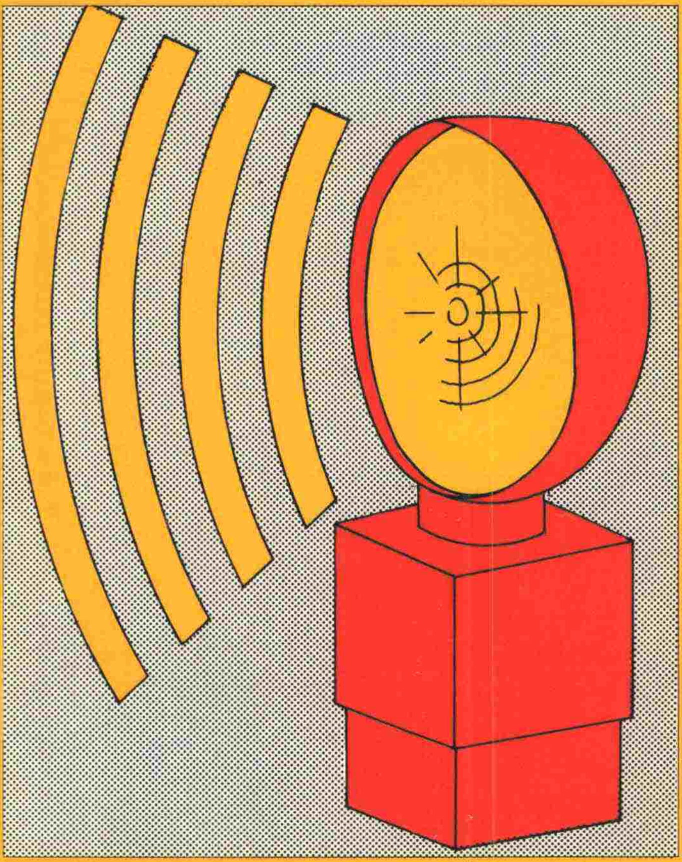

PHOTOMETRIC CHARACTERISTICS OF FLASHING LIGHT SIGNALS

A PRELIMINARY INVESTIGATION

Roads and Waterways Administration
Technical Development

Tampere University of Technology
Department of Electrical Engineering
Laboratory of Lighting Technology

TVH 723602

Helsinki 1989

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PREFACE

The technical quality requirements for battery-operated flashing signals are based in Finland on an investigation conducted over twenty years ago. The quality requirements were later revised to take into account technical developments in the fields of light sources and power supplies.

The quality requirements for flashing signals in the different Nordic countries differ to some extent. Consequently, separate type approval is required in the different countries and this causes extra work for the authorities and for the manufacturers of the equipment.

In the accompanying report by means of a survey of the literature the regulations of various countries are investigated together with research work concerning light signals, the devices for emitting light signals, and the physiological properties of the eye based on perception. In addition the report includes a critical review of the light signals adopted by various countries and of the quality requirement concerning the devices for emitting these signals.

The present preliminary investigation was commissioned by the Technical Development of the Roads and Waterways Administration and was carried out at the Laboratory of Lighting Technology of the Department of Electrical Engineering at Tampere University of Technology under the leadership of Professor Juhani Kärnä. The practical research work was carried out by Tapani Nurmi, research engineer. The investigation was commenced in May 1988 and completed in February 1989. On behalf of the Technical Development of the RWA the work was supervised by Esko Hyytiäinen, M.Sc.(Eng.) and Esko Tuhola, B.Sc. (Eng.).

CONTENTS

1. INTRODUCTION

The first quality requirements for battery-operated flashing signals were drawn up in Finland over twenty years ago as a joint project of the Roads and Waterways Administration and the Electrical Laboratory of the State Centre for Technical Research. Although the quality requirements also dealt with directional flashers, the emphasis was on omnidirectional amber flashers and steady-burning red lanterns, both having a filament lamp as the light source.

These first quality requirements were based as concerns illumination engineering mainly on results obtained from the literature (including the concept and calculation of effect luminous intensity, and the colour of the lights), on measurements already in use in Sweden (including the minimum extinction level for horizontally incident light (1000 cd), lighting-up and extinguishing illuminations levels, and load test), and on the equipment marketed by various manufacturers (including luminous intensity and distribution pattern). A detailed theoretical examination of the various alternatives was not made, nor was the feasibility of implementing the requirements investigated. These matters were also the subject of considerable criticism in the initial years.

Later revised quality requirements were based to a large extent on these first quality requirements, but naturally also took into account technical developments in light sources (gas discharge tubes) and power supplies (accumulators).

In order to survey the present situation it has proved necessary to review the latest research work and the regulations of different countries, and also to investigate as thoroughly as possible the foundations of the requirements from the point of view of lighting technology.

2. THE COLOUR OF THE LIGHT

2.1 Colours Defined by Finnish Regulations

The colours used in Finland for warning flashers and lanterns are defined in Publication no. 741808 of the Roads and Waterways Administration. A restrictive factor in the construction of the lenses is an additional requirement that the colored light shall be produced by means of a lens of solid-dyed material. The use of separate filters is prohibited.

In Finland devices emitting a flashing amber light and a steady-burning red light are defined. Figure 1 shows part of a CIE chromaticity diagram, on which the amber region required in Finland has been drawn.

Figure 1. The amber region according to the requirements of the Finnish RWA.

The red region is shown in Figure 2.

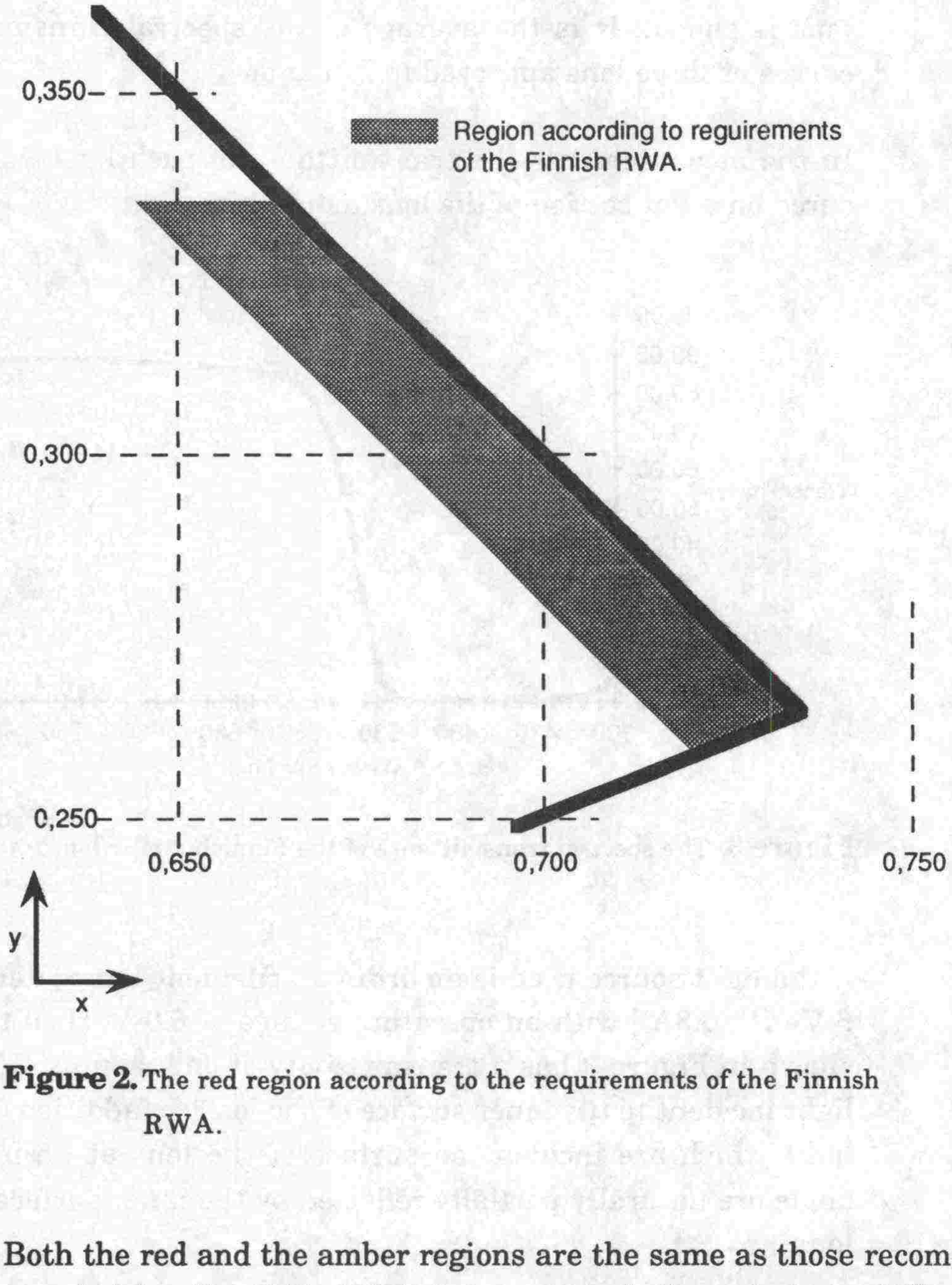

Figure 2. The red region according to the requirements of the Finnish RWA.

Both the red and the amber regions are the same as those recommended by the CIE. [CIE: International Commission of Illumination, Publication CIE no. 2.2., 1975, Colors of Light Signals.]

In making comparisons between different light signals emitting coloured light, it must be remembered that only flashers emitting light of the same colour can be compared with each other, because the colour has a very large effect on the amount of light emitted. The transmittance of the lens is affected not only by the optical design of the flasher, but also by the colour required of the lens. In Figure 3 a spectral transmittance curve for an amber lens is shown. It is the average of the spectral transmittance curves of three lens approved in Finland.

In the measurements the transmittance of each lens was measured on a flat section of the lens 3 mm thick.

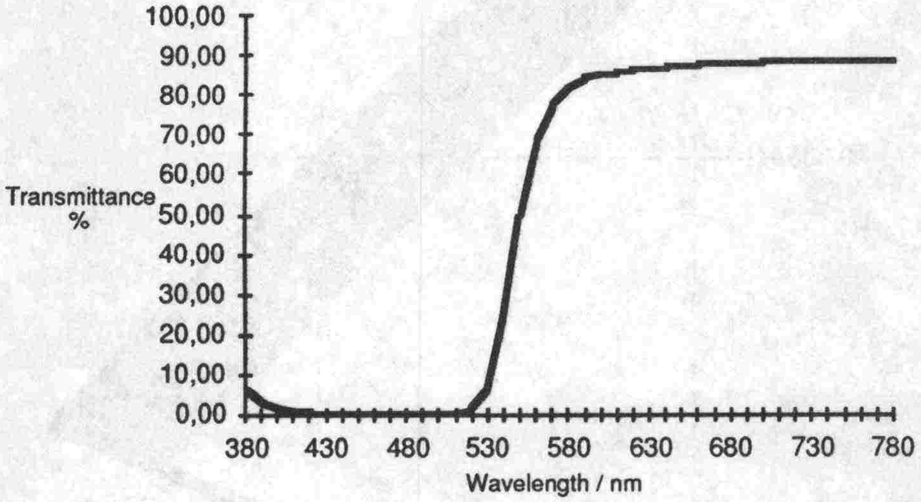

Figure 3. The spectral transmittance of the Finnish amber lens.

If the light source used is an ordinary filament lamp [Renpulssi 6 V (4V, 0.3A)] with an operating voltage of 6.0 V, then the lens shown in Figure 3 has a transmissivity of only approx. 60 % for light incident to the inner surface of the lens. In addition, rays of light which are incident on surface of the lens at an inclined angle are naturally partially reflected by the inner surface of the lens.

