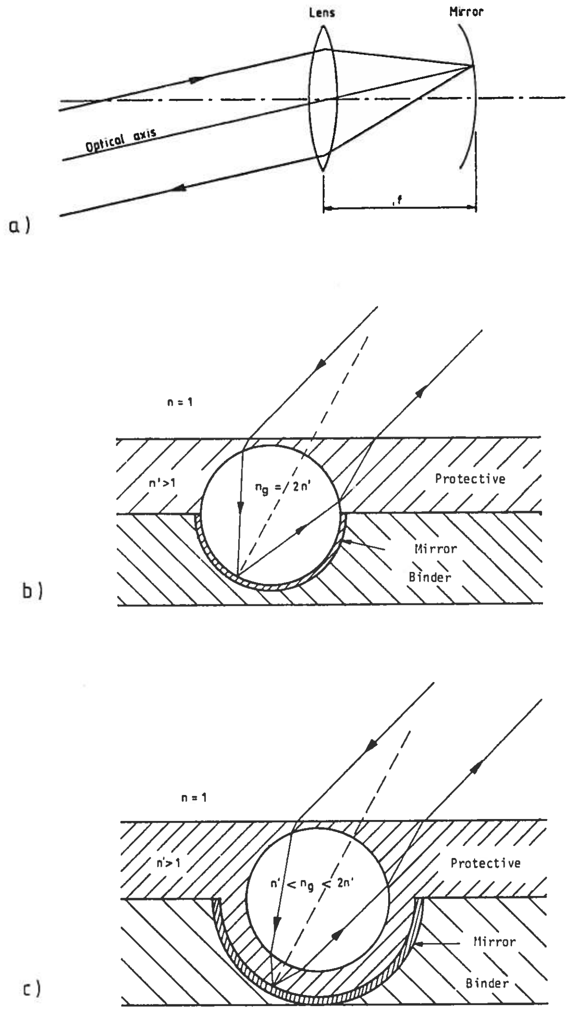


Figure 2.2 Optical principle of a glass sphere retroreflector. Incoming light is focused and returned in the same direction by a mirror placed in the focal plane of the focusing lens (a). If a glass sphere has an index of refraction which is twice that of its environment, it focuses light on its own back wall (b). If the index of refraction is lower, the mirror must be placed at a certain distance from the sphere (c).

certain difficult situations, most retroreflectors are today supplied with a transparent protective layer covering the beads and ensuring a plane front surface.

These types of retroreflectors are manufactured in large sheets, and with a variety of backing materials, depending upon their intended use.

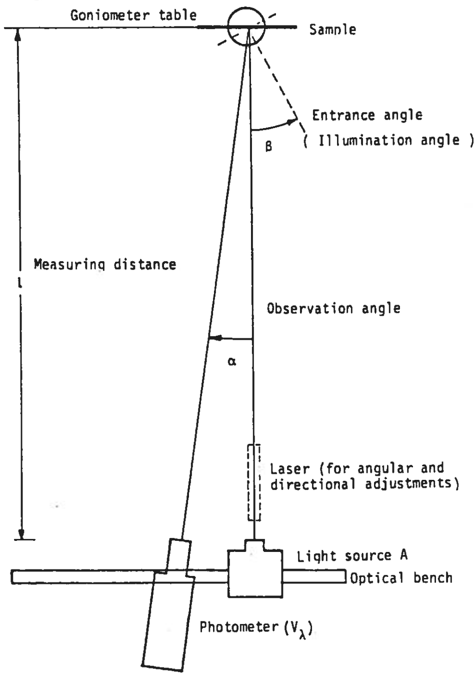


Figure 2.3 Geometry for retroreflection measurements. The entrance angle β is varied by moving the sample holder by a two-axes goniometer, while the observation angle α is changed by moving the detector relative to the light source. (The figure is a sketch in the horizontal plane).

2.2 Geometry and measurement of retroreflection

2.2.1 Measurement principle

Retroreflection characteristics are measured by means of a set-up, the principle of which is shown in figure 2.3. This is a sketch of the arrangement in the horizontal plane. The retroreflector is mounted on the sample holder of a two-axes goniometer (horizontal and vertical axes). It is uniformly illuminated by the source, which is light source A, to simulate night-time traffic conditions. The detector is V_λ-corrected to account for the sensitivity of the human eye, and may be moved horizontally in relation to the light source to change the angle of observation, α. The retroreflector is assumed to have a plane front surface, defining a normal direction. As the sample is rotated about any of the two axes, the entrance angle β (angle of incidence or illumination angle) is determined by a vertical component β_1 and a horizontal component β_2. The laser is a convenient means for defining $\beta_1 = \beta_2 = 0$ (Reference position).

2.2.2 Geometrical conditions

To measure true retroreflection, the detection should take place in the direction of the source (which could be achieved by means of a beam splitter arrangement). However, for practical applications this ideal situation is not the one of the greatest interest. A pedestrian retroreflector is to be viewed by car drivers, who in ordinary passenger cars have their eyes situated approximately 0.60 m above the car headlights. For a pedestrian retroreflector at 140 m distance this corresponds to an angular separation of 0.25° between source and detector. For a truck driver the situation is somewhat different (0.65°).

Table 2.1 shows relations between car types and observation angles and distances.

Table 2.1 Relations between different car sizes, observation angles and retroreflector distances.

Car type	Eye-headlight separation	Angular separation α at 140 m distance	Distance corresponding to $\alpha = 0.33^{\circ}$
Passenger car	0.60 m	0.25°	104 m
Large van/ small lorry	1.10 m	0.45°	191 m
Truck/ Semi-trailer	1.60 m	0.65°	278 m

The quantity measured is the coefficient of retroreflection R'(cd/lux/m^2) or the coefficient of luminous intensity (abbreviated CIL), R(cd/lux). The magnitude of both depends critically upon the observation angle, as can be seen from figure 2.4. This particular curve refers to a cube-corner retroreflector. For a glass bead material, the curve is generally less steep.

A relevant question is therefore: At what observation angle should the retroreflector be measured in order to obtain a relevant description of its properties as a pedestrian safety device?
It appears from table 2.1 that if one assumes the majority of cars to be ordinary passenger cars, the proper observation angle would be 0.25°. However, 0.33° (20') is an internationally adopted angle for describing several types of retroreflectors used in road traffic. Also, Swedish investigations (Berggrund and Rumar 1975, Rumar 1976) showed that a retroreflector of R = 300 mcd/lux measured at $\alpha = 0.33^{\circ}$ and $\beta = 0^{\circ}$ is sufficiently

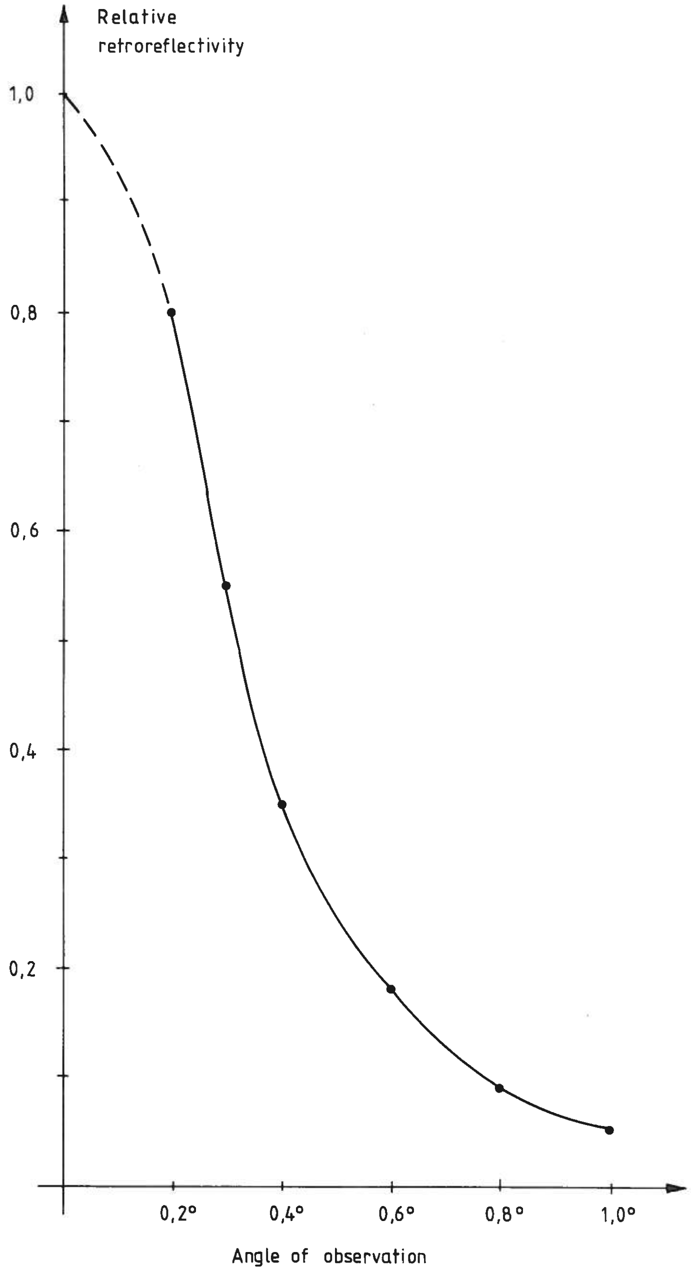


Figure 2.4 Example of relative coefficient of luminous intensity (CIL) for a cube-corner retroreflector as a function of the observation angle. For a glass bead retroreflector, the curve will be less steep.

conspicuous at D = 140 m with a passenger car. To what extent is this result also relevant for different types of cars, and other distances?

When the observation distance and/or the car size is changed, the following happens:

1. The observation angle is altered. This means moving on the curve of figure 2.4. If the distance is shortened, the angle increases, and the retroreflection is reduced. If the distance is increased, the opposite happens.

2. The illumination of the retroreflector by the headlights changes according to the inverse square law.

3. The observation condition changes according to the inverse square law.

It thus turns out that one is faced with two opposing effects:
At closer distance, there is more light available, but the angle is less favourable, and vice versa. Calculations show that the loss or gain of light with distance is the dominating factor.

Table 2.2 shows the relative brightness of a cube-corner retroreflector viewed from different car types at various distances. The reference situation (brightness unity) is observation from a passenger car at 140 m distance. When calculating the relative brightness values, the coefficient of luminous intensity (CIL) is corrected for the change in observation angle, using figure 2.4.

The luminous intensity I_D of the retroreflector at distance D can be expressed by:

$$I_D = R_\alpha \cdot E_D$$

where R_α is the coefficient of luminous intensity (CIL) for the observation angle α in question, and E_D is the actual illumination of the retroreflector.

Using the observation at 140 m from a passenger car as the reference situation, the illumination E_D can be written

$$E_D = E_{140} \frac{(140 + L)^2}{(D + L)^2}$$

where L is a factor correcting for the reduced divergence of the headlight beam, when using the inverse square law.

The luminous intensity of the retroreflector is then

$$I_D = R_\alpha \cdot E_{140} \frac{(140 + L)^2}{(D + L)^2}$$

It is generally assumed that the visual brightness is determined by the illumination of the observer's retina, which again depends upon the illumination E_p and area A_p of the eye pupil. The pupil illumination is simply

$$E_p = \frac{I_D}{D^2}$$

and the flux entering the eye is therefore

$$F_p = \frac{I_D}{D^2} \cdot A_p$$

On the retina, this flux is redistributed across a smaller area:

$$E_r = \frac{F_p}{A_r} = \frac{I_D}{D^2} \cdot \frac{A_p}{A_r}$$

where E_r is the retinal illumination, and A_r is the area of the retinal image.

If the retroreflector is sufficiently small, the area A_r will remain equal to the Airy disc (central diffraction pattern) of the eye pupil. This will be the case with a dangling tag at a distance of about 125 m and above. As long as the adaptation of the eye does not change, A_p will be constant, and therefore also A_r, independent of the distance D.

The apparent brightness of the retroreflector is now expressed by the following formula:

$$B \sim E_r = \frac{R_\alpha}{D^2} \cdot E_{140} \frac{(140 + L)^2}{(D + L)^2} \cdot \frac{A_p}{A_r}$$

$$= \frac{R_\alpha}{D^2 (D + L)^2} \left(\frac{E_{140} (140 + L)^2 A_p}{A_r} \right)$$

Since the expression within parenthesis is constant, the relative visual brightness is given by

$$B \sim \frac{R_\alpha}{D^2 (D + L)^2}$$

The factor L is of the order of -1 m for ordinary European car headlights (dipped). At distances D = 50 m and above this correction can be safely neglected, thus

$$B \sim \frac{R_\alpha}{D^4}$$

The relative brightness values of table 2.2 are of course approximate. Also, it should be remembered that the subjective (apparent) brightness of an observed source is a non-linear function of the objective (measured or calculated) brightness. To take this into account, one should allow the calculated relative value to be lower than 1 and still consider the retroreflection to be sufficient. In table 2.2 a border is drawn arbitrarily at $B_{rel} = 0.5$, thus limiting a region where the retroreflector may be considered as efficient.

Table 2.2 Relative visual brightness of a cube-corner retroreflector as seen by drivers of different car types and at various observation distances D. The brightness at D = 140 m with a passenger car is taken as unity.

Car type \ Distance D	60 m	100 m	140 m	180 m	220 m
Passenger	7.5	2.5	1.0	0.5	0.2
Lorry/van	2.0	0.8	0.5	0.3	0.2
Truck	1.0	0.3	0.2	0.1	0.1

In conclusion, the above analysis shows that a specification made to meet the observation requirements at D = 140 m for a passenger car, should be adequate for most car types, except possibly the very large trucks at distances above ~ 100 m. For these cases, it might be considered to make a specification at the observation angle $\alpha = 0.5^{\circ}$ or 0.7°.

The preceding discussion is based on a plane retroreflector oriented with its front surface in the vertical plane and its surface normal directed towards the light source, i.e. angle of incidence $\beta = 0^{\circ}$. In practice retroreflectors will move relative to the source and observer, and the angle of incidence may change considerably. It is therefore of interest to know the performance of the retroreflectivity as this change takes place, and to specify minimum retroreflectivity values at various angles.

Due to their physical limitations, as discussed in chapter 2.1, the retroreflectors will necessarily show limits to their effective angularities.
As the angle of incidence increases, the following happens:

- The effective retroreflective area decreases
- The relative amount of absorbed, diffracted and transmitted light increases.

Generally one finds that the effective angular region is $\pm 30^{0}$ to $\pm 50^{0}$, somewhat less for cube-corners than for glass bead retroreflectors.

If for a given angle of observation α the CIL is measured as a function of β, one obtains characteristic curves like those shown in figure 2.5.

The difference in response between cube-corners and glass bead materials is typical. The cube-corner has a higher peak and steeper curve than the other one. If the response is measured with $\beta_1 = 0$ and β_2 varying, a sharp peak will appear on top of the response curve at $\beta_2 = 0$, due to mirror reflection on the retroreflector's front surface. To avoid this unwanted effect, it is useful to give the retroreflector a small tilt of about 5^{0} in the vertical direction while measuring.

Recommendations for a standard geometry for measuring retroreflectors have recently been given by CIE (CIE 1980). These recommendations are followed in this presentation.