Central European flashers particularly often employ a brighter amber lens than that used in Finland. The spectral transmittance curve of a lens of this type is shown in Figure 4. The curve in question is the average of the transmittance curves of two different types of amber lens manufactured by NISSEN. These curves were also measured on a 3 mm thick section of the lens.

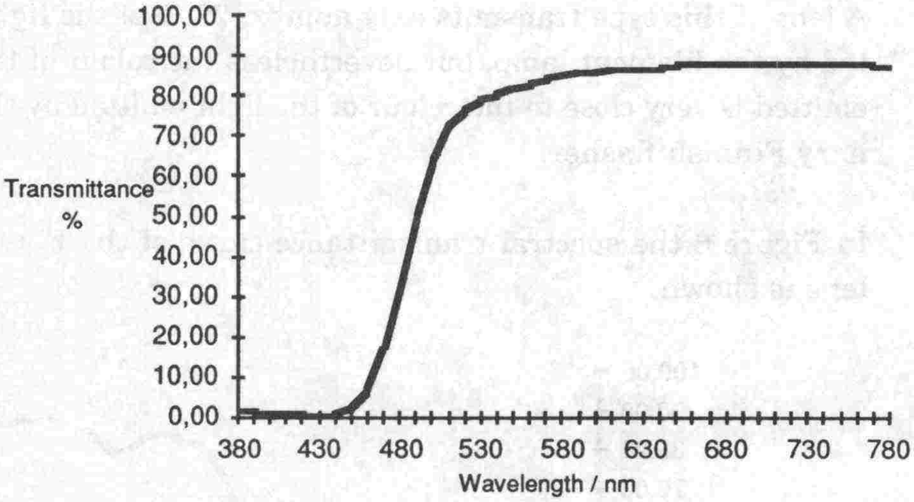

Figure 4. The spectral transmittance of the NISSEN lens.

A lens of this type transmits approx. 80 % of the light from the filament used in flashers, so that using the same lamp approx. 35 % more light is obtained from the flasher just due to the colour difference.

In Figure 5 the spectral transmittance curve of a amber traffic light lens is shown for comparison. This curve was measured from a 3 mm thick section of a lens manufactured by FUTURIT.

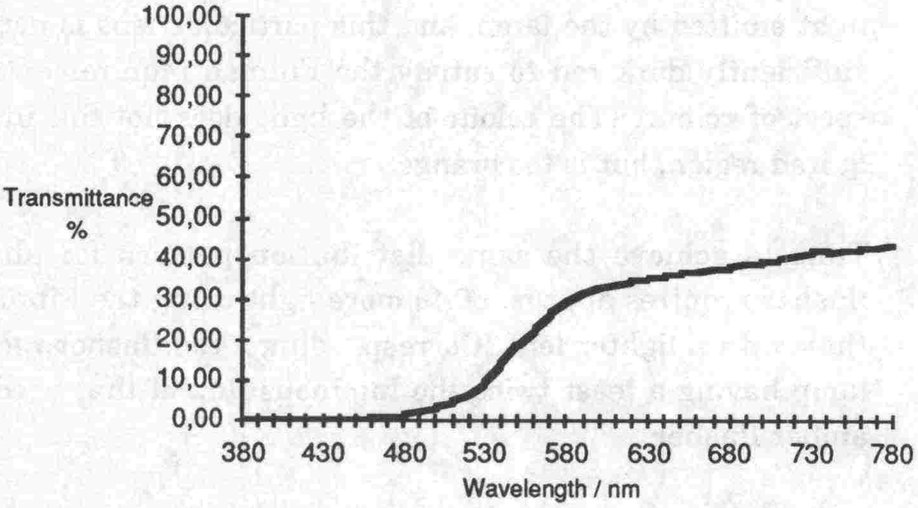

Figure 5. The spectral transmittance of the FUTURIT amber traffic light lens.

A lens of this type transmits only approx. 25 % of the light emitted by the filament lamp, but nevertheless the colour of the light emitted is very close to the colour of the light emitted by the ordinary Finnish flasher.

In Figure 6 the spectral transmittance curve of the Finnish red lens is shown.

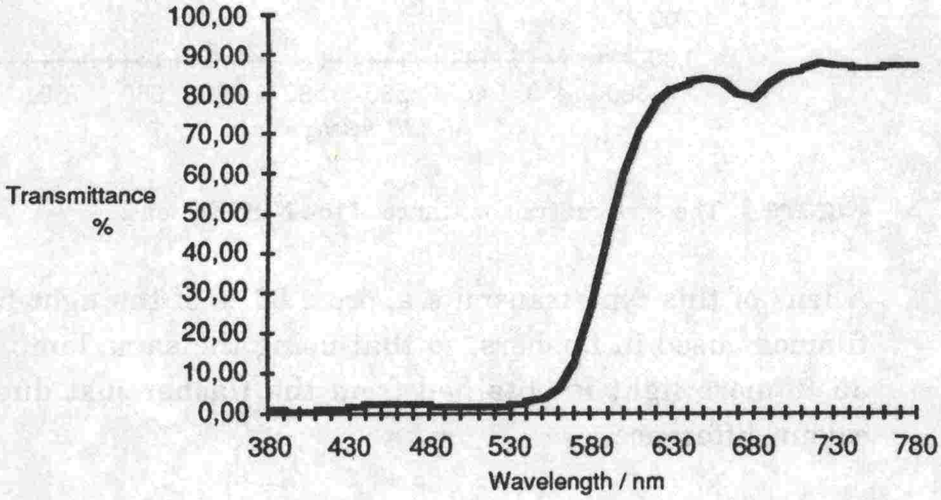

Figure 6. The spectral transmittance of the Finnish red lens.

The lens shown in Figure 6 transmits only approx. 30 % of the light emitted by the lamp, and this particular lens is not even a sufficiently dark red to satisfy the Finnish requirements in respect of colour. (The colour of the light does not fall in the required region, but is too orange.)

Thus to achieve the same distribution pattern for an amber flasher requires approx. 60 % more light using the Finnish lens than with a lighter lens. Corresponding a red flasher requires a lamp having a least twice the luminous flux of that used in the amber flasher.

2.2 Colours Defined by Other Regulations

2.2.1 Amber

The colour region of the amber light used in Finland is thus the same as the region recommended by the CIE. The same colour region is also used in Sweden and Norway for amber flashers intended for road use.

If the amber colour region recommended by the CIE is compared with the regions defined in other generally used standards and recommendations, then it is found that they are almost the same.

The amber colour used in traffic lights is defined in the standard DIN 6163. This definition is identical with the CIE guidelines, except that the region according to the DIN standard is slightly narrower at the green edge of the region.

Figure 7 shows the location of the region according to DIN standard 6163 compared with the region recommended by the CIE.

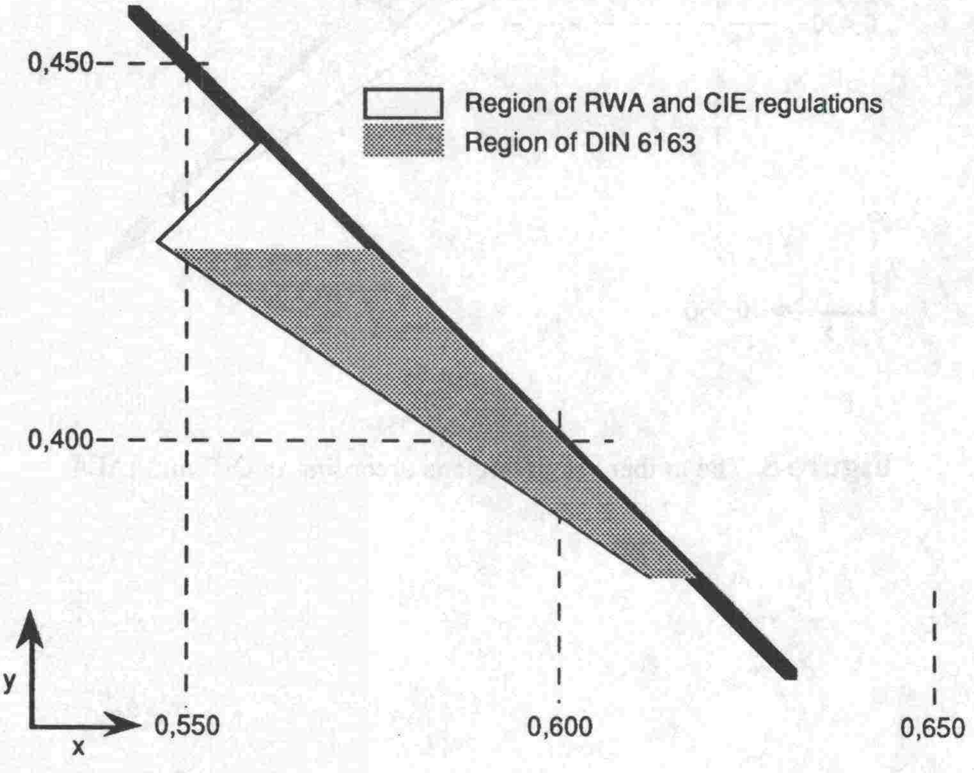

Figure 7. The amber colour regions according to CIE and DIN 6163.

In seafaring the colours most commonly employed are those according to the recommendations issued by IALA [IALA: Recommendations for the colours of light signals on aids to navigation, December 1977]. IALA employs two different specifications for each colour, a general region and a narrower preferred region. For the amber light both these are somewhat narrower than the CIE region.

Figure 8 shows the amber colour regions defined by the CIE and IALA.

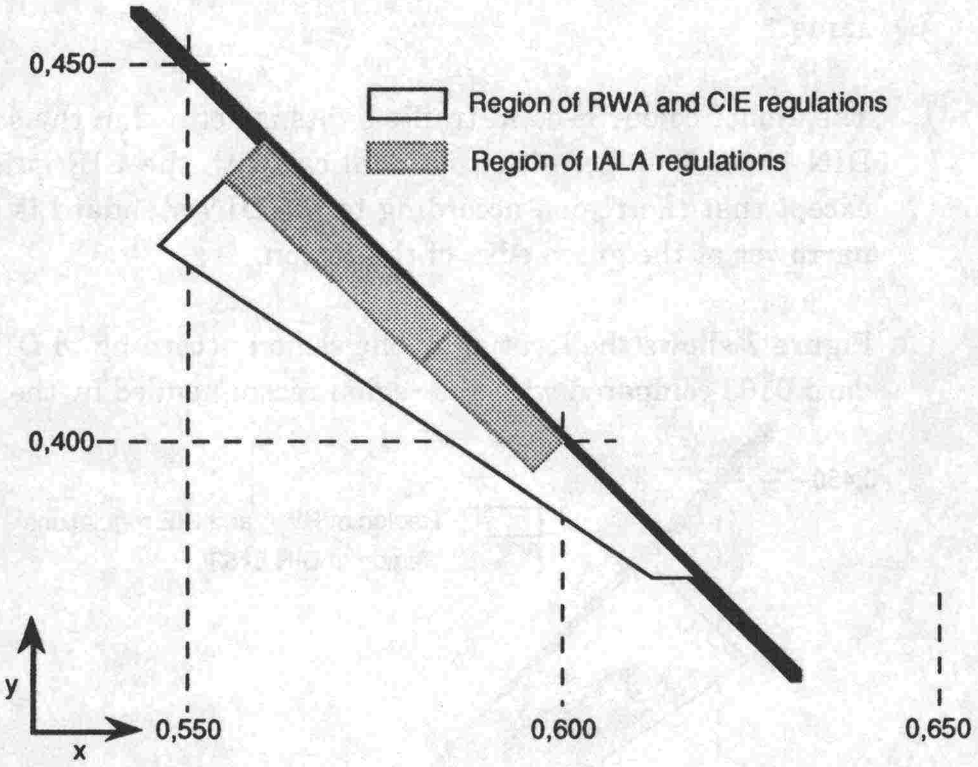

Figure 8. The amber colour regions according to CIE and IALA.