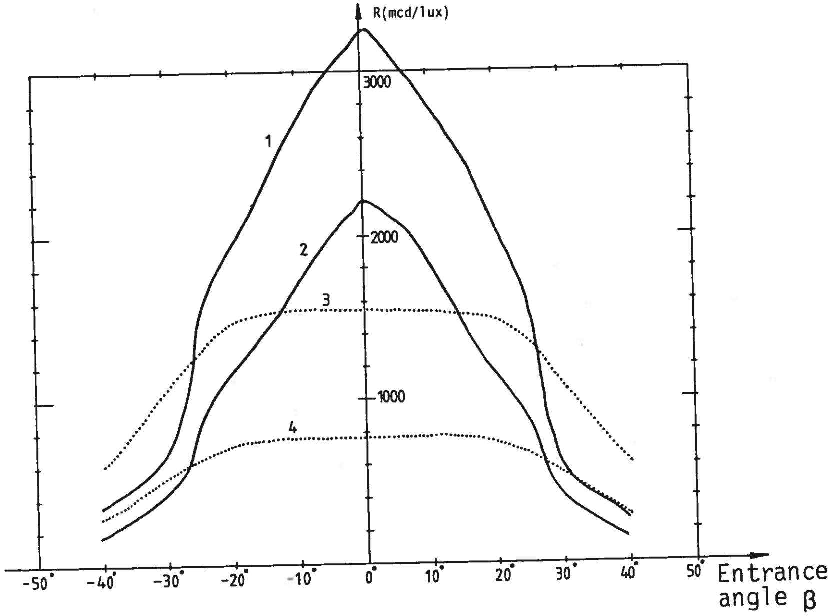


Figure 2.5 Characteristic shapes of CIL-curves for retroreflectors. Curves 1 and 2 are for two different circular cube-corner tags, area approximately 20 cm^2. Curve 4 is for a circular piece of a glass bead retroreflector of the same area, while curve 3 is for twice the area of the same glass bead material. It appears from the curves that the efficiency of the retroreflector is less dependant upon the entrance angle of the light in the case of glass bead material.

2.3 Practical application of retroreflectors

2.3.1 Functional requirement

Experimental investigations under true night time traffic conditions (Berggrund and Rumar 1975, Rumar 1976) have demonstrated that a retroreflector with an exposed CIL-value of approximately 300 mcd/lux has a visibility distance of about 140 m, which is the minimum safety distance recommended by the Nordic Association for Road Technique (NVF) for rural roads with 90 kmph speed limit. (It should be noted that the CIL-value is then measured at an observation angle of 0.33°).

The functional requirement for any pedestrian retroreflector which is meant to serve as a safety device on the roads within the Nordic countries, may therefore be formulated as follows:

<u>To provide safety, any pedestrian retroreflector must expose a CIL-value of at least 300 mcd/lux in the direction of oncoming cars</u>.

The most important implication of this requirement is that the pedestrian must, to be considered safe, be equipped with retroreflectors which expose the necessary 300 mcd/lux in all directions simultaneously. Otherwise, the pedestrian may still be invisible to drivers approaching from certain directions.

Any specification of technical requirements for retroreflectors must aim towards improving the ability of retroreflectors to fulfil the functional requirement. In order to achieve this, it is useful to start with an analysis of how the main types of retroreflectors may be arranged to ensure maximum visibility.

2.3.2 Dangling tags

The dangling tag has been the most commonly used pedestrian retroreflector for many years. Its characteristic feature is the blinking effect that arises from a more or less regular rotation. The rotation will inevitably occur if the string of the tag is sufficiently long, due to the person's movements, air draughts and so on. The blinking increases the conspicuity of the retroreflector, as was also observed in the Swedish investigations (Rumar 1976). This is in accordance with the commonly observed effect that an intermittent light signal is more conspicuous than a steady light of the same intensity (Imperial College, 1971). However, this enhancement effect on the visual impression does not allow a reduction of the required CIL-value. The tag does not necessarily always rotate, and even when it is oriented at an angle it should fulfil the functional requirement.

Due to the physical limitations of the retroreflector, this is not possible for any orientation. What one can do, is to extend the effective angular region as much as possible. The most common type of dangling tag retroreflector is the moulded cube-corner type. As one can see from figure 2.5, it has a rather narrow angular characteristic, with a high, peaked maximum retroreflectivity. This goes well with the rotation and blinking principle. To ensure maximum performance over a certain range of the illumination angle, the minimum top value should be higher than 300 mcd/lux, and at least 400.

This minimum top value should not be specified for $\beta_1 = \beta_2 = 0$, but at a small tilt angle in one of the directions, due to the problem of surface reflection. Also, to avoid too narrow angular characteristic, another minimum CIL-value should

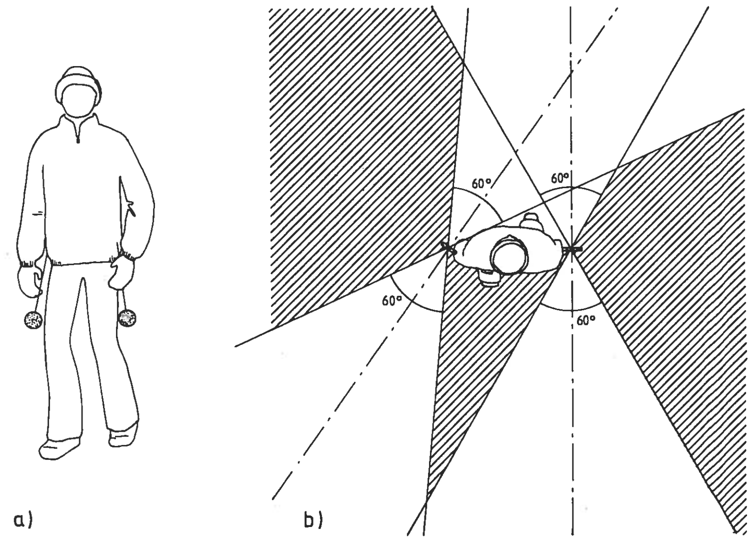


Figure 2.6 Cube-corner retroreflector tags have relatively narrow effective angular domains. Therefore tags must be allowed to rotate, and should always be worn in pairs (a).
For a certain orientation of the tags, the "dark" domains of the horizontal plane are considerable (b).

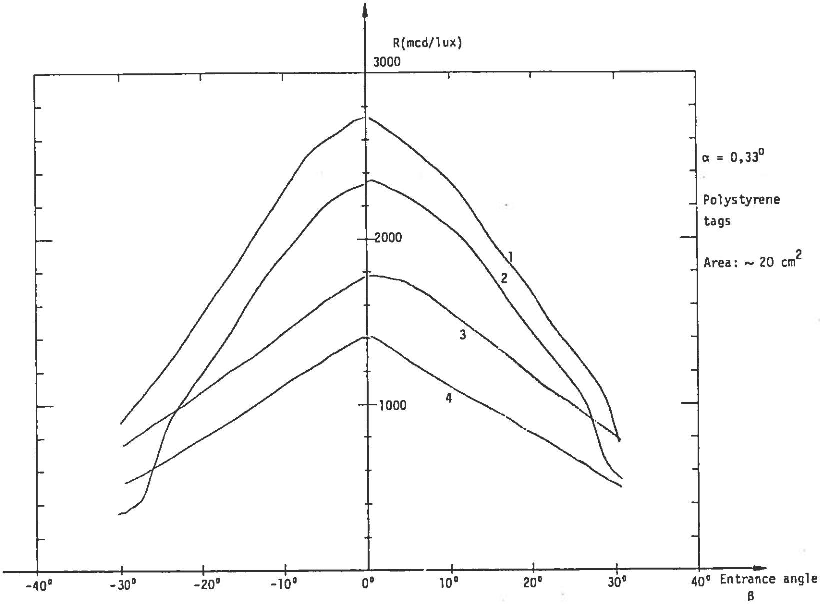


Figure 2.7 Typical CIL-curves for cube-corner tags on the Nordic market in 1981. Compared to the requirement of 400 mcd/lux as the minimum top value, these retroreflectors are extremely good, at least in new condition, as these curves show.

be specified at a higher entrance angle. Since most cube-corners tend to drop drastically in retroreflection at about $\pm 30^{\circ}$, the additional specification should be made for instance for $\pm 20^{\circ}$. By studying the performance of common retroreflectors on the market, 250 mcd/lux seems to be a reasonable value at $\pm 20^{\circ}$ (see figure 2.7).

It appears that the practical, effective angular domain for a cube-corner retroreflector is approximately 60°. The ordinary, two-sided tag thus may cover 120° at a given orientation, but this is still only one third of the total horizontal plane. Therefore, the tag can never fulfil the functional requirement without rotating.

To achieve the best result, the tags should be worn in pairs, one on each side. They should be suspended in strings that are long enough to allow rotation and avoid the tag being covered by arms or hands. Also, this arrangement should allow at least one of the tags to be freely exposed in any direction of the horizontal plane with very short intervals. Figure 2.6 illustrates the situation discussed above.

Since the first official regulations concerning dangling tags were introduced a few years ago, the quality of the cube-corner retroreflectors on the market has been greatly improved. Figure 2.7 shows average performances of a few of the more important types, all manufactured and sold in 1981. It appears that all of them has a CIL-performance high above the minimum requirement, some satisfying the functional requirement also at maximum angle ($\pm 30^{\circ}$).

However, it must be remembered that these measurements were made on new (unworn) samples. It is important that specifications are made for the retroreflectors to fulfil after a certain time of use. All retroreflectors are degraded with use, due to damage to the outer surface, as explained earlier (chapter 2.1, figure 2.1c).

Coloured tags.
Nordic road authorities have advised that pedestrian retroreflectors should not appear orange or red in colour to the observer. This is to avoid confusion with other retroreflectors and lights in road traffic, like rear lights of bicycles, motorcycles and cars, stopping lights and directional lights. It is therefore required to specify colours in the region of white to yellow-white for tags, but any precise (measured) colour limits are considered unnecessary, at least in the present situation.

Another reason for not using strongly coloured retroreflectors, is that they will generally be far inferior to the colourless ones regarding CIL-value. This is especially true for colours in the red and blue regions, where the sensitivity of the human eye is low.

Colours in the yellow and green regions affect the quality less, and there are several types of tags made with fluorescent colours, especially in the yellow region. The loss of retroreflectivity due to the colouring is 10-20% for these tags, but as long as the CIL-values still are 2-3 times as high as the minimum requirement, the loss cannot be said to be of any importance.

The effect of the fluorescence by itself has not yet been studied, but it has been noted by several persons that the effect is conspicuous at dusk and dawn, when there is sufficient blue light scattered in the atmosphere to exite the fluorescence, but too little of longer wavelengths to give the impression of true daylight. The same is observed in dull weather, in heavy rain and in foggy conditions. The fluorescence is observed as a constant luminance, independent of car headlights or other light sources. The tag gives under such circumstances the impression of possessing its own interior light source. In particular a yellow-green type of fluorescent colour seems to be very prominent. Although this is based on subjective judgements, there seems to be reasons to investigate closer the effects of light fluorescent colours in cube-corner tags.

2.3.3 Retroreflective fabrics

Retroreflective fabrics are made to be sewn or adhered to the surface of garments. In some instances they appear as integrated parts of the garments themselves.

The main difference in practical performance between a dangling tag and a piece of garment-mounted retroreflective fabric, is that the latter does not rotate. Even when the pedestrian is walking, all angular changes are small and slow, and no blinking effect is observed. The fact that most retroreflective fabrics are of the glass bead type and show a rather flat retroreflection characteristic (figure 2.5) adds to the impression of steady light.

This type of retroreflector has a useful angular domain of about 80° (i.e. $\pm 40^{\circ}$) when mounted on a flat background. To fulfil the functional requirement it is necessary to ensure 360° covering. This can only be achieved by mounting retroreflective fabric on several parts of the garment.

Roughly one could say that the body has four "sides", and to cover 360° requires one piece of material corresponding to CIL = 300 mcd/lux on each side. Figure 2.8 shows how the retroreflectors may be arranged.

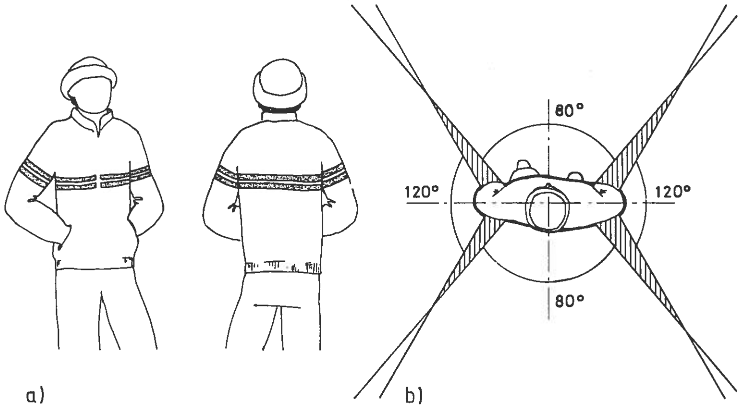


Figure 2.8 Retroreflective fabrics must be mounted on all sides of a garment to ensure visibility from all directions of the horizontal plane (a). Since the materials have a certain angularity, it may still not be necessary to cover the whole circumference (b).

The fact that the retroreflectors generally are not flat, is a problem when establishing relations between test results and practical performance. The actual curving of garment-mounted retroreflectors vary considerably, from the near flat back of a jacket to small wrinkles in the sleeve. One possible way to overcome this is to measure the retroreflection of test samples mounted on a cylinder of medium radius; another is to measure flat samples and later correct for actual curvature by the use of an empirical correction factor. Both methods have been tried, and prove to yield equally valid results. The latter method is preferable due to its simpler measurement conditions.

To establish the correction factor, two particular garments, children's overalls equipped with sufficient amounts of high quality retroreflective fabrics, were stuffed to correct shape and CIL-values measured from various directions. Simultaneously, the total visible area of retroreflector material was measured, and the corresponding CIL-values for the area in flat shape was calculated. Table 2.3 compares the measured and calculated CIL-values and gives the resulting correction factors. The value of the factor is found to vary between 1.4 and 3.0. It should therefore be safe to adopt the mean value of 2.0 for all cases. The same factor may also be used for other materials, since the angular characteristics differ very little between materials.

Since retroreflective fabrics are manufactured in large sheets and may be mounted in any shape and size on actual garments, it is not realistic to put CIL requirements on the material as such. Instead, the material should be tested for resistance to environmental factors (washing, rain, low temperature and so on), while a combined minimum CIL/area requirement is put on the use of the material on a single garment.

The calculation of the necessary area A_{min} to yield CIL = 300 mcd/lux when mounted on a garment, is based on measurement of the CIL-value R_{test} of a test sample of area A_{test}, and is made as follows:

$$A_{min} = \frac{300}{R_{test}} \cdot A_{test} \cdot 2$$

where 2 is the curving correction factor.

Table 2.3 Correction factors for curved retroreflective fabrics in relation to flat state. Measurements made on two different garments.

Direction of view	Visible area (cm^2)	Measured R_m (mcd/lux)	Calculated R_c (mcd/lux)	Correction factor $\frac{R_c}{R_m}$
Front	85	1535	2771	1.8
Front-left	55	1116	1793	1.6
Left	42	653	1369	2.1
Back-left	55	1239	1793	1.4
Back	85	1781	2771	1.6
Back-right	50	1027	1630	1.6
Right	35	443	1141	2.6
Front-right	50	1027	1630	1.6
Front	30	414	978	2.4
Front-left	23	352	750	2.1
Left	26	409	848	2.1
Back-left	22	340	717	2.1
Back	25	310	815	2.6
Back-right	17	291	554	1.9
Right	19	201	619	3.0
Front-right	18	256	586	2.3
			Mean value	2.05

The calculated area is the minimum requirement for exposure in any direction. The total area necessary for a pedestrian is therefore roughly four times as large, and the distribution should be as even as possible in the horizontal plane, as figure 2.8 shows.

Figure 2.9 contains measurement results for some retroreflective fabrics presently available on the Nordic market. Also included is a micro-prism material, since this is a flexible, variable area retroreflector intended for application to garment surfaces.

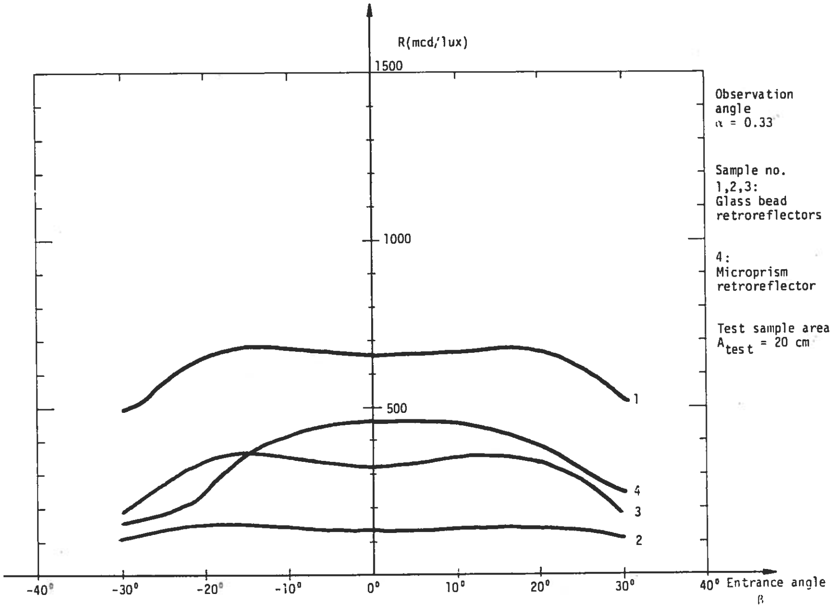


Figure 2.9 Typical CIL-curves for retroreflective fabrics on the Nordic market in 1981. Curves 1,2 and 3 are for 3 different glass bead materials of good quality, while curve 4 is for a micro-prism material.

The CIL curves indicate that the angular variation is very moderate, within the region ±30°, which is advantageous for just this sort of application.

Of the best material in this investigation only 9 cm^2 is needed to fulfil the functional requirement, or 36 cm^2 for a total garment. Of other materials of good quality four or five times as much is needed.

These results are for new (unworn) materials. The actual specifications must also in this case be made for the retroreflectors after a certain time of use, i.e. an average wear and tear of reasonable magnitude.

General retroreflection requirement.

So far, no restrictions have been put on the coefficient of retroreflection of the materials that may be used, as long as enough material is applied. It is true that this is mostly a question of design, since from a safety point of view it does not matter much whether one applies a small area of a high performance material, or a larger area of a material with a lower R'-value. This "reciprocity" rule is valid at least within reasonable limits. However, there may exist a limit to what should be considered a retroreflector within this context. To establish this limit, one might consider the case when the whole backside of a children's jacket is covered by a retroreflective material corresponding to 300 mcd/lux. The coefficient of retroreflection for such a material would be approximately 5 cd/lux/m^2.

However, at this stage it does not seem appropriate to establish a definite limit for such retroreflectors. Furthermore, the 300 mcd/lux-requirement should in any case exclude materials of inferior quality.

2.3.4 Area and shape requirement

It appears from the preceding discussions that there are no other limitations as to the actual size of retroreflectors than those given by the optical or physical properties of the devices. There may, however, be limits to what can be regarded as practically usable sizes.

In the first place, it is reasonable to require that the retroreflector must not be too small. The smaller it is, the greater is the probability that it is hidden from view, for instance by wrinkels in the garment. Also, a tag must have a certain size and weight to ensure rotation. A value of 15 cm^2 for the minimum area of all types of retroreflectors is arbitrarily chosen. Also, very few retroreflectors of any type will be able to fulfil the functional requirement after being worn for some time, if they are smaller than 15 cm^2.

There can obviously not be specified any maximum area for retroreflective fabrics. For a tag, it is of some importance that it does not become too large to carry in a pocket. An arbitrary limit of 40 cm^2 is chosen as this maximum area.

Also the shape of the tag has some influence on its performance. It will obviously rotate better if it is allowed to do so about its longest axis. A reasonable requirement is therefore that it should never be wider than its own length.

2.4 Environmental influence on retroreflection

Pedestrian retroreflectors are exposed to varying environmental conditions. It is of particular importance that they are manufactured to be influenced as little as possible by climatic and meteorological variations when in normal use. However, being optical devices, they tend to be rather vulnerable, especially to wet conditions. As a consequence, all retroreflectors are least effective when most needed, namely in rain- or snowfall with seriously reduced visibility. It is necessary to specify minimum performances under difficult conditions, but specifications must be set within the physical limitations of the retroreflector principles and construction.

2.4.1 Rain

A uniform layer of water on the front surface will not affect the retroreflector's performance. However, under natural conditions rain does not form a uniform film but rather tends to stay as droplets and clusters of droplets clinging to the surface. The droplets act as diffraction objects both for incident and emergent light, causing a smaller or larger part of the light to be scattered and "lost" in unwanted directions. A retroreflector with water droplets on some isolated parts of its surface, appears to have dark patches when illuminated by car headlights. As more and more of its surface is covered by droplets, it grows steadily darker to the observer. Since small droplets causes a wider spread of the light than large ones, the worst case is an even distribution of tightly packed small droplets.

New polystyrene tags have very smooth surfaces that droplets do not easily cling to. Also, the tag is always in movement, thus making it still more difficult for droplets to keep in position. Generally, therefore, a new polystyrene dangling tag will not be very much affected by rain. The situation is probably more serious with worn tags, since an injured surface is much better for droplets to cling to than a smooth one. It is, however, still difficult to talk about a "wet" condition for this type of retroreflector. Even if it is possible to cover some of its surface with droplets, the situation will never be reproducible, and it is not realistic to specify a standard condition for test measurements.

The situation for the flexible micro-prism sheeting is approximately the same as for tags.

A more serious problem for cube-corner retroreflectors is the possibility of water getting into the air-filled cavity behind the prisms. In general, the chance is very small that the cavity should be filled with water, but if the cavity is not completely sealed off, small quantities of water may enter, and according to the temperature, more or less of this moisture may deposit as dew on the prisms and may almost completely "extinguish" it. A test for water-tightness is therefore highly relevant for this type of retroreflector.

Retroreflective fabrics are generally more seriously affected by water. Firstly, the surface of these materials is usually not smooth, and raindrops thus have a better chance of staying in place. Also, there is very little movement in a garment-mounted retroreflector. Nevertheless, it is just as difficult to define a "wet" condition for this type of retroreflector, when talking about surface droplets. However, fabrics also tend to be more or less soaked after prolonged exposure to rain, and some of the absorbed water also contributes to the "extinguishing" effect. Thus, a retroreflective fabric can generally not be expected to behave very well in rainfall, either in new or worn condition. What can be expected, is that it retains its efficiency within reasonable time after the rain has stopped. The retention time can be applied as a test criterion for this type of retroreflector.

2.4.2 Snow and ice

The situations where falling snow deposits on more or less vertical retroreflector surfaces and stay there are probably not occurring very often, and are consequently less interesting. In most cases the snow will either fall off the surface, or melt instantly to form water droplets. Under certain meteorological conditions, with an excess of water vapour in the atmosphere and sinking temperature, rime may deposit on the retroreflector surface. All types of surfaces are about equally liable to be rimed, and rime is even more deteriorating to the retroreflection than raindrops. There is, however, at present no known way of protecting the retroreflectors against these effects.

2.4.3 Low temperatures

Low temperatures alone do not affect the optical properties of retroreflectors, but may be harmful to retroreflector materials.

Moulded tags may become brittle at low temperatures, and since tags are often banged against hard objects while hanging in their strings, the result may be cracks that either directly reduces the retroreflectivity, or allows water to enter into the cavity in later situations.

Retroreflective fabrics may also become brittle, and crack when the garment wrinkles as the wearer moves. The cracks may first lead to loosening of beads, and later to the disintegration of smaller or larger pieces of the material. It is necessary that this type of retroreflector can withstand considerable bending at low temperatures.

3. STUDIES OF RETROREFLECTORS WORN BY NORMAL USE AND UNDER ARTIFICIAL CONDITIONS

by Birger Nygaard.

3.1 Introduction

The retroreflective quality of the pedestrian retroreflectors depend greatly upon the conditions to which they are subjected, and the circumstances under which they are used.

The environmental conditions for retroreflectors on cars, motor-cycles and bicycles are - to a certain degree - relatively constant while this is not the case for pedestrian retroreflectors.

Depending on material type and use purpose (tag or retroreflective fabric) they will be subjected to hittings, washing, folding, waving, cutting, etc., influences which are infrequent on retroreflectors fitted on vehicles.

Besides we have to consider the decreasing functional value of the retroreflective materials as the observation angle grows, especially for pedestrians who are moving constantly. This puts heavy demands on the retroreflectivity of the constantly changing surfaces on which the illumination changes from moment to moment.

Those or similar differences between vehicle retroreflectors and pedestrian retroreflectors make other demands on the studies and the material tests in the type approval:

- it should be ensured that the tests will consider. on one hand, the various environments to which pedestrian retroreflectors are subjected,

- and on the other hand that the demand for functioning in all directions, irrespective of the movements of pedestrians, should be weighted in relation to the size, the design or location of the retroreflector.

Thus, it is obvious that test procedures for vehicle retroreflectors only to a certain extent are usable in these connections. It is, furthermore, doubtful if the existing test procedures like those at present used in the Nordic countries could be considered to meet fully with the basic demands mentioned above.

A condition president for the validity and the reliability of a test procedure is that it corresponds to the deterioration and changes of the retroreflection under conditions during which the deterioration of the material takes place.

Common for the prevalent procedures is, however, that they, as far as the pedestrian retroreflectors are concerned, only to a certain extent are based on controlled measurements of material qualities after normal, daily use, but instead they are based on laboratory simulations.

From lack of this important basic knowledge for the authorization of a proposal to a common Nordic norm and approval procedure, the working group has started various studies of material changes on some common retroreflector types, both by normal, daily use and by various laboratory tests.

The working group has not disposed of real research means for these studies, this has affected the content and extent. For example, only a limited number of the existing products has been tested. In spite of that the working group has found it necessary, however, to carry out some functional tests in order to have an idea of the retroreflector qualities after normal use.

We would like to thank all the Nordic pedestrians, who for months have worn and used the tested retroreflectors as well as the light-technical laboratories and institutes, which have made time-consuming measurements of the qualities of the retroreflectors from period to period.

At the same time it is pointed out that the number of tested samples is limited and the results should be estimated in relation to that. However, there is nothing in the test material that points to the fact that the results are not representative for the current retroreflector types and therefore the conclusions presumably have a general character.

The studies have covered 5 different conditions:

1. Measurement of retroreflection for new materials
2. Change of retroreflection in tags after normal use by Nordic pedestrians
3. Measurement of the retroreflection of children's clothes with sewed-on retroreflective fabrics
4. Washing tests of retroreflective fabrics
5. Simulated wear of retroreflective tags

In the following the results of these studies will be reported separately.

3.2 Measurement of the retroreflection for new materials

The measurements were made by the Norwegian member of the working group at the beginning of 1980 and included measurement of the retroreflection of new retroreflectors in the horizontal entrance angle up to $\pm 30^{o}$ on six different tag makes and nine different retroreflective fabrics, the latter being all products from the same manufacturer.

The used measurement methods for the two retroreflector types are described in chapter 2.2.

The results of the new value measurements are shown in Appendix 1a-d resp. Appendix 2a-b. It is obvious that retroreflectors of cube corner macro-type generally have the highest initial values but the angle dependence is less in the region $\pm 20^{\circ}$ for a retroreflector type with glass beads.

However, the new values for two types of tags - with glass beads and cube corner micro-type - are so low that they, in the common size after some time's use hardly can reach the working group's suggestion for retroreflectors corresponding to 400 mcd/lux at $\pm 5^{\circ}$.

Regarding size and area for tags and retroreflective fabric it can be concluded that

- some existing tag makes, for the main part of bead or cube corner micro-types
- and most fabrics

in their present size and with area demands for the fabrics of 40 cm^2, will not fulfil the working groups proposals for minimum values.

3.3 Change of retroreflection in tags after normal use by Nordic pedestrians

The study has comprised long-time tests of five different tag makes over a period of 1½ years.

The study has exclusively been based on a voluntary and unpaid participation, and the practical possibilities of making further tests in the Nordic countries have been of various extent. Thus, Norway and Sweden have been able to continue the tests beyond the 3 - 4 periods that were the original ambition of the working group. In Norway the test of the original tags covered six months.

Each country has tested two different makes (one of them of cube corner type identical in all three countries). The tags have been distributed to ten persons, children and grown-ups. In each country the wearers were instructed to fasten the tags in the string in the left or the right pocket of the used overclothes.

The test persons have furthermore been instructed to keep usual objects in their pockets (keys, money, etc) and to treat the retroreflectors in a normal way, i.e. let them hang down from the pockets when moving in night traffic.

Totally 80 retroreflector tags have been included in the test. Some of them were lost owing to torn strings.

In general, the strings have shown up to be very deficient and had to be exchanged now and then.

All tag types are double-sided - consequently the test totally included 160 retroreflector units. The two sides of the tags will be regarded as independent retroreflectors, each of them with a retroreflection and other characteristics. (In the Swedish tests there is no difference between these two sides and therefore the analyses include a smaller number of data than optimum. As these tests are relatively few and have been made randomly on the two sides, this fact has no vital importance for the total results of the test).

All tags were new from the start and were taken from big production series. Before the distribution to the Nordic countries the two sides of the tags were measured according to the standard procedure described in chapter 2.2, and the values at horizontal entrance angles $\pm 5^{\circ}$ and $\pm 20^{\circ}$ were chosen to represent the tag quality. For running identification every tag has been provided with a colour code and a marking of front and back side. This marking has not changed the characteristics of the tag.

These introductory measurements were made in Norway, and afterwards the tags were distributed to the other members of the working group. When received, the tags were then measured in accordance with the standard method in the laboratory of the respective country. Finally the tags were sent to the test persons.

After a wearing period of about one month, the tags were collected and measured at the laboratory and since returned to the user.

Efforts were made to control that the same pedestrian did wear the same retroreflectors during the whole study, but in some cases there has been a change of tags between persons.

Owing to the small use of overclothes and retroreflector tags in the Scandinavian countries during the summer, the studies have usually been called off during this time of the year.

Therefore it can be presumed that the tags have been worn about one month in every test period, and that the users, both regarding use and age, have been representative for Nordic people.

Table 3.1 shows the number of measured retroreflector sides for all the test periods in the four participating Nordic countries. As said before, more tests were made in Norway and Sweden but in all four countries tags of type 1 have been included.