2.2.2 Red

The colour region of the red colour used in Finland is the same as the region recommended by the CIE. The same colour region specification is also used in Sweden and Norway.

If the red colour region recommended by the CIE is compared with regions specified by other generally used standards and recommendations, then it is found that the other regions are clearly narrower, although they are located in the same place on the chromaticity diagram.

The red colour region employed in traffic lights is narrower at both the yellow and dark-red edges.

Figure 9 shows the location of the region according to DIN standard 6163 compared with the region recommended by the CIE.

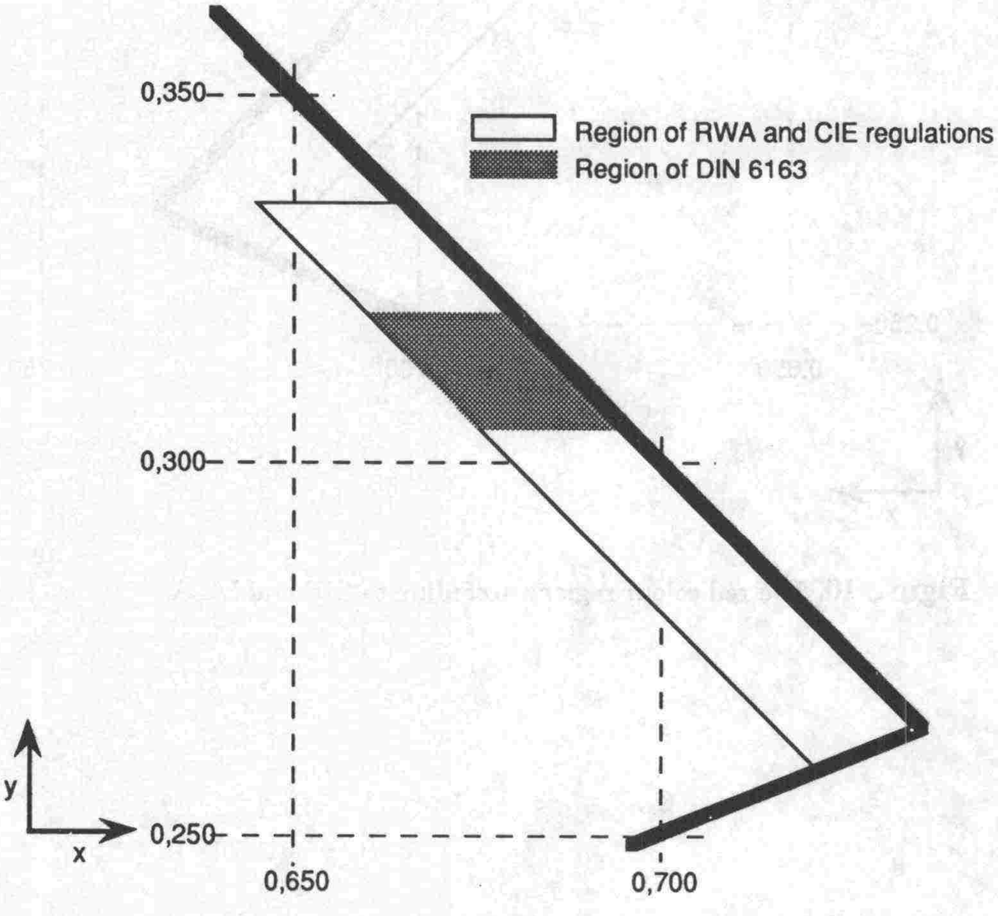

Figure 9. The red colour regions according to CIE and DIN 6163.

The general region defined by IALA is the same as the CIE region, but the preferred region is appreciably narrower.

Figure 10 shows the red region defined by CIE and IALA.

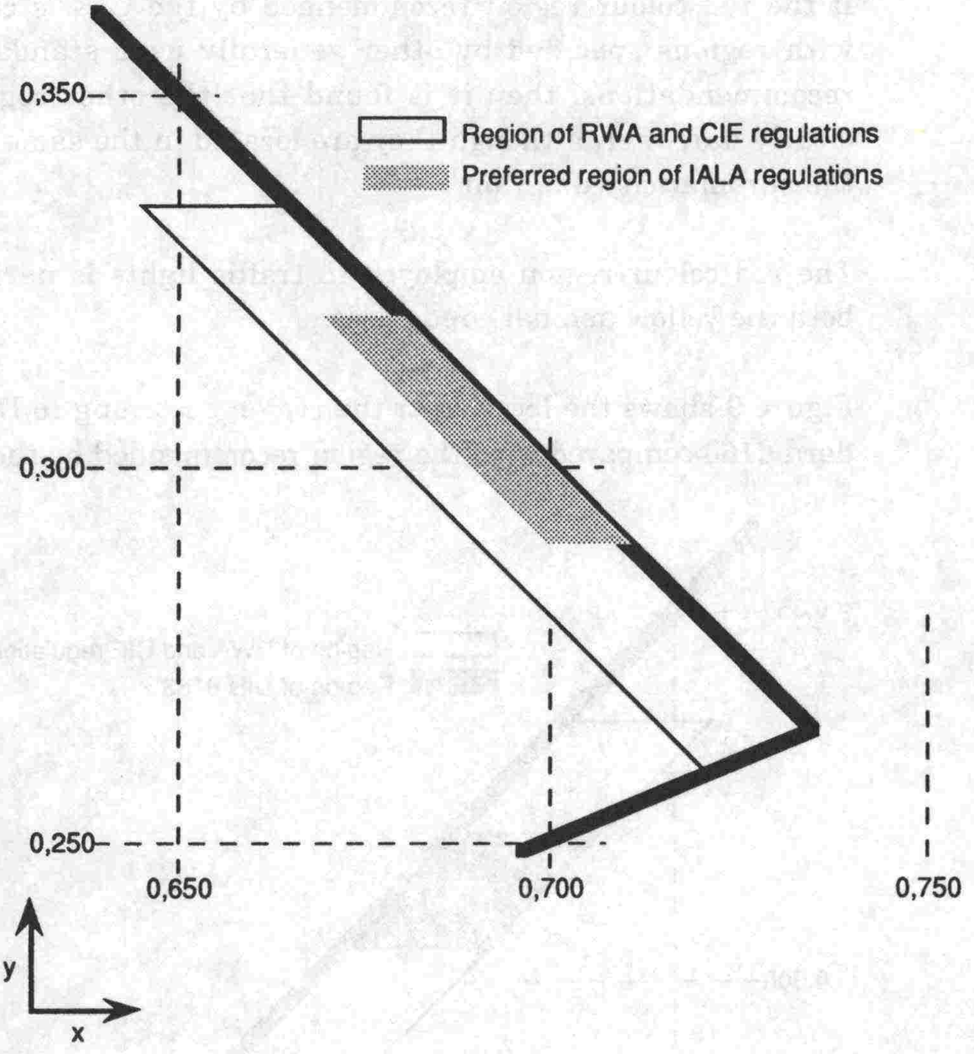

Figure 10. The red colour regions according to CIE and IALA.

3. LUMINOUS INTENSITY

3.1 General

In this section we examine how the intensity distribution pattern of a flasher affects the amount of light required, i.e. the luminous flux required to achieve various types of intensity distribution pattern. The different regulations of the Nordic countries are also compared in this respect. In this comparison the following regulations were used:

- Finland: TVH / 12.11.1984, Julk. nro 741808
- Sweden: Trafiksäkerhetsverket / 1.1.1987
- Norway: Vegdirektoratet / 1.2.1985
- No information received on Danish regulations

3.2 Effect of the Pattern of Distribution

The effect of the width and shape of different distribution patterns were examined with the aid of a computer program prepared at Tampere University of Technology.

The first to be examined was the omnidirectional flasher according to Finnish regulations, for which a "triangular" distribution pattern is required in the vertical direction (Figure 3). The effects of the width of the triangle and the luminous intensity required at its edges on the luminous flux necessary are shown in Table 1. The value 100 denotes the total luminous flux necessary for the combination currently in use (width of triangle 5° / luminous intensity at edges 0.5 cd).

Table 1. The luminous flux necessary for different types of triangular intensity distribution.

Luminous intensity edges / cd Width	0	0,25	0,5	0,75	1,0	1,25
2,5°	40	45	50	59	64	68
5 °	81	90	100	119	129	139
7,5 °	121	136	150	180	194	209
10 °	161	181	200	240	259	279

If the requirements were changed from a triangular intensity distribution to an intensity distribution which attempted to follow to an approximate sinusoidal intensity distribution having a peak value of 2 cd (as is described in certain requirements in the field of navigation), then the luminous flux required for the realisation of such an intensity distribution would be that given in Table 2.

Table 2. The luminous flux necessary for different types of sinusoidal intensity distribution.

Luminous intensity edges / cd width	0	0,25	0,5	0,75	1,0	1,25
2,5°	51	55	58	62	65	68
5 °	103	110	118	125	132	139
7,5 °	154	166	177	188	198	209
10 °	205	221	236	250	264	278

The values of luminous flux necessary are shown on the same scale as used for luminous flux in Table 1, so that they can be compared directly with each other. It will be seen from the table that if the requirement was for a sine-shaped intensity distribution with intensity values in the horizontal plane of 2 cd and a width in the vertical direction of 5°(0.5 cd), then approx. 18 % more light would be required to realise such a distribution than is required to produce the present intensity pattern. These two intensity distributions are both shown in Figure 1.

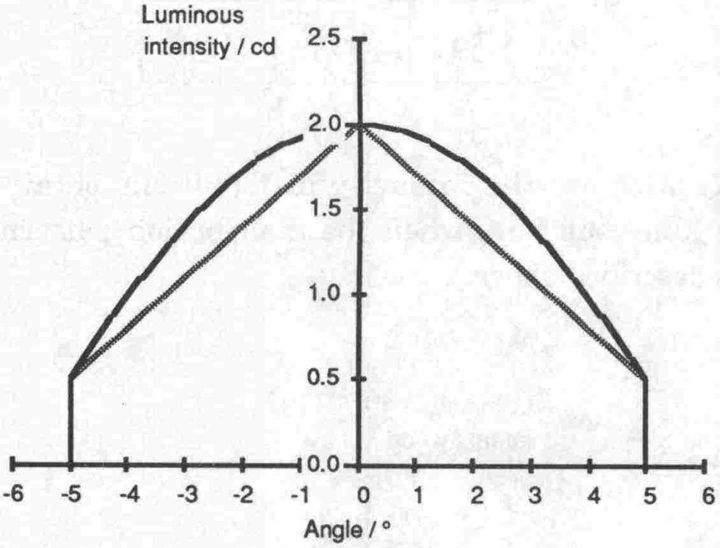

Figure 1. Different vertical intensity distributions.

In Table 3 the luminous flux necessary for the realisation of "uniform" intensity distributions of differing widths is compared.

Table 3. Luminous flux necessary for different uniform intensity distributions.

Width \ Luminous intensity / cd	1,0	1,5	2,0
2,5°	40	61	81
5 °	81	121	161
7,5 °	121	181	242
10 °	161	241	321

Figure 2 shows the intensity distributions obtained with the same luminous flux, when the distribution patterns are of the types described above.

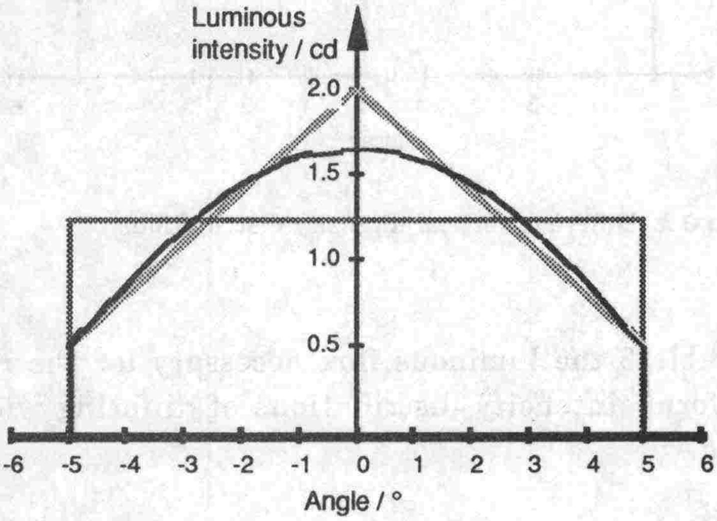

Figure 2. Intensity distributions obtained with the same luminous flux.