Table 3.1 Survey of tag makes included in the Nordic test; number of measurement periods for every country and number of measured retroreflector sides

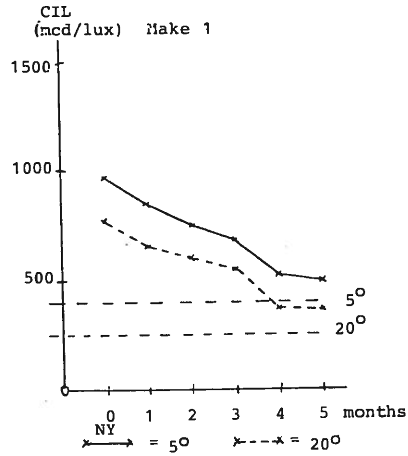
Number	Denmark	Finland	Norway	Sweden	totally
Make 1 (cube-corner)	10	10	10	10	40
Measurement periods	3	(3)2	6	5	(17)16
Measurements	4	3	7	6	20
Retroreflector sides	76	58	140	54	328
Make 2 (micro prism)	10				10
Measurement periods	3				3
Measurements	4				4
Retroreflector sides	76				76
Make 3 (glass bead)		10			10
Measurement periods		(3)2			(3)2
Measurements		3			3
Retroreflector sides		60			60
Make 4 (cube corner)			10		10
Measurement periods			6		6
Measurements			7		7
Retroreflector sides			140		140
Make 5 (cube corner)				10	10
Measurement periods				5	5
Measurements				6	6
Retroreflector sides				54	54
Totally					
Types	20	20	20	20	80
Measurement periods	6	(6)4	12	10	(34)32
Measurements	8	6	14	12	40
Retroreflector sides	152	118	272	108	650

The decrease of retroreflection has thus been measured during the whole test and table 3.2 shows the average CIL-values and the variation of the tested makes. Furthermore the k-values are reported; i.e. the relative retroflection in relation to the initial values = 1.0.

Table 3.2 Mean values, spreading, number and k-values for all the measurements. Both sides, 5^{o} and 20^{o} horizontally

	New value	1	2	3	4	5
Make 1						
5^{o}-mean value	980.1	845.3	754.2	689.4	517.9	498.2
Spreading	241.7	248.5	236.6	203.0	195.1	205.1
Number	70	70	68	65	28	28
k-value		.86	.77	.70	.53	.51
20^{o}-mean value	780.2	665.8	603.4	543.2	388.9	380.0
Spreading	145.9	167.7	168.5	137.7	140.9	143.0
Number	70	70	68	65	28	28
k-value		.85	.77	.70	.50	.49
Make 2						
5^{o}-mean value	461.7	451.3	413.3	330.6		
Spreading	214.4	227.8	173.5	150.3		
Number	20	20	18	18		
k-value		.98	.90	.72		
20^{o}-mean value	429.1	382.5	344.9	277.6		
Spreading	149.8	180.2	146.8	124.2		
Number	20	20	18	18		
k-value		.89	.80	.65		
Make 3						
5^{o}-mean value	417.3	343.4	343.4	294.3		
Spreading	18	35.2	35.2	42.4		
Number	20	20	20	20		
k-value		.82	.82	.71		
20^{o}-mean value	394.8	322.2	322.2	276.2		
Spreading	13.6	31.2	31.2	40.2		
Number	20	20	20	20		
k-value		.82	.82	.82		
Make 4						
5^{o}-mean value	1412.0	1084.5	840.5	640.0	510.0	517.0
Spreading	201.8	251.3	236.1	309.3	286.7	302.1
Number	20	20	20	20	20	
k-value		.77	.69	.45	.36	.37
20^{o}-mean value	997.5	754.5	568.5	427.5	328.0	343.5
Spreading	148.8	185.7	159.7	214.6	193.4	198.5
Number	20	20	20	20	20	20
k-value		.76	.57	.43	.33	.34
Make 5						
5^{o}-mean value	1049.0	930.0	858.0	819.9	733.3	653.3
Spreading	159.5	196.8	202.9	78.0	50.0	48.2
Number	10	10	10	9	9	9
k-value		.89	.82	.78	.70	.62
20^{o}-mean value	759.0	634.0	557.0	567.8	498.9	444.4
Spreading	99.6	134.3	126.2	51.9	40.8	44.2
Number	10	10	10	9	9	9
k-value		.84	.73	.75	.66	.59

Figure 3.1 shows the average CIL-values graphicly with a marking of the proposal of the working group for minimum values at 5° and 20°.



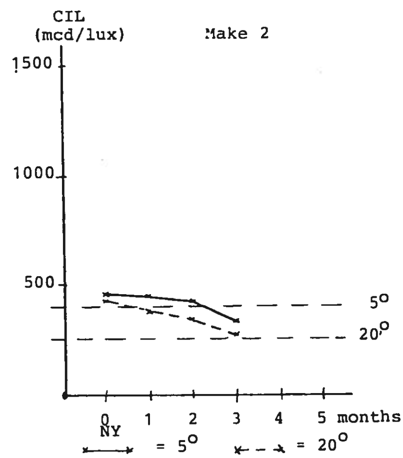


Figure 3.1 Mean values in CIL of pedestrain retroreflector tags after normal use in 3-5 months. Entrance angles 5° and 20° hor. The demand proposals of the working group are shown by the broken lines.

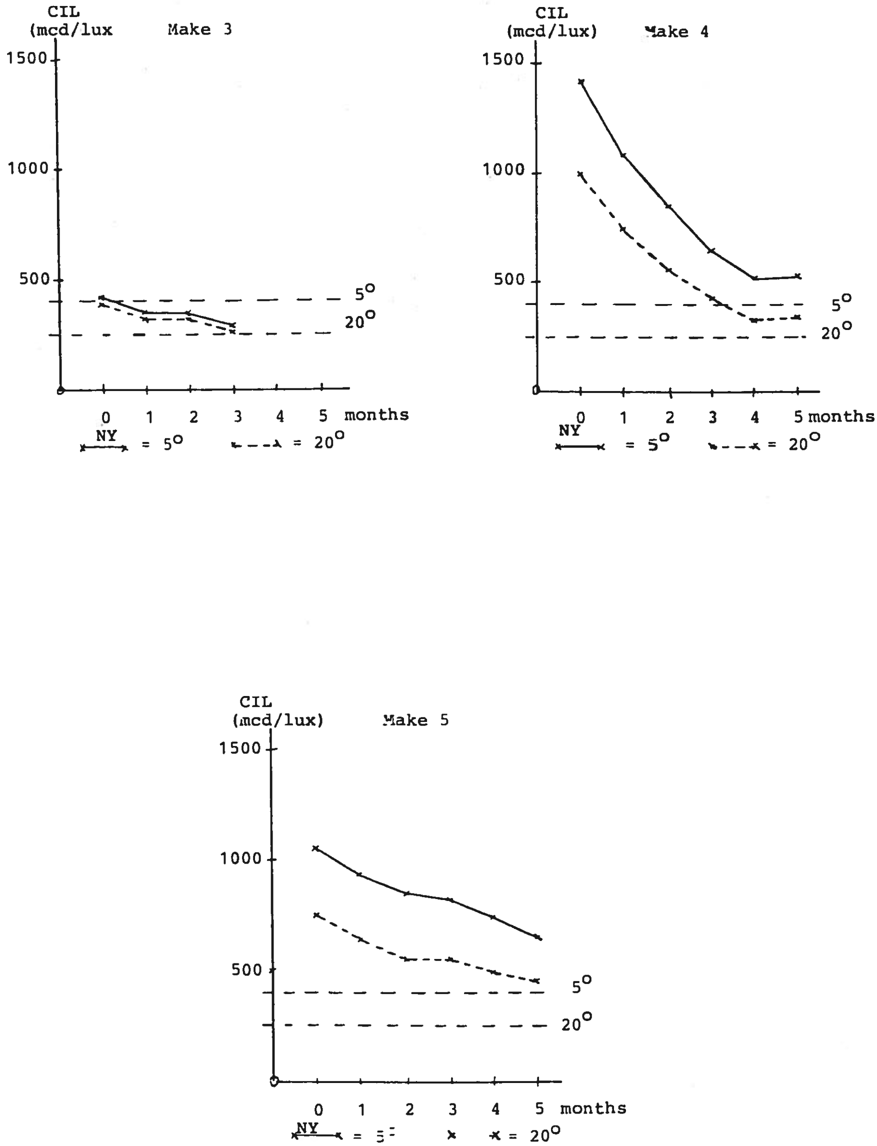
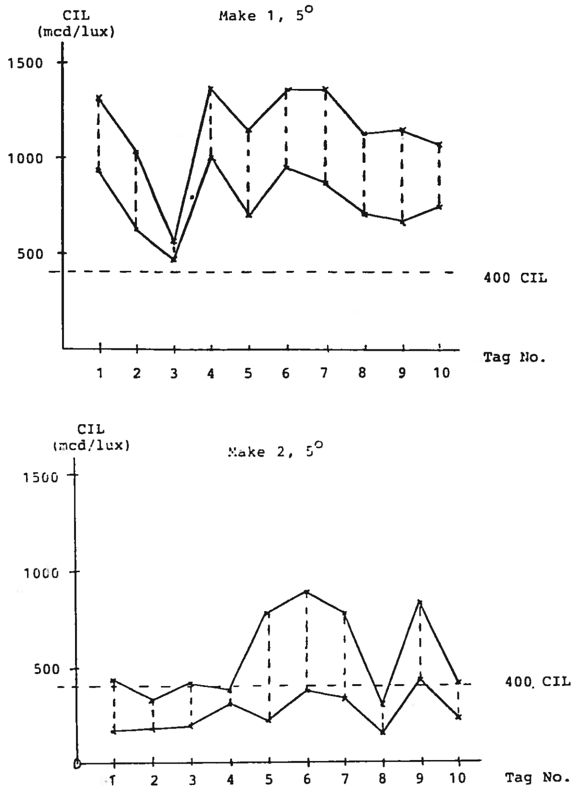


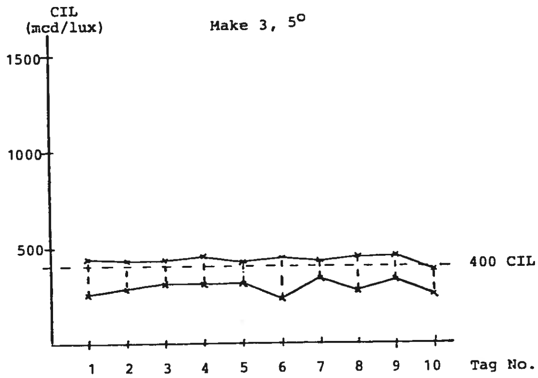
Figure 3.1 Cont.

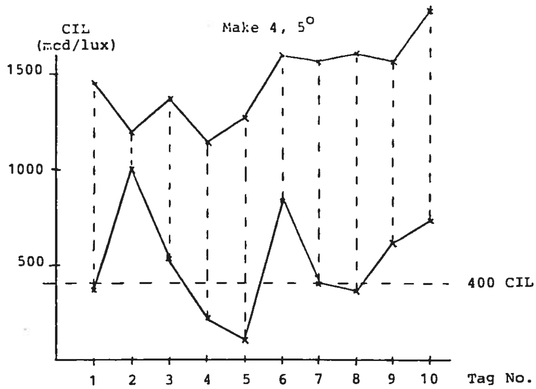
It is evident that only tags of cube corner macro-type fulfil the suggested demands after some months' normal use and that the limit will be passed after about six months for all tags. <u>This corresponds to a maximum time of use of one winter season for the best retroreflectors in the Nordic test</u>.

Graphs of the individual characteristics of the retroreflectors are shown in figure 3.2 where the maximum and minimum values of any of both retroreflector sides are indicated for the five makes. In regard to the comparison only the values for the first three measurement periods have been indicated and for make 1 only the Danish results are indicated.



<u>Figure 3.2</u> Maximum and minimum CIL-values for the 5 tested makes. Value ranges from new-values to values after 3 months of use. Any of both sides. Only values from one country (Denmark) shown for make 1. Entrance angle = 5°





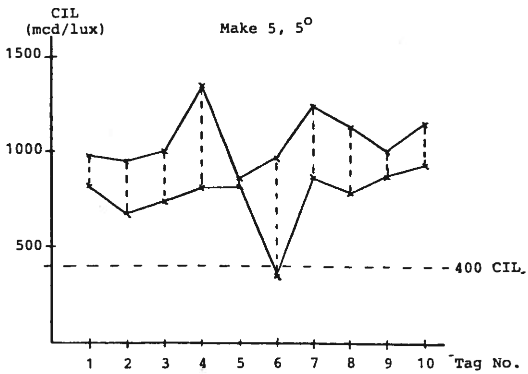


Figure 3.2 Cont.

As a conclusion it can be established that only a few of the tested tags fulfil the demands of the working group as regards the reflective power after 2 - 6 months' use and that the retroreflection decreases to half the new value during this period on most of the makes.

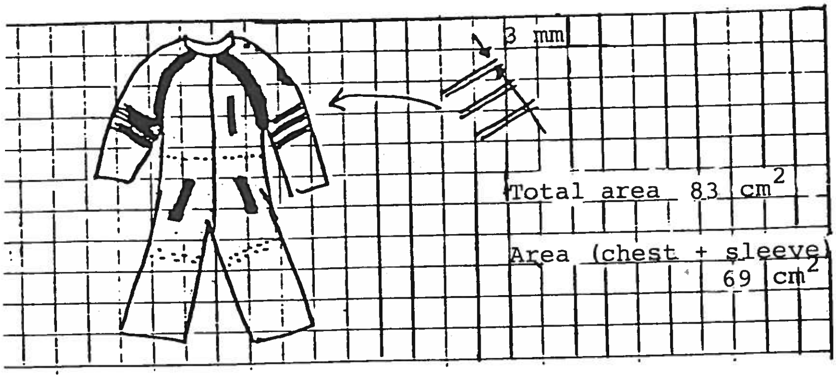
3.4 Measurement of the retroreflection of children's clothes with sewed-on retroreflective fabrics

For retroreflective tags the proposal from the working group requiring visibility from all directions will be met by hanging them on a string, giving free mobility and rotation during the use.

When using the retroreflective fabric it is, however, necessary to spread the retroreflector area to the circumference of the clothes in order to obtain a satisfactory result.

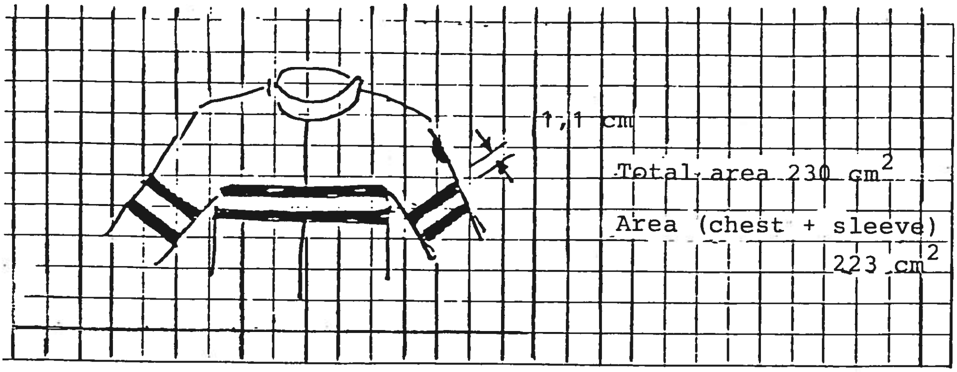
The Finnish members have made a test with two different applications of one type of retroreflective fabric on children's clothes in order to have an idea of the area demand in accordance with the proposal of the working group. In both tests a new and unused material has been used.

(The same investigation is referred to in chapter 2.3). The placing of the retroreflective fabric and the result of the measurements are shown in figures 3.3a-b.



(°)	visible area (cm²)	CIL (mcd/lux)	side
0	30	414	front
45	23	352	front left
90	26	409	left
135	22	340	back left
180	25	310	back
225	17	291	back right
270	19	201	right
315	18	256	front right

Figure 3.3a Retroreflection dependent on visible area for sewed-on retroreflective fabric on childrens' clothes. Unused fabric



(°)	visible area (cm^2)	CIL (mcd/lux)	Side
0	85	1535	front
45	55	1116	front left
90	42	653	left
135	55	1239	back left
180	85	1781	back
225	50	1027	back right
270	35	443	right
315	50	1027	front right

Figure 3.3b Retroreflection dependent on visible area for sewed-on retroreflective fabric on childrens' clothes. Unused fabric

It is shown that the application of the retroreflective material on the clothes has a great and vital importance for the visibility effect in relation to the direction of the pedestrian.

As a conclusion it can be stated that a satisfactory effect can be reached with 100 - 200 cm^2 material of the above mentioned type optimally spread over the clothes. With other types with less retroreflection larger areas must be used in order to reach the same result.

3.5 Washing tests of retroreflective fabric

The proposals from the working group contain many demands for durability under various conditions and as told before the corresponding test procedures are based on more or less realistic estimation of the deterioration of the retroreflective materials by daily use.

As regards the retroreflective fabrics it is, however, realistic to assume that reduced retroreflection will appear especially as a consequence of repeated washings during the use period.

The Norwegian member of the working group has made several washing tests of the retroreflective fabrics previously reported in Appendix 2a-b.

Appendix 3a-i shows the result of the washing tests before and after one and ten washings respectively. By all the tests SIS 251239, V3 is followed. A summary of the washing results is shown in table 3. (Some of the newest materials were washed as much as 25 times, as shown in the appendix).

Table 3.3 Retroreflection measurements for nine retroreflective fabrics after ten washings and necessary visible area in order to comply with the proposal of the working group (min. 300 mcd/lux).
Measurements units = $cd/lux/m^2$

Material No.	Type/ colour	Initial condition		After 10 washings	
		R^1 ($cd/lux/m^2$)	Req.area (cm^2)	R^1 ($cd/lux/m^2$)	Req.area (cm^2)
1	white	78	38	53	57
2	yellow	65	46	33	91
3	red	113	27	8	375
4	yellow	68	44	5	600
5	grey	58	52	55	55
6	white	75	40	44	68
7	red	78	38	45	67
8	silver	340	9	198	15
9	yellow	62	48	not measured	

* Declared not washable by the manufacturer.

According to the table already one washing affects the retroreflection considerably but the relative wide-angle performance is, on the whole, unchanged after ten washings. Type 8 differs characteristicly by showing much higher values and for the rest the separate retroreflective fabrics show very variable results.

Washing tests were also carried out in Finland in order to study retroreflector washability. The tests were designed to resemble as closely as possible washing done at home with an automatic washing machine. Finnish SFS 2998 standard washing cycles 3 (coloureds, 60°C) and 5 (light wash, 40°C) were used. The corresponding cycles are included in the SIS 251239 standard. Before washing the 50 x 150 mm² retroreflectors were fixed on a 300 x 600 mm² cotton/polyester piece of cloth as shown in figure 3.4. A maximum of 2 such pieces of cloth per 1 kg of laundry were put into the washing machine. Each type of retroreflector was washed 1 - 10 times, the cloth being dried between washes.

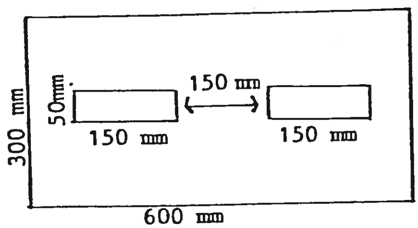


Figure 3.4 Test sample

For most materials it was found that washing at a temperature of +60°C results in a sharp drop in the retroreflection after only a few washes, while washing at a temperature of +40°C is significantly better. It therefore seems that a light wash cycle at a temperature of +40°C should be chosen. This, however, would mean that the recommended washing cycle for clothing with non-removable retroreflectors would be determined mainly on the basis of the retroreflective material, and not the actual clothing material.

Summing up the results of the Nordic washing tests the conclusion is that the retroreflection of the retroreflective fabrics is reduced by washing. However, a reasonable and fully acceptable compensation for this reduction can, in most cases, be obtained by a relatively modest increase of the area of the visible retroreflector.

3.5.1 Effect of humidity

The retroreflection of the retroreflector materials was found to decrease sharply when the reflector gets wet. The effect of water was studied with test samples which had gone through a frost test in accordance with the SFS 4410 standard (1 h, -30^{o}C) and a washing test (+40^{o}C). The retroreflector materials were placed in a rain simulator (30 min, +50^{o}C and 30 min, +15^{o}C). The recovery of the retroreflection as a function of time was then measured. Figure 3.5 shows the results for some materials. It is evident that immediately after the rain simulation the retroreflection of all materials dropped by 1 - 5% from the value measured when the materials were dry. It is also clear that reversion to a 50% retroreflection level takes several minutes.

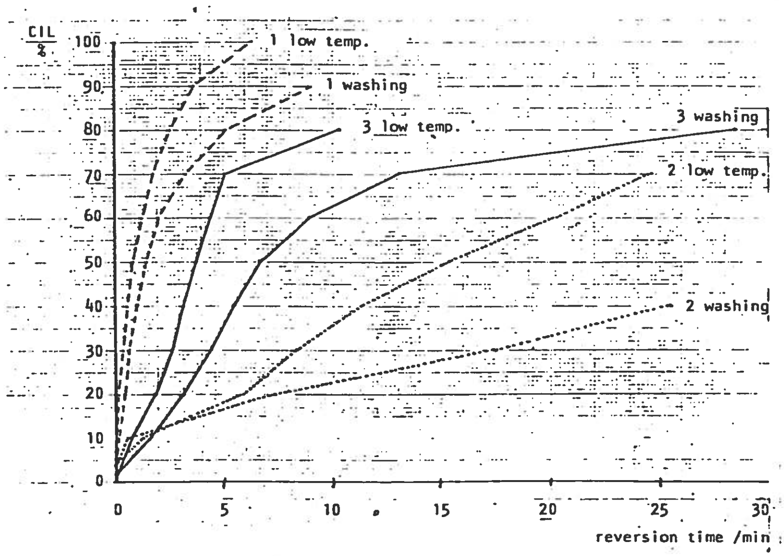


Figure 3.5 Humidity test

3.6 Simulated wear of retroreflective tags

As far as the tags are concerned it can be assumed that the greatest deterioration of the retroreflection is the friction against the outside of the clothing and specially the touch against hard and sharp-cornered things in the pocket.

The normally used friction test, where a brush mecanically is rubbed against the exterior of the tag a certain number of times, gives hardly a realistic picture of the environment of an overcoat pocket as the movements of the pedestrian cause rotations and other influence from more aspects than those shown by the brush test.

The working group has therefore under Swedish guidance made a number of tests where the pocket environment has been simulated by a small tumbler (drum of hard rubber which rotates 30 times/minute, motor-driven).

In this drum a pedestrian retroreflector of type 1 was put together with 10 Swedish coins and a piece of cloth. After that, measurements of the retroreflection were made at intervals of 40 minutes during three hours. The test was repeated with five tags, all of type 1.

Figure 6 shows graphicly the results of the test in average values for the five tags compared with the ten tags of the same make in the Swedish part of the test with wear under normal circumstances.

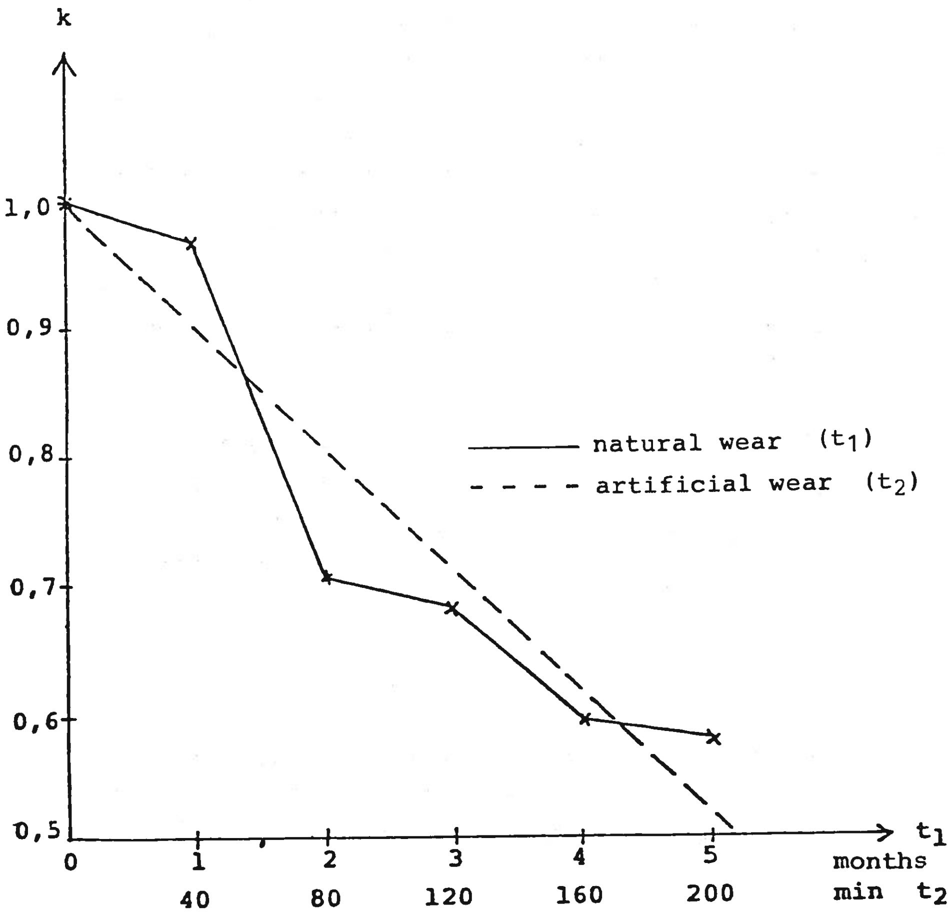


Figure 3.6. Comparison between natural and artificial wear of retroreflective tags. The values refer to ten naturally and five artificially worn-out tags

If a linear conversion factor for both functions is accepted, the half-life for the retroreflective properties of the tag, which normally is about five months, will be 210 minutes in a tumbler, i.e. a test time of 40 minutes corresponds to one month's real use.

A summing up of these tests shows, that by this test procedure a reduction of the retroreflection of the tags occurs, similar to the wear tested under normal circumstances. At the same time this test method permits a wide range when choosing environment factors for the test.

3.7 Conclusion

The Nordic proposal for approval demands for pedestrian retroreflectors especially intends to guarantee the funtionally safe values, even after a certain time of normal use. The reference time has been 6 months of normal use (corresponding to one winter season) of the tags and ten washings for the retroreflective fabrics.

In the absence of reference values from long-time tests outside the laboratory the working group has tested the qualities of some common makes of tags after normal use by children and grown-ups in four Nordic countries.

Furthermore, the working group has made retroreflection measurements on new retroreflectors, test washings up to ten times of retroreflective fabrics, measurements of area claims for suitable application of retroreflective fabrics on childrens' clothes and finally tested a method for artificially wear of tag retroreflectors with the aid of a tumbler.

It is stated that retroreflective tags of cube corner macro-type generally have higher retroreflection values and on an average fulfil the proposal for approval demands within 4 - 6 months of normal use. This is not valid for the tested tags with glass beads or micro prisms. In this connection the tested makes of those types are considered as unsuitable.

The retroreflective fabrics are influenced by washing and thus lose at least 1/3 of the retroreflection after ten washings.

Areas of 100 - 200 cm^2 optimally spread all over the clothes seem to be sufficient to reach retroreflective values in all directions at levels proposed by the working group.

The tumbler test shows, compared with the obtained results under normal use, many similarities and points at a realistic alternative to the normally used brush test.

Thus, the accomplished tests show that especially the retroreflection greatly decreases by normal use. After regular use in the winter season even the best type must be considered as worn-out. The retroreflective tags deteriorate most substantially by the first washing and lose, only gradually, the retroreflection in the following washings. Some tag- and retroreflective fabrics show such low values that they, in their present shape, cannot comply with the proposals suggested by the working group.

4. SPECIFICATIONS PROPOSAL

by Bjørn Brekke and Kåre Rumar (4.4)

4.1 Introduction

From the preceding discussions, studies and experiments, a proposal of technical specifications for all types of pedestrian retroreflectors has emerged. Due to the differences both in physical properties and in practical application, it has been found reasonable to present a different set of specifications for dangling tags and retroreflective fabrics, respectively.

The proposal should be regarded as a collection of minimum requirements upon which national standards may be based.

Each set of specifications contains the following main constituents:

- Definitions of retroreflectors, measurement method and units.
- Statement of the functional requirement.
- Description of the appropriate laboratory tests which the retroreflectors must undergo and withstand in order to fulfil the functional requirement under practical conditions.
- Statement of various other requirements of importance to the practical use of the retroreflector type in question.

The main difference between the present proposal and the existing regulations is that the proposal puts the requirements on worn retroreflectors, thus ensuring sufficient safety value over a reasonable length of time, the functional life time of the retroreflector.

The life times aimed at are confirmed by practical experiments to be realistic. They may be shorter than desirable, but it should be noted that they may well be extended by various precautions. This is especially true with retroreflective fabrics. In this case the life time is not fixed, but relative and related to the number of washings of the garment. Ten washings is a fairly high number for outerwear of grown-ups, while for the clothes of small children it may be a very low number. In that case one should also remember that the test results (Chapter 3.5) indicate that by doubling the area of the retroreflector, the corresponding life time is more than doubled.

There is, however, another problem associated with retroreflectors on children's clothes. Investigations indicate (Brekke, 1981) that mechanical wear is responsible for approximately the same amount of degradation as washing during a given period of time. However, the material from the experiment referred to is limited, and more investigations are required before conclusions may be drawn. If, however, the above indication turns out to be correct, this suggests that for children's clothes up to 4 times as much retroreflective fabric may be needed to provide safety during a given period of time, as in the case of grown-ups' clothes.

While the specifications for tags put the responsibility solely on the retroreflector manufacturer, the specifications for fabrics are directed partly to the retroreflector manufacturer and partly to the manufacturer of the particular garment. The practical procedure will be that the retroreflector manufacturer subjects his various types of fabrics to the tests described in the specifications. Based on the results, tables showing the minimum area requirement for each of the fabrics are worked out. The garment manufacturers are then responsible for the correct distribution of the retroreflective material when applying it to their products.

During the work with the specifications, the project group has discussed some of the more important aspects with other research laboratories, traffic organizations, consumers' organizations and manufacturers of retroreflectors. A still larger number of such institutions were asked to comment on the draft versions. Several valuable suggestions and corrections emerged in this way.

4.2 Technical requirements for retroreflective tags

4.2.1 Definitions

4.2.1.1 In this context, the term retroreflector refers to a freely hanging, string-suspended retroreflecting device worn by a pedestrian (dangling tag).

4.2.1.2 The retroreflection is expressed by the coefficient of luminous intensity (CIL) in millicandela/lux (mcd/lux).

4.2.1.3 The measurement geometries for retroreflection measurements are those recommended by CIE TC-2.3 Subcommittee "Retroreflection". Terminology and coordinate system are used in accordance with these recommendations.