It will be seen that the "triangle" required in Finland corresponds in its luminous flux to a uniform distribution pattern having a luminous intensity over its entire area of approx. 1.24 cd. The difference between the sinusoidal and triangular distributions is relatively minor, there being a significant difference in the intensity required mainly in the angular range –1.5°...+1.5°.

3.3 Regulations of the Nordic Countries

3.3.1 Omnidirectional Flashers and Lanterns

In Finland at least the values of effective luminous intensity shown in Figure 3 are required for omnidirectional amber flashers.

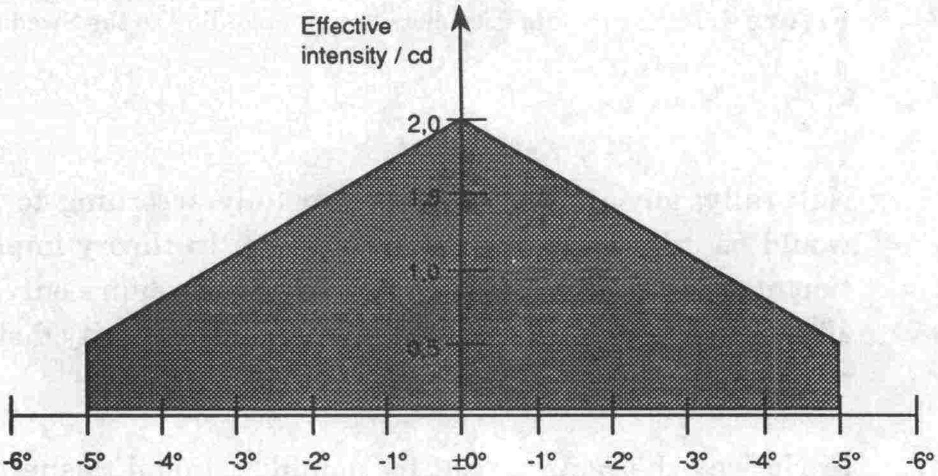

Figure 3. Vertical intensity distribution required in Finland for omnidirectional flashers.

In Sweden for omnidirectional flashers effective average luminous intensity of average at least 1 cd in the horizontal plane is required, and at other angles in the vertical plane in the range –5°...+5° the average should be at least 10 % of the value in the horizontal plane. Accordingly e.g. the vertical intensity distribution shown in Figure 4 would satisfy the Swedish requirements.

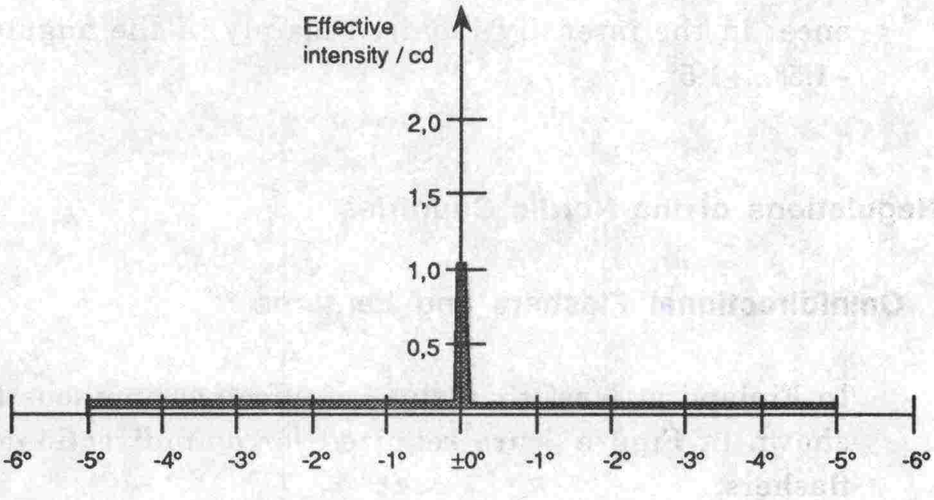

Figure 4. Minimum intensity distribution according to the Swedish regulations.

Naturally, an intensity distribution fully according to Figure 4 would be difficult to achieve in practice. In theory implementation of such an intensity distribution would require only approx. 10 % of the luminous flux necessary for the intensity distribution required in Finland.

In Norway the requirement for omnidirectional flashers in daytime use is 35 cd and in night-time use 4 cd in the vertical plane in the range -5°...+5°. The minimum intensity distribution required for night-time use in Norway is shown in Figure 5.

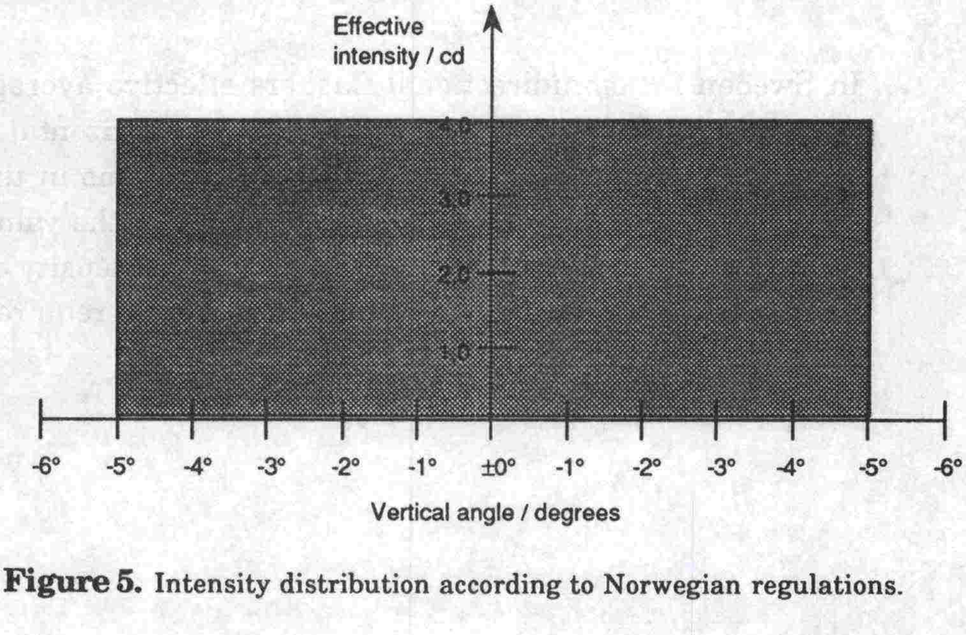

Figure 5. Intensity distribution according to Norwegian regulations.

The Norwegian requirement presented above is made somewhat less severe since in Norway the effective luminous intensity is calculated by Allard's method, which generally yields values 15...30 % greater than those obtained by the Blondell-Rey method employed in Finland and Sweden. The realisation of the intensity distribution required in Norway for night-time use nevertheless needs approx. 2.5 times more light than the intensity distribution required in Finland.

In addition to the omnidirectional amber flashers described above, in Sweden and Norway an omnidirectional amber lantern is defined for which the required luminous intensity is at least 2 cd over the entire vertical range -5°...+5°, and in Sweden also a red lantern satisfying the above requirements.

3.3.2 Directional Flashers and Lanterns

In Finland for directional amber filament-lamp flashers an average effective luminous intensity of at least 5 cd is required over the vertical range -5°...+5° and the horizontal range -10°...+10°, with a minimum value in the same region of at least 2.5 cd. For flashers fitted with gas discharge tubes, in Finland an average of 0.75 cds is required over the horizontal range -20°...+20°, the realisation of which needs about 7.5 times the luminous flux which is required for the realisation of filament-lamp flashers.

In Sweden and Norway an effective luminous intensity of at least 4 cd is required over the entire range ±5°/±10°. In theory such a flasher could be realised with 25 % less luminous flux than a flasher according to the Finnish regulations, but in practice it is very difficult to produce a uniform intensity distribution, so that in most cases the Swedish regulations mean that if the minimum is 4 cd, then the average of the entire range will be at least 8...10 cd, so that the necessary luminous flux is doubled compared with the Finnish regulations.

In addition to the flashers described above, in Sweden and Norway quality requirements have been put forward for steadyburning amber and red directional lanterns. In Finland only a steady-burning red omnidirectional lantern has been defined.

4. EFFECTIVE LUMINOUS INTENSITY

4.1 Steady-Burning Light Signals

In order to understand the various factors associated with the visibility of a flashing light signal, we will first examine some aspects of steady-burning light signals. The level of illumination produced on the retina of an observer by a light signal emitting light continuously determines whether the light signal is seen or not. As is known, for a point light source emitting light continuously the illumination created on a plane perpendicular to the direction of radiation and at a distance s from the source is

$$E = \frac{I\tau^{s}}{s^{2}} \qquad (1)$$

,where

I is the luminous intensity of the light source

τ is the transmissivity of air (<1).

In order that the light signal shall be visible to an observer at a distance s, the following condition must be satisfied:

$$E = \frac{I\tau^{s}}{s^{2}} \geq E_{min} \qquad (2)$$

,where

E_{min} is the minimum perceptible illumination (threshold illumination)

Since generally it is desired to know at what distance a light signal of given luminous intensity is visible in given weather conditions, it is necessary to solve equation (2) with respect to s. Since there exists no analytic solution, we must content ourselves with nomograms, graphs of ready calculated values, or numerical solutions.

The minimum perceptible illumination is not a constant, but depends on the background luminance (Figure 1), on the location of the light source in the field of vision, on the angular size and shape of the light source, on the angle from which the light source is viewed, and on the colour of the light. The curves shown in Figure 1 are valid only if the observer knows precisely where the light source is located.

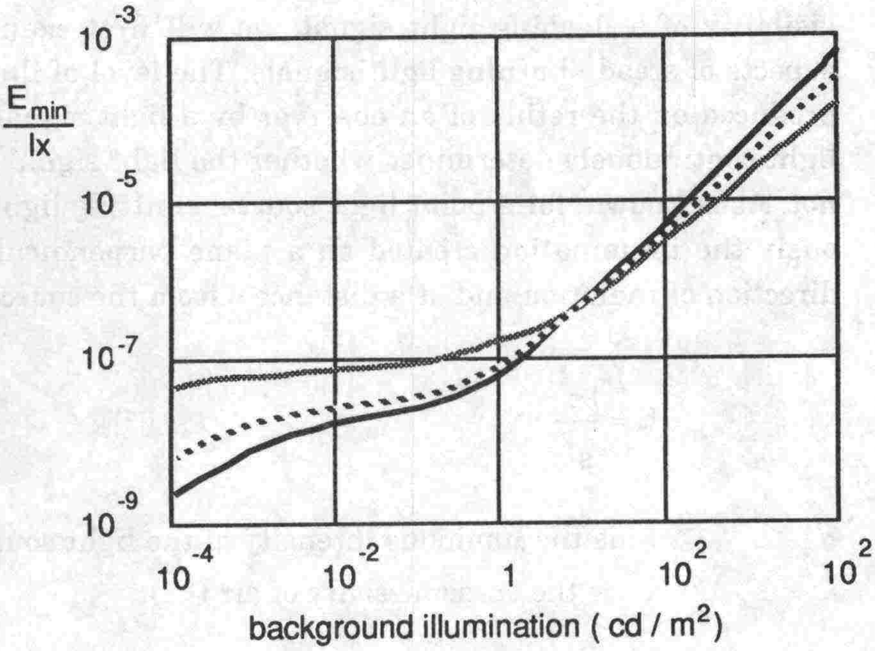

Figure 1. The relation between the threshold illumination at the eye and the background illumination for a point source of white light, according to different research workers.

According to some research workers, the levels of illumination presented should be multiplied by ten in order that the source shall be readily located, and in cases where the observer is not looking for the signal but the signal must instead attract the observer's attention, these levels of illumination should be multiplied by as much as one thousand.

4.2 Flashing Light Signals

When the signal from a signal light consists of discrete flashes of light of similar form and repeated at regular intervals, then the peak instantaneous luminous intensity of the flashes must be greater than the intensity which would be needed for a steady-burning light signal if both signals are to be visible at an equal distance. In order to compare the effectiveness of different flashing light signals the concept of the "effective luminous intensity" of a flash of light has been adopted. By this is meant the luminous intensity of a steady-burning light signal of the same shape, size and colour which in identical conditions is visible at the same distance as the flashing light signal in question. Experimentally it is possible to determine the effective luminous intensity of a flash of light of given form and magnitude by locating the flashing source in question at such a distance from the observer that it is only just visible and by comparing the flashing light with a nearby steady-burning light signal of adjustable luminous intensity. On the basis of investigations which have been made, several slightly different methods of calculating the effective luminous intensity have been proposed, of which the most commonly used are the formulae proposed by Schmidt-Clausen, Allard, and Blondell-Rey. These calculation formulae, however, give different values for the effective luminous intensity, so that this must be taken into account when comparing the regulations of different countries.

4.2.1 The Schmidt-Clausen Method

The variation of the instantaneous luminous intensity I as a function of time is described the the function I(t). The peak intensity of the flash is denoted by I_0. The integral of the instantaneous intensity with respect to time taken over the entire duration of the flash is defined by:

$$J = \int I \, dt \qquad (3)$$

Then according to Schmidt-Clausen the effective intensity I_e of the flash is given by the equation:

$$I_e = \frac{J}{C + \frac{J}{I_o}} \qquad (4)$$

,where

C is a time constant for which the value 0.2 s is used for nighttime observations and 0.1 s for daytime observations. In this form the formula is particularly suitable for calculating the effective intensity of gas discharge tubes, for which J can easily be measured directly. For flashes of longer duration the formula can be used in the form

$$I_e = \frac{I_o \tau}{\frac{C}{F} + \tau} \qquad (5)$$

,where

τ is the total duration of the flash

F is the Schmidt-Clausen form factor, which is defined as follows:

$$F = \frac{\int_{t_1}^{t_2} I(t)\,dt}{I_o \times (t_2 - t_1)} \qquad (6)$$

,where

t_1 is the time of commencement of the flash

t_2 is the time of cessation of the flash, so that

$\tau = t_1 - t_2$.

For very brief flashes of light the value of τ becomes negligibly small compared with C / F, so that equation (5) can be written:

$$I_e = \frac{J}{C} \qquad (7)$$

This form can be used for flashes of light with a duration of less than 0.05 s. When C = 0.2, then

$$I_e = 5 \times J \qquad (8)$$

4.2.2 The Allard Method

This method also starts by the representation of the flash as a function of time I(t). The corresponding instantaneous effective intensity is defined as the function i(t). According to Allard's theory the functions are related by the differential equation:

$$\frac{di}{dt} = \frac{I(t) - i(t)}{A} \qquad (9)$$

,where

A is a time constant, for which the value 0.2 s can be used in practical calculations. According to Allard the effective intensity I_e of the flash is then the peak value of i(t). The explicit solution of equation (9) is:

$$i(t) = \int_{t_1}^{t} \frac{I(u)}{A} e^{-\frac{(t-u)}{a}} \qquad (10)$$

,where

t_1 is a time before which no light is exhibited.

For very brief flashes of light the value of the effective intensity becomes

$$I_e = \frac{J}{A} \qquad (11)$$

, where

J is the integral of the light flash, as in equation (3),

so that if A = C then these two methods give the same result for very brief flashes of light.

4.2.3 The Blondell-Rey Method

According to Blondell-Rey the effective luminous intensity I_e can be defined as follows:

$$I_e = \frac{\int_{t_1}^{t_2} I(t)\,dt}{a + (t_2 - t_1)} \qquad (12)$$

,where

I(t) is a function which describes the variation of the instantaneous luminous intensity with time,

a is the Blondell-Rey visual time constant

t_1,t_2 are time instants at which $I(t) = I_e$.

Originally in Blondell-Rey's investigations no particular values were defined for the time instants t_1 and t_2, but later Douglas proposed that t_1 and t_2 should be chosen so that I_e assumes a maximum value. He also showed that the maximum value is attained when $I(t_1) = I(t_2) = I_e$.

4.3 The Effective Intensity of Different Flashing Sources

It was desired to determine by practical measurement what values are obtained for the effective luminous intensity of the flashes emitted by current warning flashers using the different methods of calculation. In order to investigate this the variation of instantaneous luminous intensity with time was measured for four different flashing sources, after which for each flash the effective luminous intensity was calculated using the different methods. Figure 2 shows the flash from a filament-lamp flasher with an electrical pulse duration of approx. 90 ms.

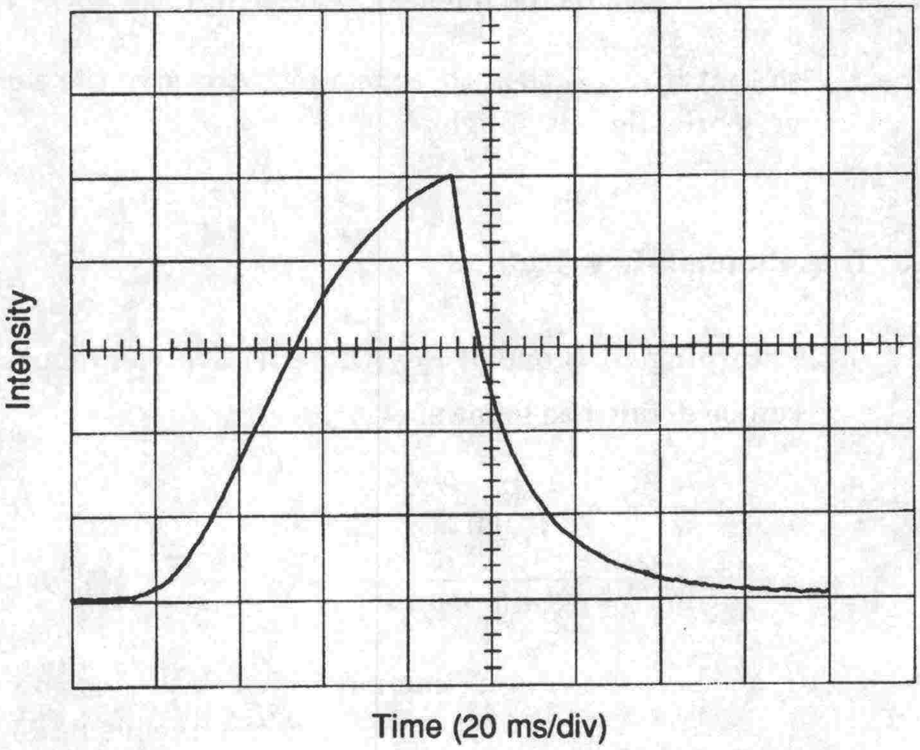

Figure 2. Instantaneous luminous intensity of the flash as a function of time I(t).

For this flash of light the different methods of calculation give the following values for the effective luminous intensity:

Schmidt-Clausen	0.219 x peak value
Allard	0.215 x peak value
Blondell-Rey	0.181 x peak value

Figure 3 shows the flash from a filament-lamp flasher with an electrical pulse duration of approx. 150 ms.

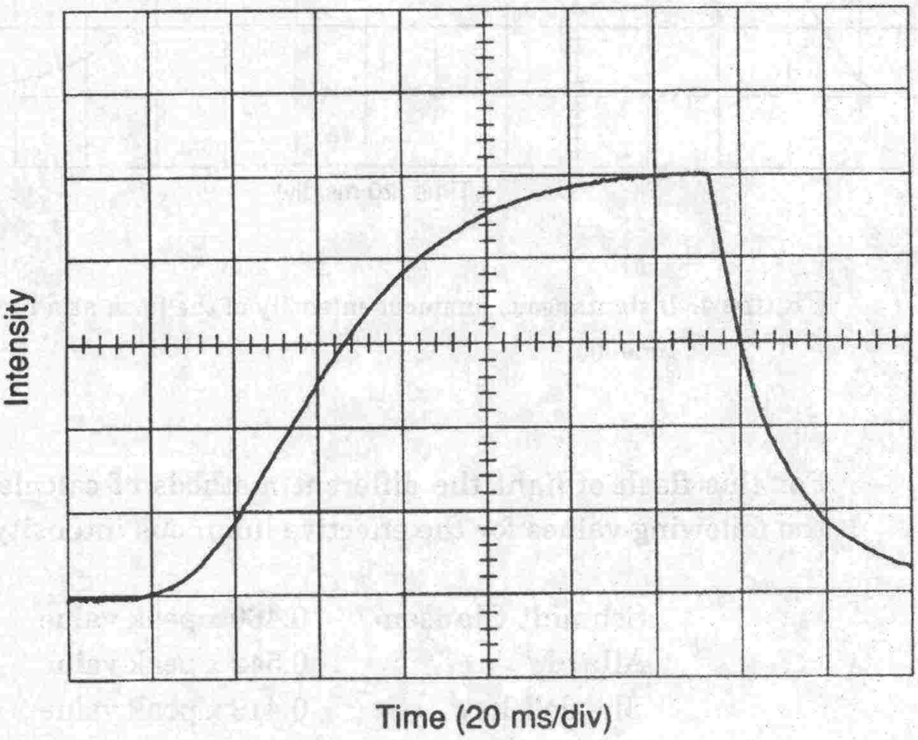

Figure 3. Instantaneous luminous intensity of the flash as a function of time I(t).

For this flash of light the different methods of calculation give the following values for the effective luminous intensity:

Schmidt-Clausen	0.349 x peak value
Allard	0.377 x peak value
Blondell-Rey	0.301 x peak value

Figure 4 shows the flash from a filament-lamp flasher with an electrical pulse duration of approx. 205 ms.

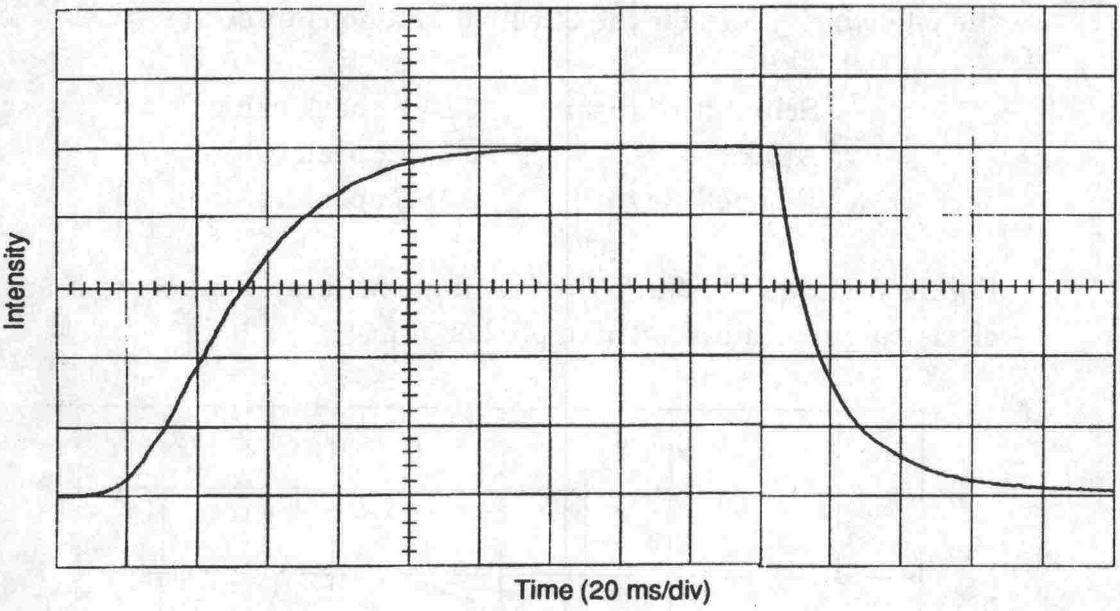

Figure 4. Instantaneous luminous intensity of the flash as a function of time I(t).