4.2.1.4 The coefficient of luminous intensity is measured with a fixed observation angle (α) of 20' (0.33^{0}) which is defined as lying in the vertical plane. The entrance or illumination angle (β) is varied in both the vertical plane (β_1) and the horizontal plane (β_2) (figure 2.3).

4.2.1.5 The measurements require a standard light source corresponding to CIE standard illuminant A (2856K) with a tolerance of ±50K, and a photometer head adapted to the CIE photopic standard observer. The angular subtenses of the light source and the photometer head at the sample should not exceed 6'.

4.2.2 Retroreflection requirements

4.2.2.1 In order that a retroreflector shall be regarded as functionally efficient, it must satisfy the requirement that, worn by a pedestrian in real night time traffic, it can be seen by a car driver at a distance of at least 140 m in a passing situation when both cars have dipped headlights. This corresponds to a coefficient of luminous intensity of at least 300 mcd/lux.

4.2.2.2 After being subjected to the water immersion test (4.2.4.1), the low temperature test/hit test (4.2.4.2) and the wearing test (4.2.4.3), the retroreflector must satisfy the photometric requirements of table 4.1, expressed in mcd/lux:

Table 4.1 Photometric requirements for dangling tag retroreflectors.

Observation angle (α)		Entrance angle (β)	
	Horizontal: β_2 Vertical : β_1	0° $\pm 5^{\circ}$	$\pm 20^{\circ}$ $\pm 5^{\circ}$
20' ($0,33^{\circ}$)		400 mcd/lux	250 mcd/lux

(Comment: The value 400 instead of 300 mcd/lux is chosen because the tag is supposed to rotate when hanging from its string, and therefore is exposing the maximum value for a very short time).

4.2.3 Colour requirements

The retroreflected light from the retroreflector, when using light source A as an illuminant, shall appear to be white or light yellow to the observer. The colour determination is made by visual inspection only.

4.2.4 Durability requirements

4.2.4.1 Water immersion test.

After being kept under water for 24 hours (in horizontal position, with the upper surface at least 2 cm below the water surface), the retroreflector must retain its functional efficiency, and it must not have its shape or functional properties altered in any way by this. In particular, joints must not be deteriorated and water must not have entered into the interior cavities of the retroreflector body.

4.2.4.2 Low temperature test/hit test.

Immediately after being kept at a temperature of (-30 ±3) ^{O}C for 24 hours, the retroreflector must withstand the following test: The retroreflector is attached by the end of its string to a vertical steel plate (figure 4.1). It is then raised to an angle of 90^{O} so that the string is straight. The retroreflector is then released so that it hits the steel plate edgewise. The test is performed 10 times in succession at a temperature of (-30 ±3) ^{O}C. After this test, the retroreflector must not show any damage that may reduce its functional abilities.

4.2.4.3 Wearing test.

The retroreflector must undergo a simulated wearing test corresponding to approximately 6 months of normal use. This test is especially designed and is described in chapter 4.4.

4.2.5 Other requirements

4.2.5.1 Area and shape.

The retroreflector shall have a maximum total area on each side of 40 cm^2, and a minimum total area on each side of 15 cm^2.

When suspended by its string, the maximum allowable width of the retroreflector is equal to its height.

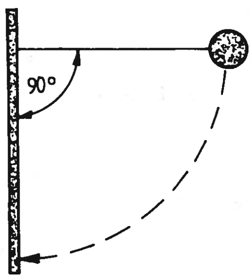
4.2.5.2 Advertisements.

Advertisements are acceptable as long as the retroreflector fulfils the photometric requirements. The approval test may be performed on the retroreflector without advertisements, and the test report should in that case indicate how large portion of the surface may be covered by advertisements. However, when the manufacturer or the authoritied find it advisable or necessary, a separate test is performed with the actual advertisement on the retroreflector.

4.2.5.3 Suspension.
The length of the string must be between 30 cm and 45 cm. The mechanical properties (strength and flexibility) must correspond to doubly twined cotton thread.

The string must be equipped with a safety pin or corresponding fastening device.

4.2.5.4 Marking.
The retroreflector must be clearly and durably marked with the name or trade mark of the manufacturer or importer. In case the manufacturer produces two or more different retroreflectors that are not easily distinguished by shape or colour, each must be marked separately with a type code. Also, if the retroreflection properties of a retroreflector is changed by the manufacturer, while the shape is retained, a different type code must be applied.



Figur 4.1 Hit test for dangling tag retroreflectors.

4.3 Technical Requirements for retroreflective fabrics

4.3.1 Definitions

4.3.1.1 In this context, the term retroreflector refers to a flexible, retroreflecting device applied to the surface of a garment, footwear, bag, etc. by sewing or adhering, or as an integrated part of the garment, footwear or bag.

4.3.1.2 The retroreflection is expressed by the coefficient of luminous intensity (CIL), in millicandela/lux (mcd/lux), when considering a fixed area of retroreflective material as an independent unit. Alternatively, when considering retroreflective material as such, the retroreflection is expressed by the coefficient of retroreflection in cd/lux/m^2.

4.3.1.3 The measurement geometries for retroreflection measurements are those recommended by CIE TC-2.3 Subcommittee "Retroreflection". Terminology and coordinate system are used in accordance with these recommendations.

4.3.1.4 The retroreflection is measured with a fixed observation angle (α) of 20' (0,33^{O}) which is defined as lying in the vertical plane. The entrance or illumination angle (β) is varied in both the vertical plane (β_1) and the horizontal plane (β_2) (figure 2.3).

4.3.1.5 The measurements require a standard light source corresponding to CIE standard illuminant A (2856K) with a tolerance of ±50K, and a photometer head adopted to the CIE photopic standard observer. The angular subtenses of the light source and the photometer head at the sample should not exceed 10'.

4.3.2 Retroreflection and area requirements

4.3.2.1 In order that a retroreflector shall be regarded as functionally efficient, it must satisfy the requirement that, worn by a pedestrian in real night time traffic, it can be seen by a car driver at a distance of at least 140 m in a passing situation when both cars have dipped headlights. This corresponds to a coefficient of luminous intensity of at least 300 mcd/lux.

4.3.2.2 The functional requirement of section 4.3.2.1 above implies that fixed retroreflective materials on garments must be mounted in such a quantity and manner that from any direction in the horizontal plane around the pedestrian, the minimum area exposed corresponds to a coefficient of luminous intensity of at least 300 mcd/lux.

4.3.2.3 The minimum area A_{min} to be visible from any direction is determined by the following procedure:

a) After being subjected to the first washing, performed according to the washing test (4.3.4.1) alternatively the first part of the wearing test (4.2.4.2), the test sample must satisfy the photometric requirements expressed as relative values in table 4.2, called test 1.

b) After being subjected to 9 more washings (4.3.4.1) alternatively the second part of the wearing test (4.3.4.2), the low temperature test (4.3.4.3), and the artificial rainfall test (4.3.4.4), the test sample must satisfy the photometric requirements expressed as relative values in table 4.2, called test 2.

Table 4.2 Photometric requirements for retro-reflective fabrics.

		Entrance angle (β)		
Observation angle (α)	Horizontal: β_2	0°	$\pm 20^\circ$	$\pm 40^\circ$
	Vertical : β_1	$\pm 5^\circ$	$\pm 5^\circ$	$\pm 5^\circ$
20' (0,33°)	Test 1	100%	75%	15%
	Test 2	50%	37,5%	7,5%

The retroreflection measurements are made with samples mounted on a plane sample holder in order to ensure a plane retroreflecting surface. The area of the test sample is not specified, but should be as large as the sample holder permits in order to reduce measurement errors. It should not, however, subtend an angle greater than 80' at the photometer head.

c) The percentages in the table thus refer to the actually measured coefficient of luminous intensity for each material. The required minimum area A_{min} is calculated in each case by means of the formula:

$$A_{min} = A_{test} \cdot \frac{300}{R_{test}} \cdot 2$$

A_{test} is the area of the test sample in cm^2. R_{test} is the actual maximum CIL-value measured with $\beta_1 = \pm 5^\circ$ and $\beta_2 = 0^\circ$ for the test sample in test 2. The factor 2 corrects for the variable curving of the retroreflective material in actual use. (see chapter 2.3.3).

d) The smallest acceptable value of A_{min} is 15 cm^2.

4.3.3 Colour requirements

The retroreflected light from the retroreflector when using light source A as an illuminant, must not appear to be red or orange to an observer. The colour determination is made by visual inspection only.

4.3.4 Durability requirements

4.3.4.1 Washing test.

Retroreflectors intended for washable garments must undergo a 40 ^{o}C machine washing test corresponding to the Swedish standard washing procedure SIS 251239. The retroreflector is mounted either on the garment which it is intended for, or on a neutral piece of cloth that does not interfere with the physical properties of the retroreflector. The performance of the washing test is described in chapter 4.5.

4.3.4.2 Wearing test.

Retroreflectors that are intended for garments, footwear, bags etc. that are not usually washed, or are not washable, are subjected to an especially designed wearing test which is described in a separate document to be published.

4.3.4.3 Low temperature test.

Immediately after being kept at a temperature of $(-30 \pm 3)^{o}$C for 24 hours, the retroreflector is bent around a cylinder with a diameter of 5 mm. After this test, the retroreflector must not show any physical damage like cracking or loosening of retroreflective beads, etc.

4.3.4.4 Artificial rainfall test.

The retroreflector is subjected to artificial rainfall for 30 minutes with water having a temperature of $(+20 \pm 2)^{o}$C. After that, the sample, in vertical position, must regain at least 70% of the retroreflection it had before the test, within a time interval of 30 minutes.

4.3.5 Other requirements

4.3.5.1 Advertisements.

Advertisements are acceptable as long as the retroreflector fulfils the photometric requirements. If necessary, a separate test must be performed for each type of advertisement on a given type of material.

4.4 Description of simulated wearing test for retroreflective tags.

Retroreflective tags must undergo a simulated wearing test corresponding to approximately 6 months of normal use. This test is designed as follows.

The sample is put in a tumbler together with ten small coins (values of 25 Swedish öre) and two rectangular pieces of soft cloth stuff (abt. 100 cm^2 each). The tumbler will rotate 30 r/m during 4 hours and 20 minutes, which corresponds to 6 months of normal wear.

The tumbler is not perfectly cylindrical. In fact it is ten-corned with the radius of 75 mm and the depth of 90 mm. Its walls are made of rubber.

A sketch of the tumbler is seen in figure 4.2.

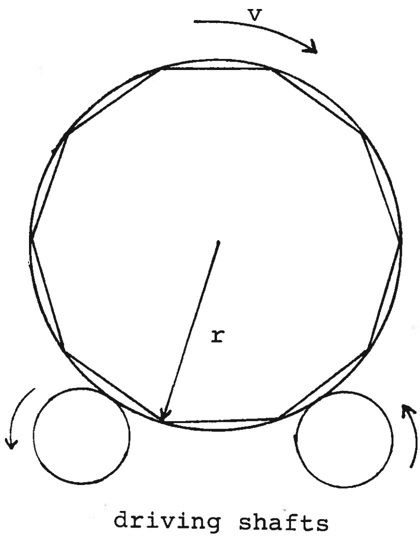


Figure 4.2. A sketch of the tumbler seen side-face. The two driving shafts make the tumbler rotate with v = 30 r/m. The radius of it is r = 75 mm and its depth 90 mm.

4.5 Description of washing test for retroreflective fabrics.

Retroreflective fabrics intended for washable garments must undergo a two-step washing test comprising altogether 10 washing cycles (Chapter 4.3). The test chosen is a 40^{0} light wash cycle described in Swedish Standard SIS 251239.

The test samples should for the washing be mounted either on the garment for which they are intended, or on a neutral (non-coloured) cloth. The ratio of test sample area to cloth area should approximate that of an actual garment equipped with the retroreflective fabric in question. To obtain normal filling of the washing machine, additional garments or neutral cloth are added.

The cloths with test samples are dried after each washing.

- Test 1 comprises 1 washing cycle followed by photometric measurement.
- Test 2 comprises the remaining 9 washing cycles followed by the final photometric measurement.

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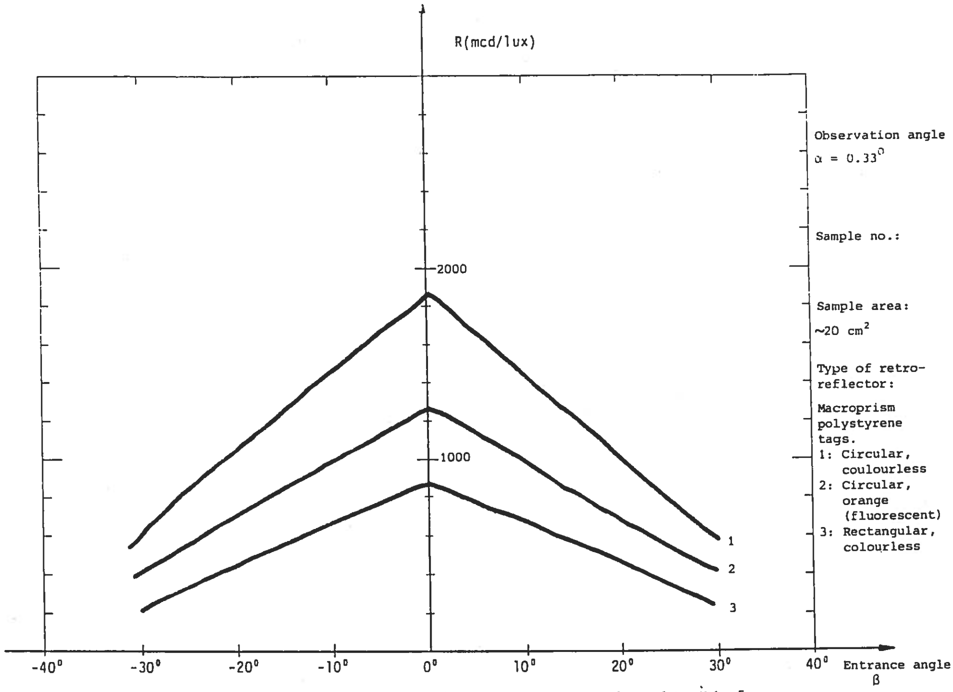
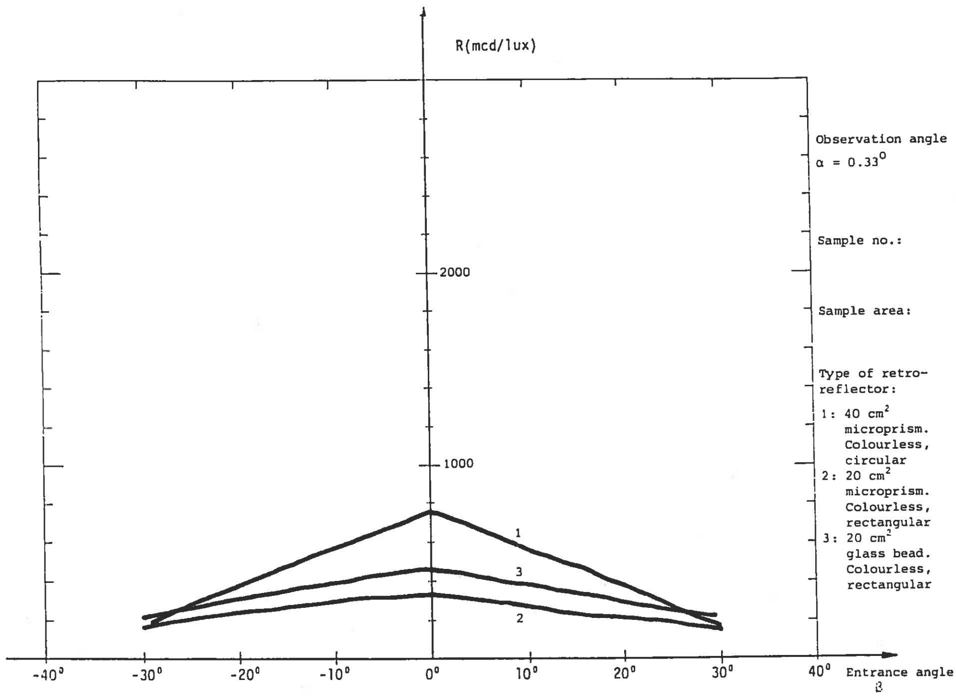
APPENDIX 1