For this flash of light the different methods of calculation give the following values for the effective luminous intensity:

Schmidt-Clausen	0.460 x peak value
Allard	0.542 x peak value
Blondell-Rey	0.419 x peak value

Figure 5 shows the flash from a filament-lamp flasher with a switching power supply and an electrical flash pulse duration of approx. 175 ms.

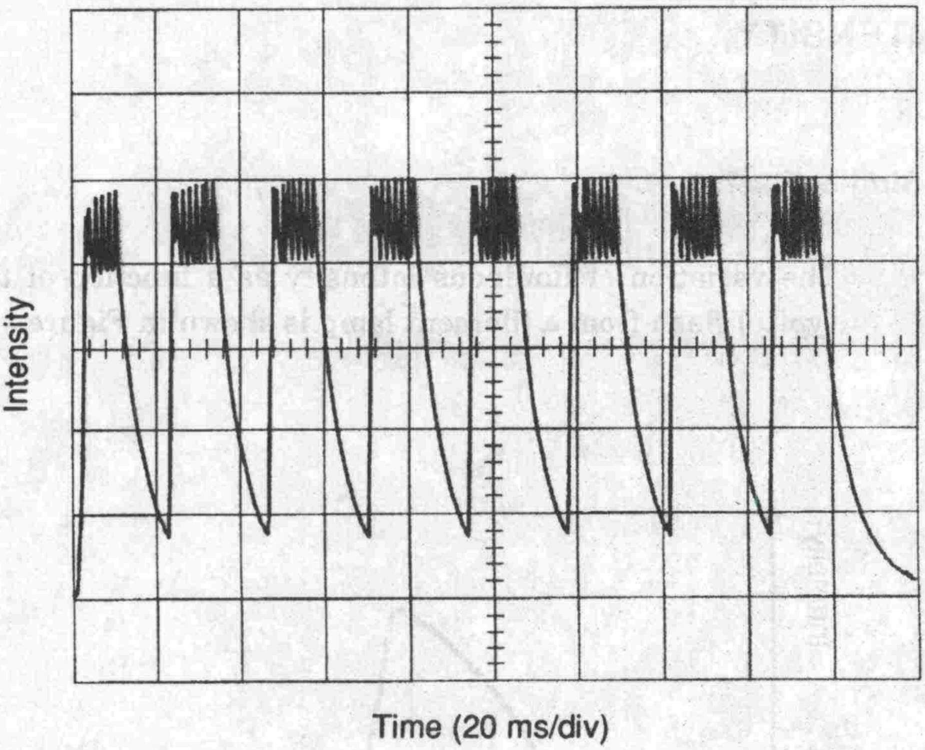

Figure 5. Instantaneous luminous intensity of the flash as a function of time I(t).

For this flash of light the different methods of calculation give the following values for the effective luminous intensity:

Schmidt-Clausen	0.369 x peak value
Allard	0.370 x peak value
Blondell-Rey	0.300 x peak value

As can be seen from the preceding examples, the values for the effective luminous intensity given by the different methods of calculation differ appreciably. For the flashes used for the examples, the largest differences were of the order of 30 %, typically 20...25 %. In view of this it is obvious that if it is intended to achieve uniformity between different countries in respect of the quality requirements for flashing signal lights, then it is also necessary to achieve uniformity in respect of the concepts and formulae associated with the calculation of effective luminous intensity.

5. CALCULATION OF THE EFFECTIVE LUMINOUS INTENSITY

5.1 Single Flash

The variation of luminous intensity as a function of time for a typical flash from a filament lamp is shown in Figure 1.

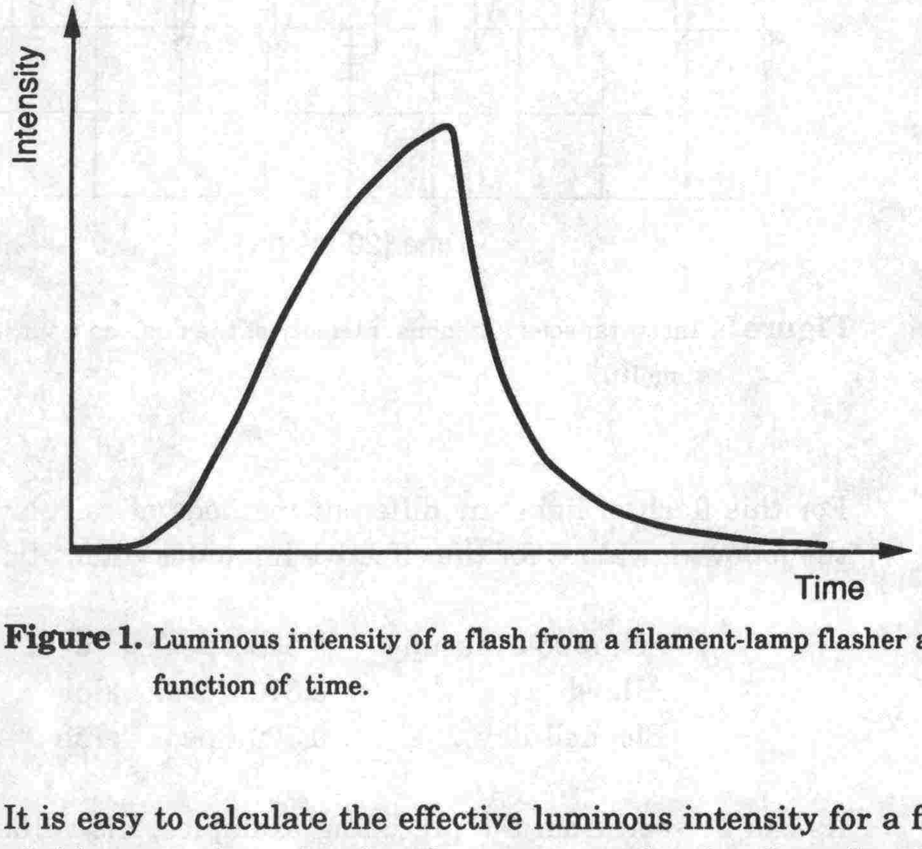

Figure 1. Luminous intensity of a flash from a filament-lamp flasher as a function of time.

It is easy to calculate the effective luminous intensity for a flash of this type, since the time instants t_1 and t_2 in formulae 6, 10 and 12 of Section 4 are uniquely defined.

Figure 2 shows a different type of light flash, in which I_b denotes the average luminous intensity in the time interval $t_b \ldots t_y$. (In the flash the time interval $t_c \ldots t_z$ is so brief that the momentary reduction in the intensity can not be perceived by the eye.)

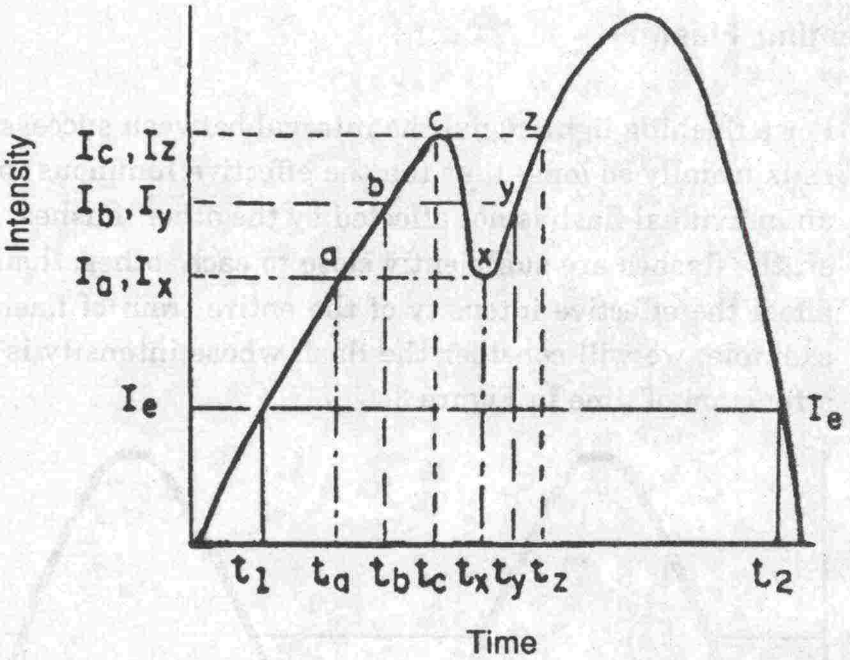

Figure 2. A flash with multiple peaks.

If I_e is less than I_a or greater than I_z, then the calculation of the effective luminous intensity presents no problems.

If, on the other hand, I_e is in the interval $I_a ... I_z$, then the definition of the time infants t_1 and t_2 may cause difficulties. It can, however, be shown that if the part of the flash in the interval $t_b ... t_y$ remains unchanged while the remaining part of the flash is changed, then the earlier time instant (t_1) can either be in the interval $t_a ... t_b$ or in the interval $t_y ... t_z$, but never in the interval $t_b ... t_y$. If I_e is equal to I_b, then either of the time instants t_b and t_y can be used and in both cases the same value for the effective luminous intensity I_e is obtained. If, however, the flashes of light are clearly discrete the methods described in Section 5.2 should be used.

5.2 Repeating Flash

For a flashing light signal the interval between successive flashes is usually so long, that the the effective luminous intensity of an individual flash is not affected by the other flashes. If, however, the flashes are sufficiently close to each other, then they also affect the effective intensity of the entire train of flashes. As an example, we will consider the flash whose intensity is shown as a function of time in Figure 3.

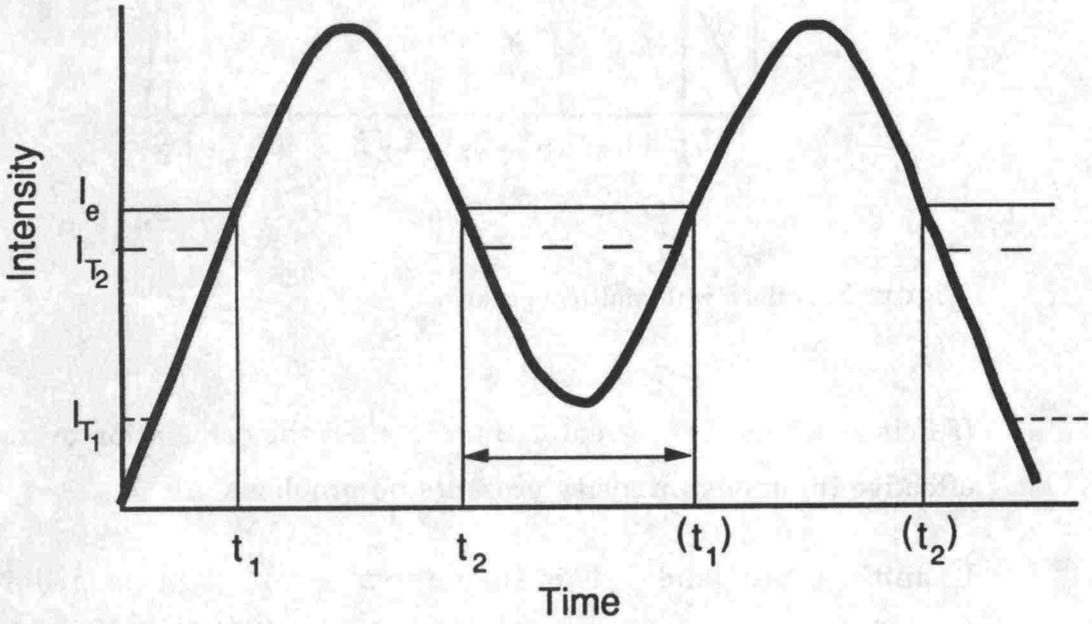

Figure 3. A flash with twin peaks.