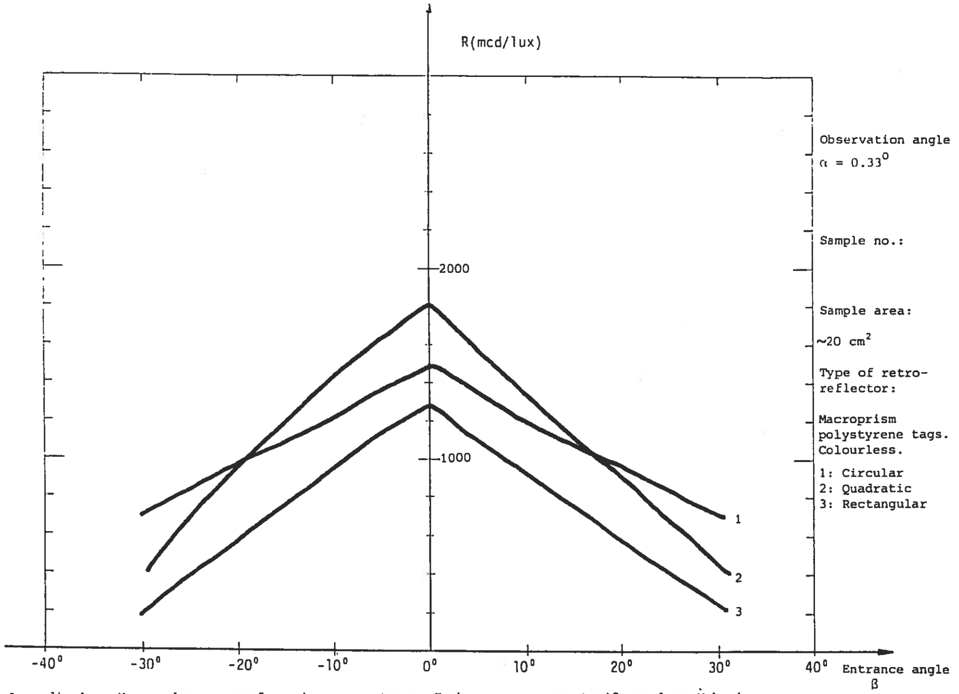
Photometric measurements of retro-reflective tags on the market in 1980.



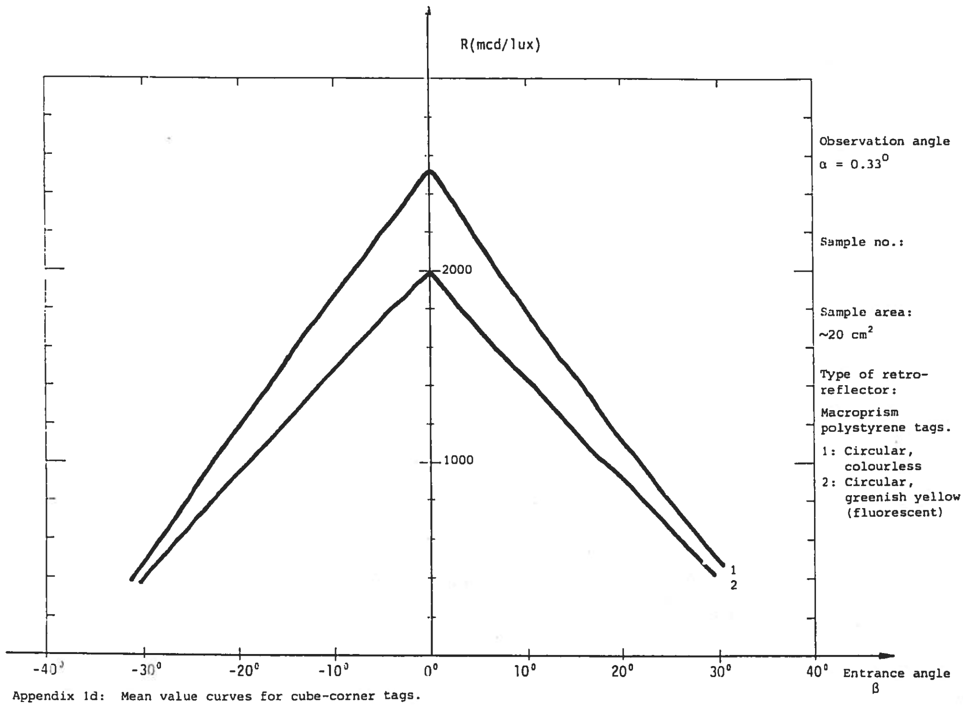
Appendix 1a: Mean value curves for cube-corner tags. Each curve represents 10 samples. Make 5.



Appendix 1b: Mean value curves for microprism tags (make 2) and glass bead tags (make 3).
Each curve represents 10 samples.



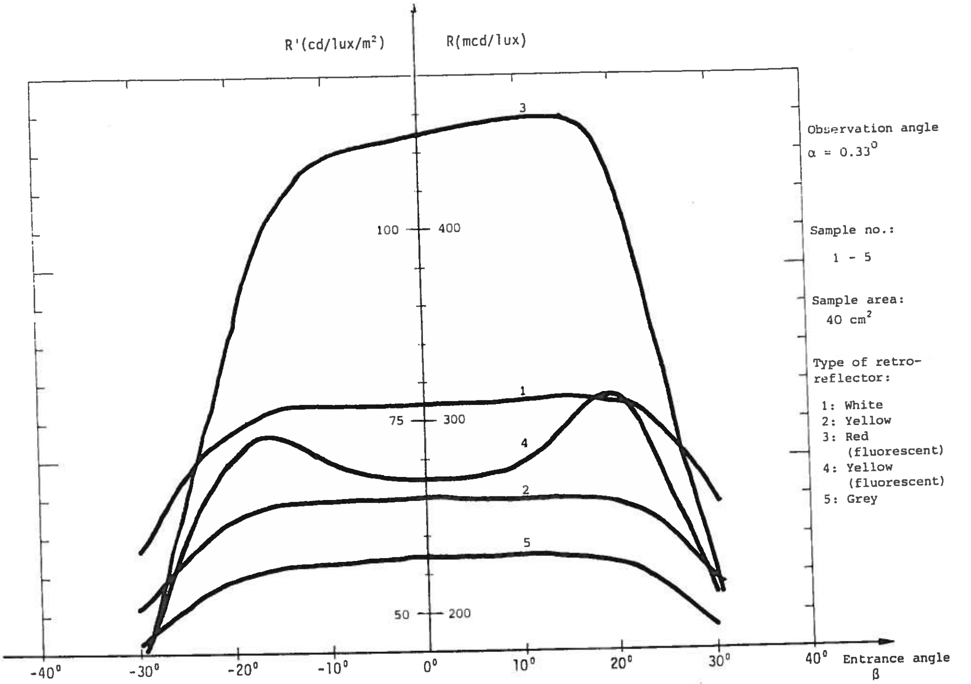
Appendix 1c: Mean value curves for cube-corner tags. Each curve represents 10 samples. Make 1.



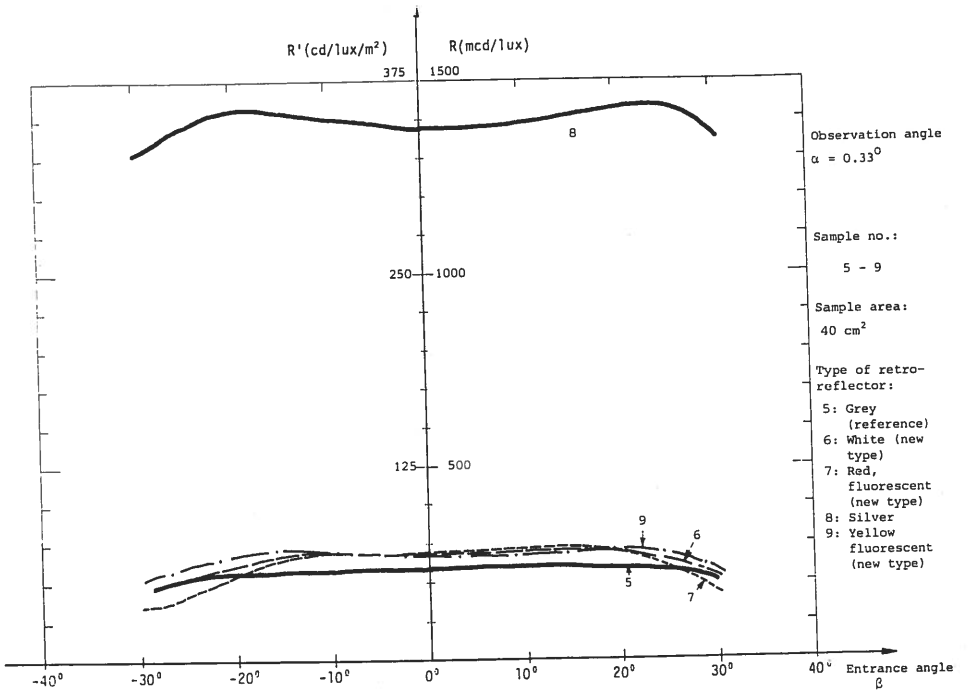
Appendix 1d: Mean value curves for cube-corner tags.
Each curve represents 10 samples. Make 4.

APPENDIX 2

Photometric measurements of retro-reflective fabrics on the market in 1980-81.



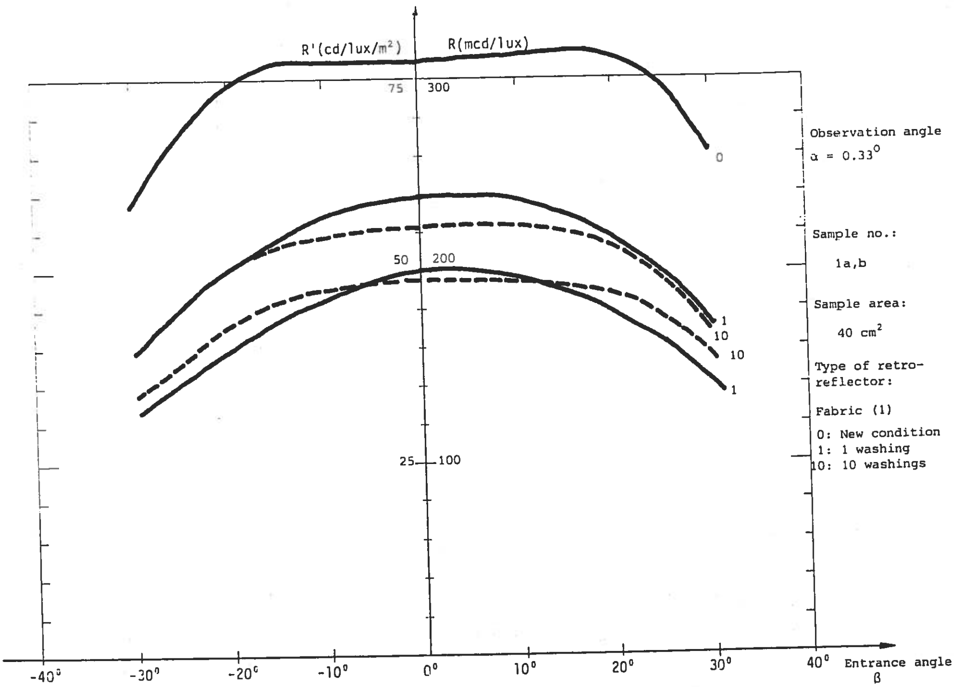
Appendix 2a: Retroreflective fabrics, new condition.



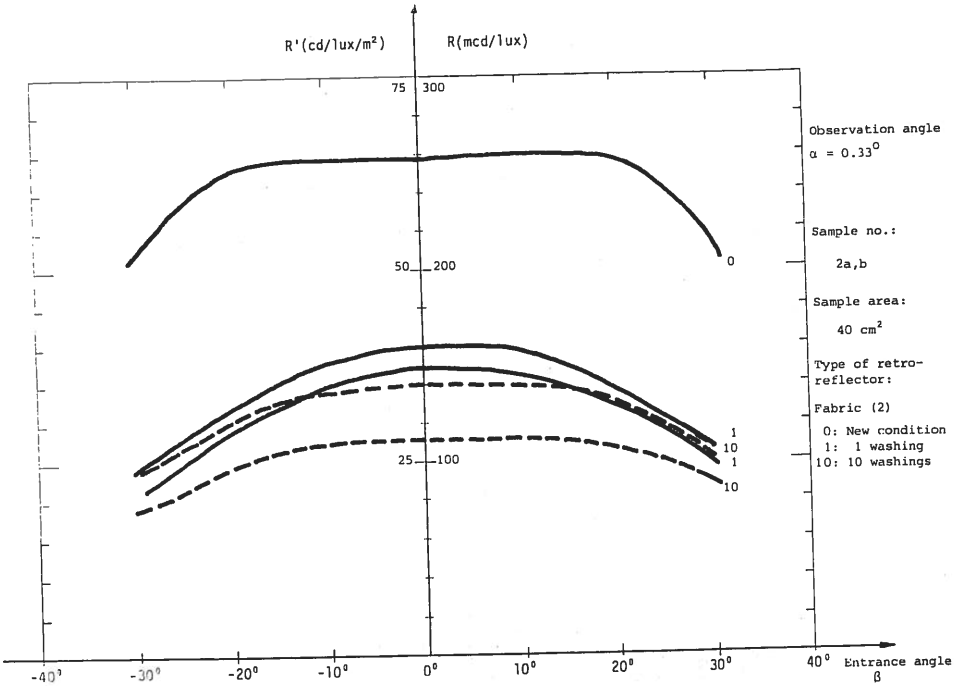
Appendix 2b: Retroreflective fabrics, new condition.