In the figure the intensity at which a steady-burning light is only just visible is denoted by I_T. If this intensity is much lower than Ie, (in the figure I_{T1}), then the flash of light will be seen as a continuous flash with twin peaks. If, however, the intensity in question is of approximately the same order of magnitude as I_e (I_{T2}), then the observer will perceive two discrete flashes of light.

If, however, the interval between the flashes is considerably less than for the pair of flashes shown in Figure 3, then the situation is changed. If during the flash the times for which the intensity is less than the effective intensity are less than 0.01 s, then the eye perceives the light signal as a single flash. An example of such a sequence of flashes is shown in Figure 4.

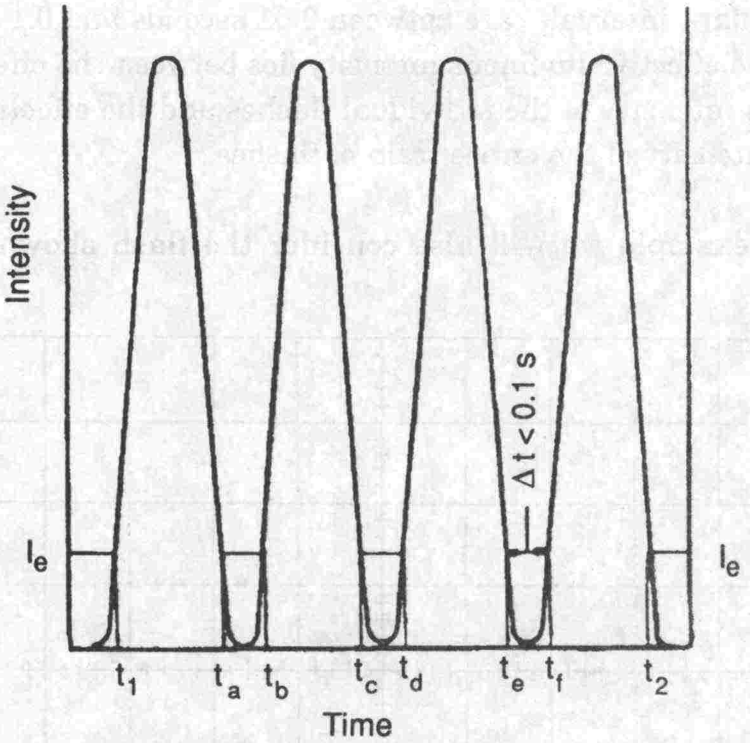

Figure 4. Successive Flashes of Light.

In this case the effective luminous intensity can be calculated from the formula:

$$I_e = \frac{\int_{t_1}^{t_a} I\,dt + \int_{t_b}^{t_c} I\,dt + \int_{t_d}^{t_e} I\,dt + \int_{t_f}^{t_2} I\,dt}{a + (t_2 + t_1)} \qquad (1)$$

t_1 and t_2 are the first and second instants when

$I = I_e$

I_e is the effective intensity of the train of flashes

It should be particularly noted that I_e is the effective luminous intensity of the entire train of flashes and not that of the individual flashes.

If the time intervals for which the luminous intensity is less than the effective luminous intensity are of the order of 0.1 s or longer, then the observer perceives discrete flashes. In such cases the effective luminous intensity must also be calculated from the luminous intensity of the individual flashes.

If the "dark intervals" are between 0.01 seconds and 0.1 seconds, then the effective luminous intensity lies between the effective luminous intensity of the individual flashes and the effective luminous intensity of the entire train of flashes.

As an example we will also consider the flash shown in Figure 5.

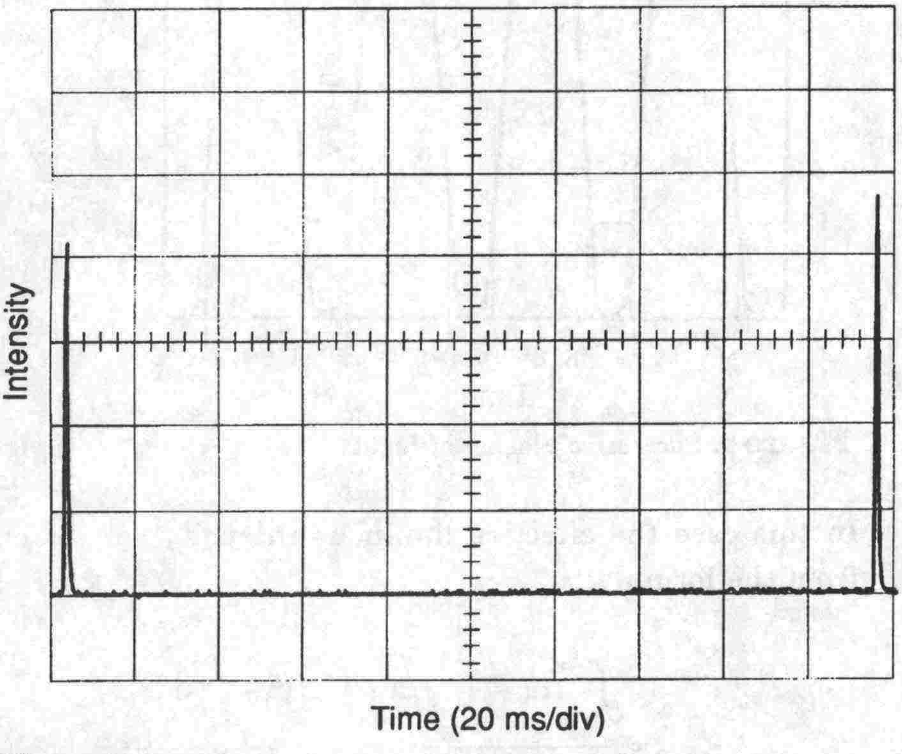

Figure 5. Variation in luminous intensity as a function of time.

If the effective luminous intensity is calculated from the Blondell-Rey formula

$$I_e = \frac{\int_{t_1}^{t_2} I(t)\,dt}{a + (t_2 - t_1)} \qquad (2)$$

then for the first flash an effective luminous intensity of I_e = 76.5 cds is obtained and for the second 84.5 cds. If t_1 and t_2 are chosen to be the start of the first flash and the end of the second pulse respectively, then the value I_{etot} = 157 cds is obtained for the total effective luminous intensity. In this case there is no significant difference whether the effective luminous intensity is calculated from formula (1) or (2).

6. LIGHTING-UP AND EXTINGUISHING

6.1 Regulations Concerning the Functioning of Flashers

According to the quality requirements of the Finnish Roads and Waterways Administration flashers, other than those fitted with gasdischarge tubes and mains-operated flashers, should be equipped with a photocell which automatically lights and extinguishes the device according to the level of ambient illumination, so that the device is always operating when the ambient illumination is below 50 lx and does not operate when the ambient illumination is above 500 lx. In addition, the automatic system should be so arranged that a light of 100,000 cd coming from a distance of 10 m in the horizontal plane does not cause extinction of the device. This requirement corresponds to an illumination level of 1000 lx in the horizontal plane.

According to the Swedish requirements the automatic lighting and extinguishing system of flashers should have an operating range of 50...300 lx. A light of 5000 lx incident horizontally must not cause extinction of the flasher.

According to the Norwegian requirements the devices should be so adjusted that they light up when the level of ambient illumination is below 500±50 lx and extinguish when it exceeds 1000±100 lx. A light of 100,000 cd coming from a distance of 10 m in the horizontal plane must not cause extinction of the flasher.

6.2 The Rates of Change of Ambient Illumination

Because the regulations of the Nordic countries differ in their requirements concerning lighting-up and extinguishing, it was decided to investigate how much these differences affect the actual period of operation of a flasher in normal operating conditions. For this purpose measurement apparatus was constructed by means of which the rate of change in the level of illumination could be registered at both the rising and setting of the sun. In practice the measurement was arranged by installing an illumination meter under a rooflight in the Department of Electrical Engineering of Tampere University of Technology. From this meter a signal for a chart recorder was obtained which was proportional to the change in illumination on the roof. The rooflight in question was located on a flat roof, so that the situation corresponded fairly well to the changes in the level of illumination in a very open place. Calibration of the equipment was carried out by comparing the signal received by the chart recorder with the reading of an illumination meter outside on the roof. The measurements were made 15 June 1988 ... 5 Jan. 1989 at approximately monthly intervals on both clear and cloudy evenings and mornings.

In examining the results it was discovered that when investigating the times when the illumination outside was in the range 50...1000 lx, there were no significant differences between the different seasons and different weather conditions. For example, in the mornings and evenings the ambient illumination was typically within the range specified by the Finnish quality requirements (50...500 lx) for only approx. 35...40 min. The difference between the Finnish and Swedish regulations (500 lx / 300 lx) means in practice that a flasher set to operate at an illumination of 500 lx would operate for approx. 20 min. longer per day than a flasher set to operate at an illumination of 300 lx.

Figure 1 shows a typical variation of illumination at sunset. This measurement was made on 27 July 1988, when the evening was cloudless.

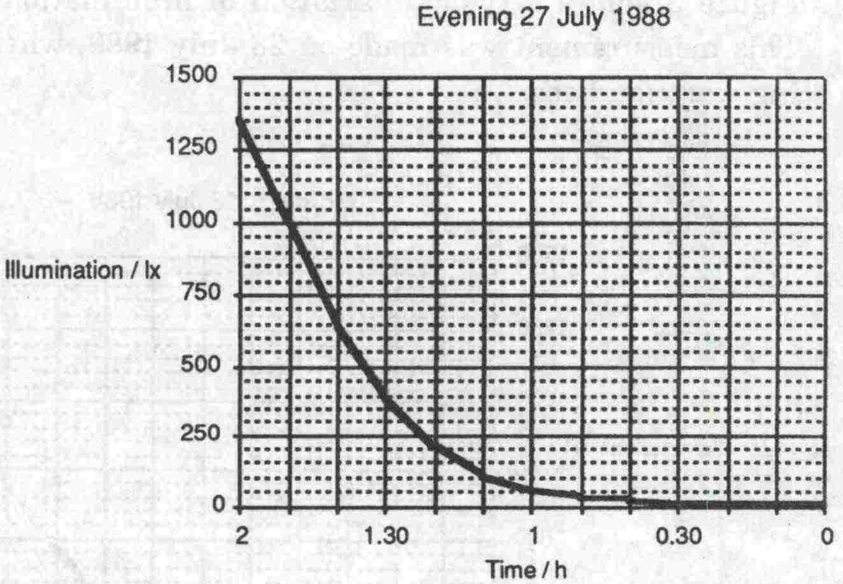

Figure 1. The variation of illumination in the evening.

Figure 2 shows the variation of illumination in the evening at different seasons of the year.