APPENDIX 3

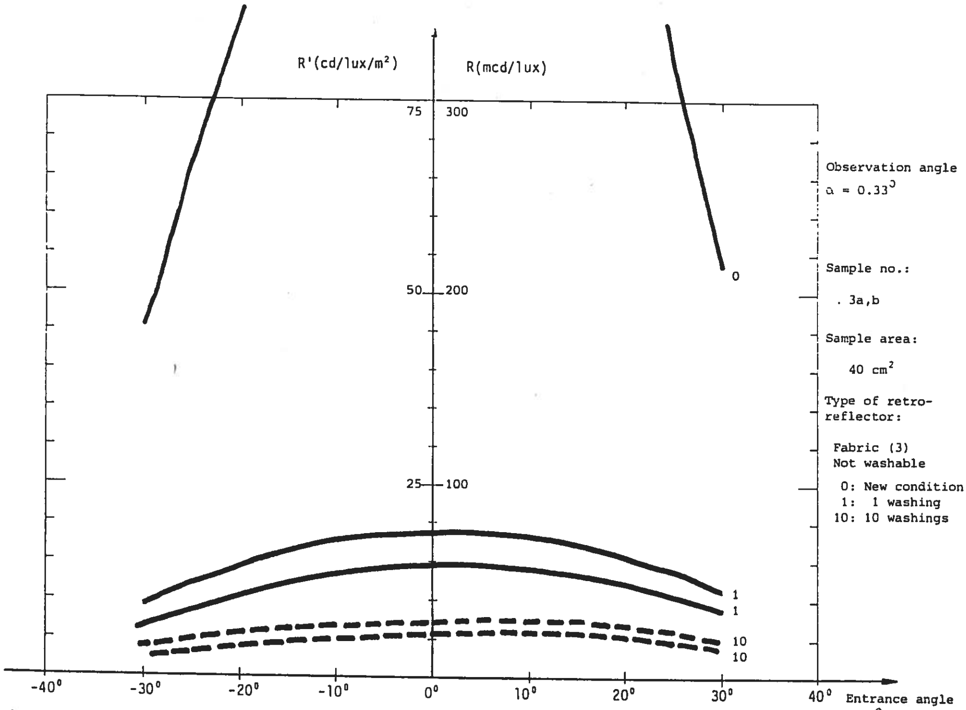
Washing test results for retro-
reflective fabrics on the market
1980-81.



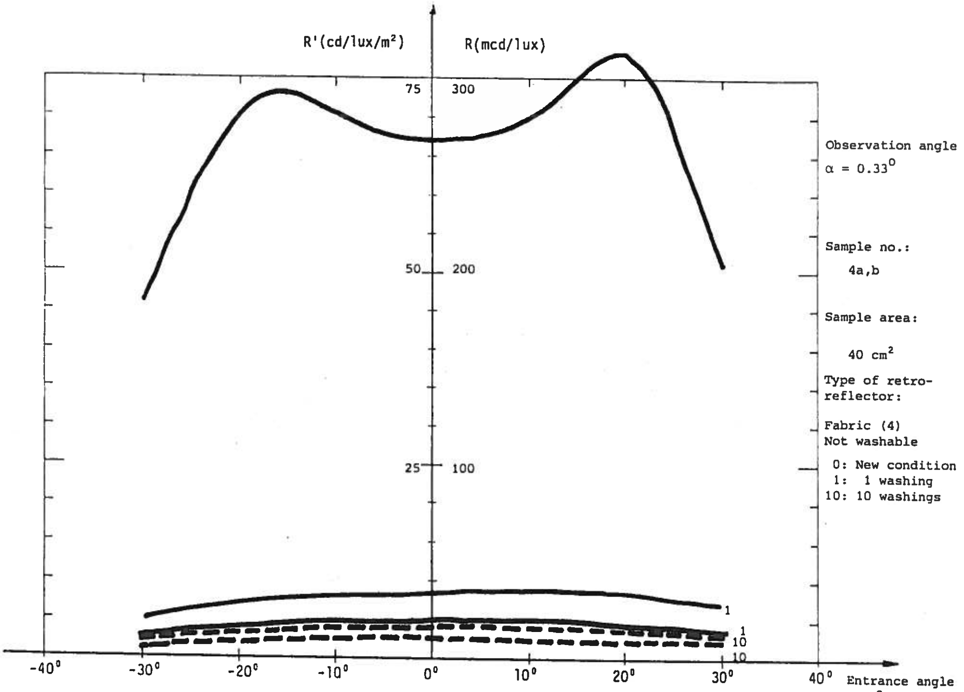
Appendix 3a: Washing test of retroreflective fabrics, two samples.



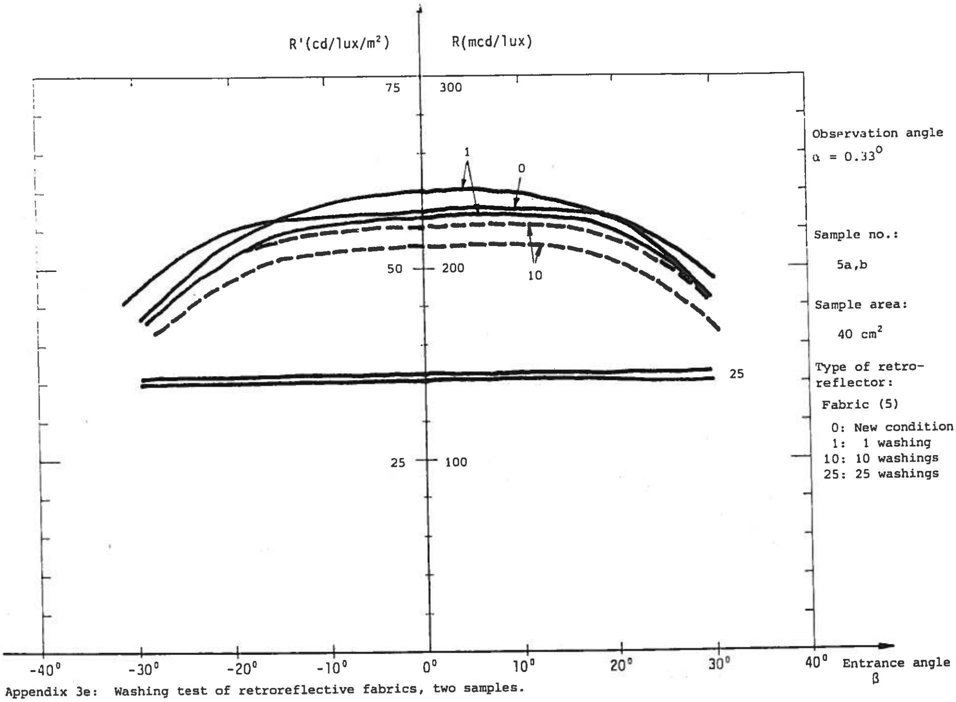
Appendix 3b: Washing test of retroreflective fabrics; two samples.



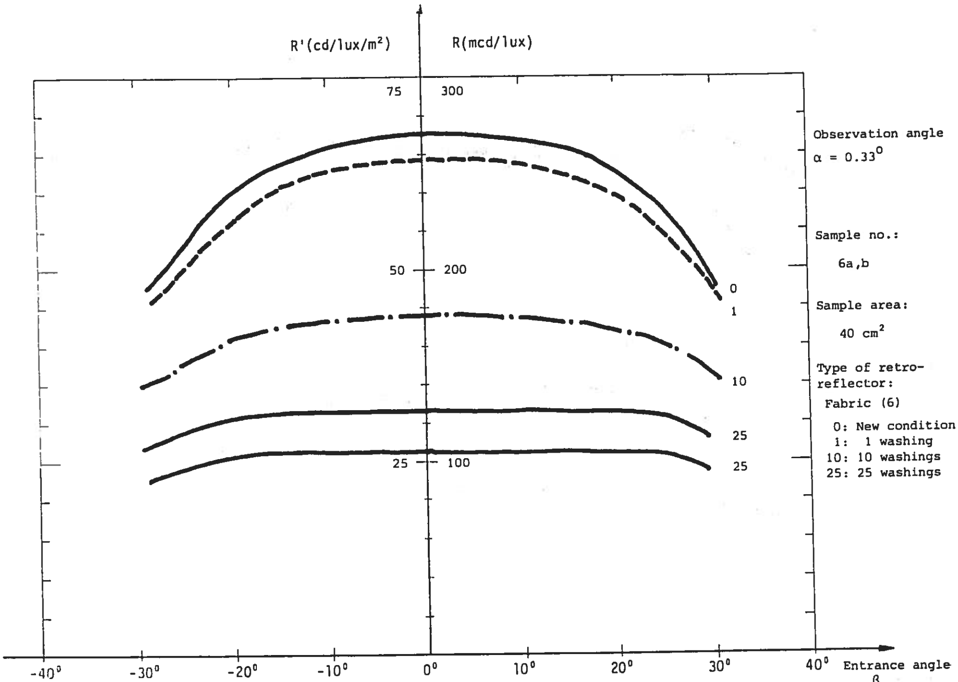
Appendix 3c: Washing test of retroreflective fabrics, two samples.



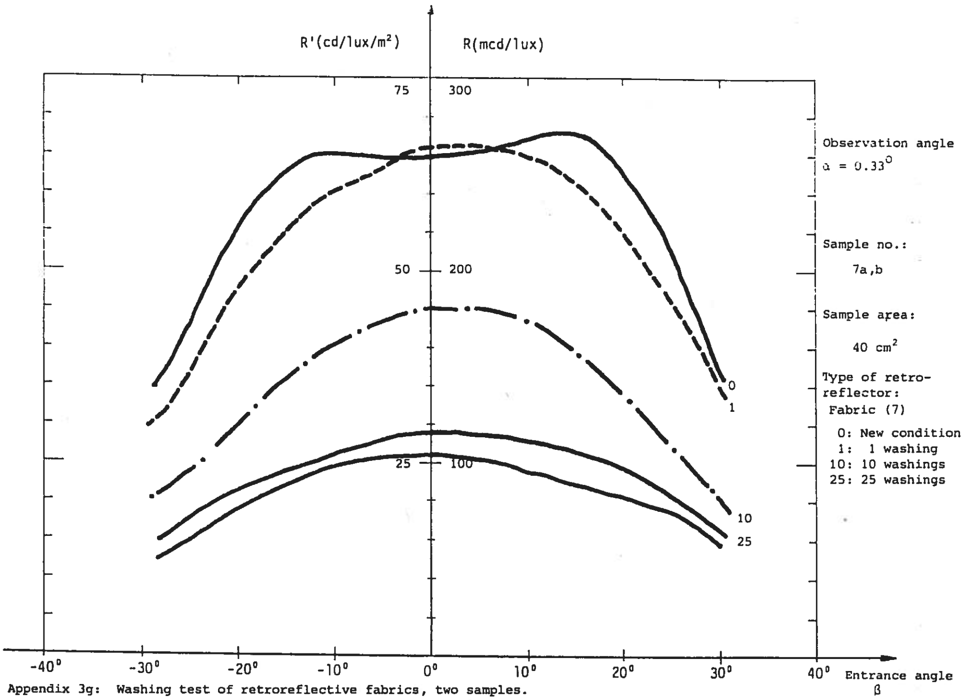
Appendix 3d: Washing test of retroreflective fabrics, two samples.



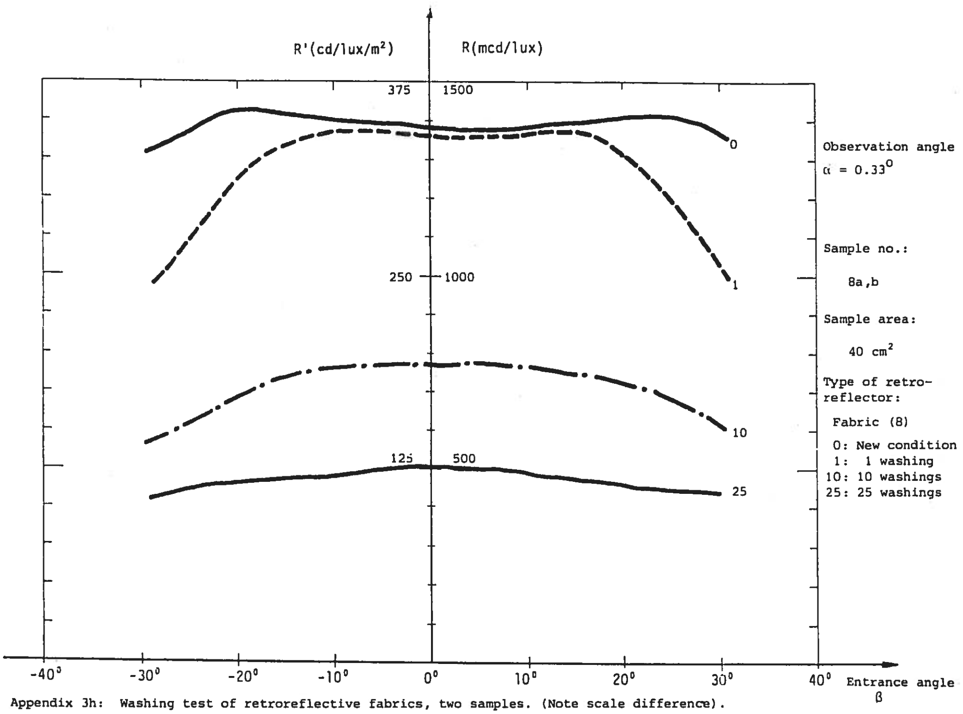
Appendix 3e: Washing test of retroreflective fabrics, two samples.



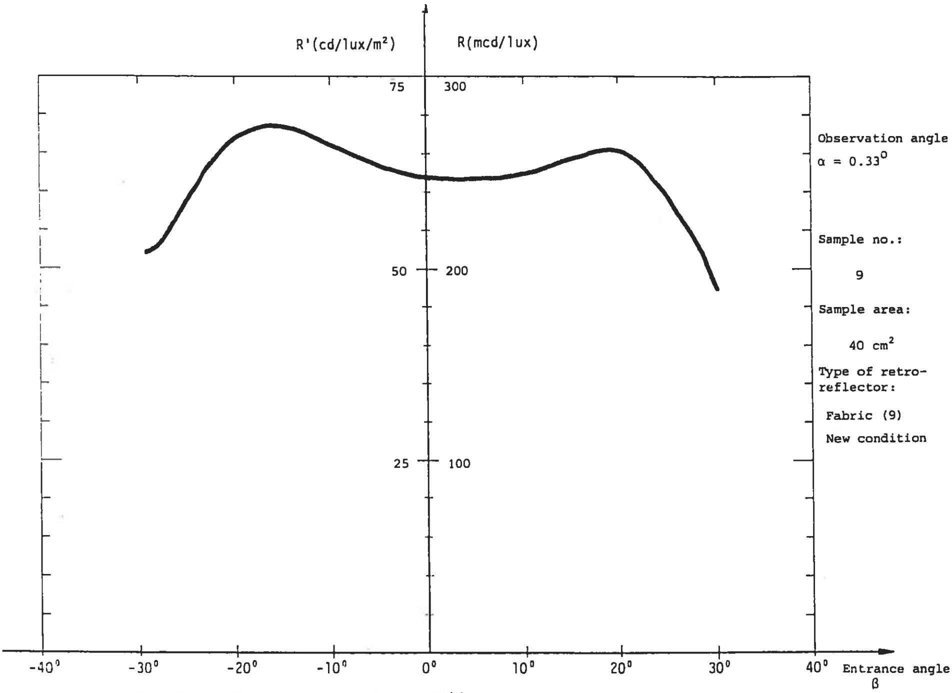
Appendix 3f: Washing test of retroreflective fabrics, two samples.



Appendix 3g: Washing test of retroreflective fabrics, two samples.



Appendix 3h: Washing test of retroreflective fabrics, two samples. (Note scale difference).



Appendix 3i: Retroreflective fabric, not tested for washing.

PREVIOUS ISSUES IN THE SERIES "NIGHT TRAFFIC".

Report no. 1 (1977): "Glare from lighting installations along roads". (In Scandinavian language, but with English summary and figure captions. Editors: VV).

Report no. 2 (1978): "Light reflection properties of road surfaces". (In Scandinavian language, but with English summaries and figure captions. Editors: VTI).

Report no. 3 (1980): "Optical and visual conditions on roads without permanent lighting". (In Scandinavian language, but with English summary and figure captions. Editors: LTL).

Report no. 4 (1982): "Reflection properties of road surfaces in headlight illumination - Dependence on measuring geometry". (In English, with summaries in Swedish and Finnish. Editors: VTI).