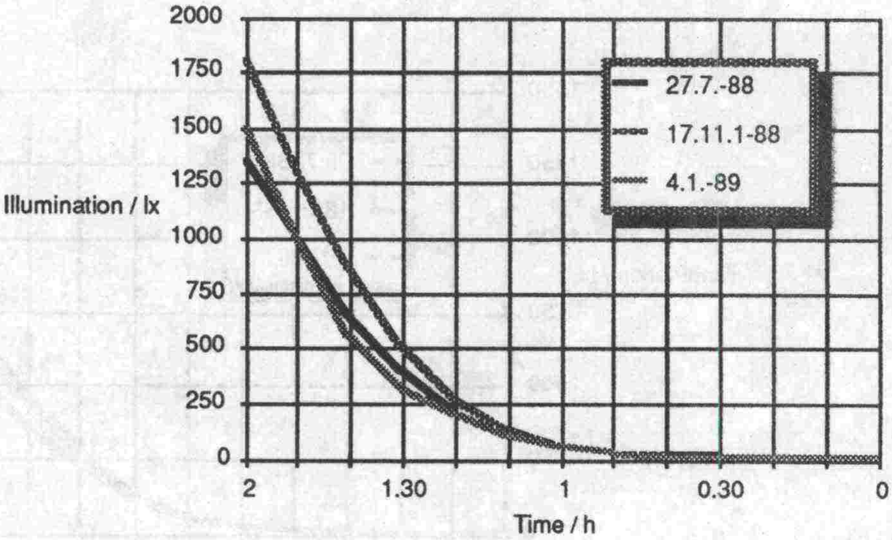

Figure 2. The variation of illumination in the evening at different seasons of the year.

Figure 3 shows a typical variation of illumination at sunrise. This measurement was made on 28 July 1988, when the morning was cloudless.

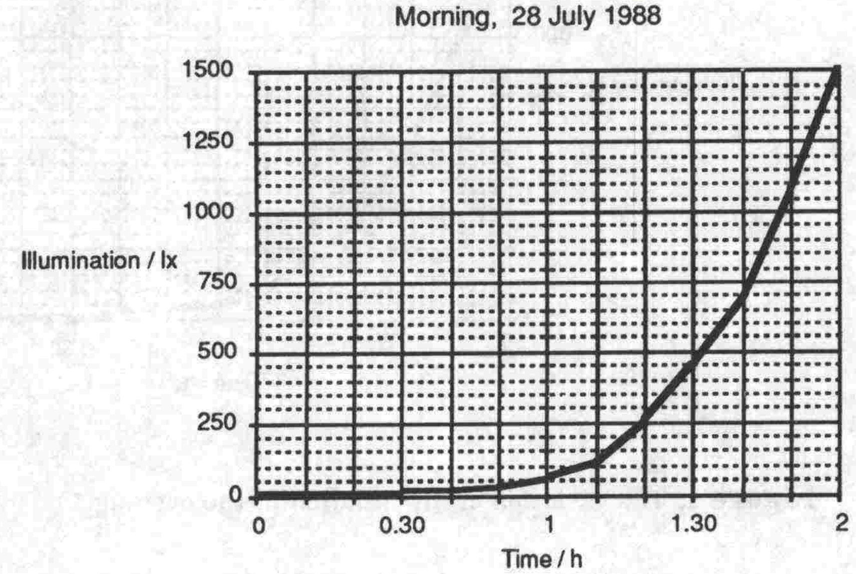

Figure 3. The variation of illumination in the morning.

Figure 4 shows the variation of illumination in the morning at different seasons of the year.

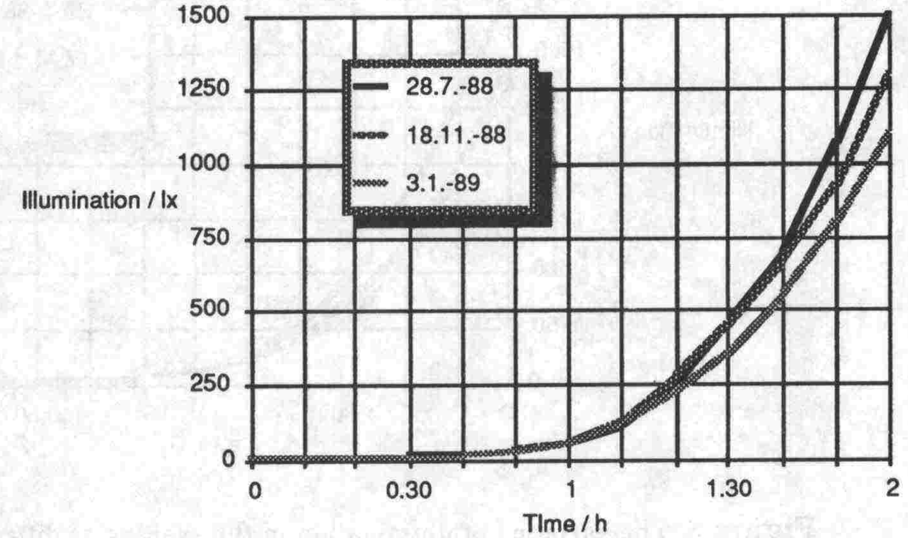

Figure 4. The variation of illumination in the morning at different seasons of the year.

On the basis of these measurements it can be stated that from the point of view of battery consumption there are no significant differences between the Swedish and Finnish regulations.

7. OPERATING DURATION

7.1 Requirements for the Minimum Operating Duration of Flashers

According to the Finnish quality requirements, warning devices should be equipped with such a power source that the technical illumination requirements are satisfied:
- for at least 7 days, if the device is operated for 16 hours a day at a temperature of +5°C
- for battery-operated devices at a temperature of –20°C one operating period (16 h)
- for accumulator-operated devices three load periods (16 h) at a temperature of -20°C.

In addition the mechanism of devices equipped with batteries or accumulators should function for 16 h at a temperature of ±40°C

According to the Swedish quality requirements, warning devices should be equipped with such a power source that the technical illumination requirements are satisfied:
- for battery-operated devices at a temperature of –20°C for the duration of one operating period (12h)
- for accumulator-operated devices for the duration of one operating period (12h) at a temperature of -40°C

According to the Swedish regulations, different requirements in respect of operating time are set for different types of warning device. The regulations do not, however, specify at what temperature the load tests are to be made, presumably at room temperature. The requirements in respect of operating time are as follows:
- for omnidirectional red lanterns, 5 days of 12 hours on and 12 hours off
- for directional red lanterns, 10 days of 12 hours on and 12 hours off
- for omnidirectional amber lanterns, 8 days of 12 hours on and 12 hours off
- for directional amber lanterns, 16 days of 12 hours on and 12 hours off
- for omnidirectional amber flashers, 14 days of 12 hours on and

12 hours off
- for directional amber flashers, 28 days of 12 hours on and 12 hours off.

Norway's own quality requirements in respect of the operating duration of warning devices are rather vague:
- it is specified that the device should operate at a "satisfactory" luminous intensity for 400 hours without replacement of battery over the entire operating temperature range of -20°C...+40°C
- further, it is required that the repetition frequency of flashers should remain in the range 60...120 flashes/min for 14 days at a temperature of +20°C, if the device is in operation for 18 hours per day
- the repetition frequency must also remain within the above limits after 18 hours use at +40°C or –20°C.

7.2 The Behaviour of Batteries

The operating duration of flashers is appreciably affected not only by the efficiency of the mechanism, the luminous intensity and the optical efficiency, but also by the general behaviour of the batteries and their Ah capacities.

Accordingly, during the course of the research it was decided to investigate how various types of batteries behave with a load corresponding to that of a flashing signal.

The following batteries were selected for the measurements:
- AIRAM Hp 16 P - 6 V
- DURACELL ID 9080
- RenPower air-alkali battery

In the measurements the test procedure was as follows: two batteries were connected in parallel and the load was a typical filament flasher lamp 4 V / 0.3 A (Renpulssi 6V). The lamp was connected to the battery voltage for 150 ms at a time, after which there was an interval of 850 ms. This loading was repeated once a second for 16 hours, after which there was an interval of 8 hours. The ambient temperature during the tests was +5°C.

In the tests it was desired to investigate not only the total ampere-hour capacity of one battery in the service in question, but also in what voltage range these ampere-hours were accumulated. Figure 1 shows the variation in the battery voltage of each battery as function of time in the range 6 V...3 V. Figure 2, on the other hand, shows the accumulated ampere-hours as a function of voltage. The ampere-hours shown in these figures are those of a single battery, although in the tests two batteries were connected in parallel.

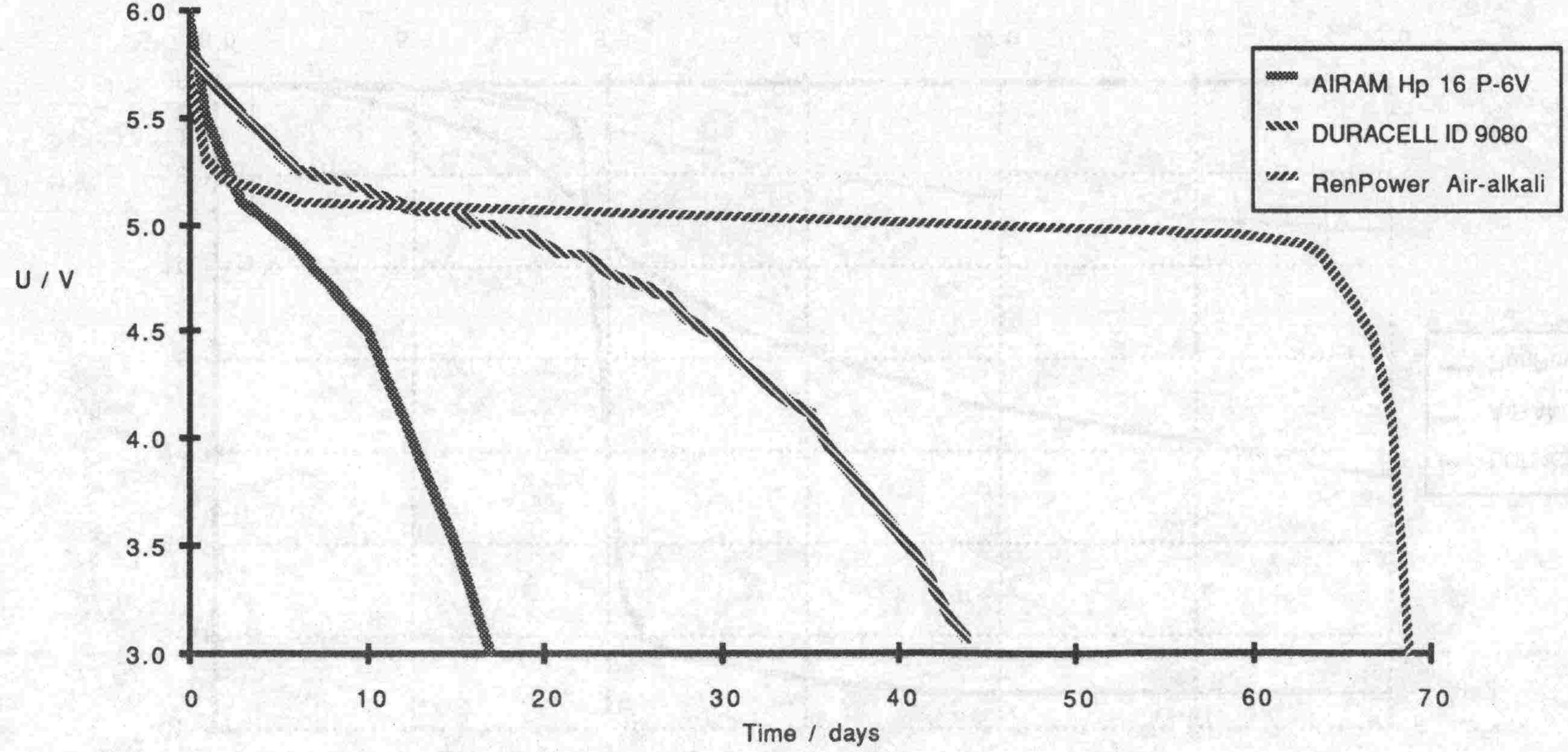

Figure 1. The variation of battery voltage as a function of time

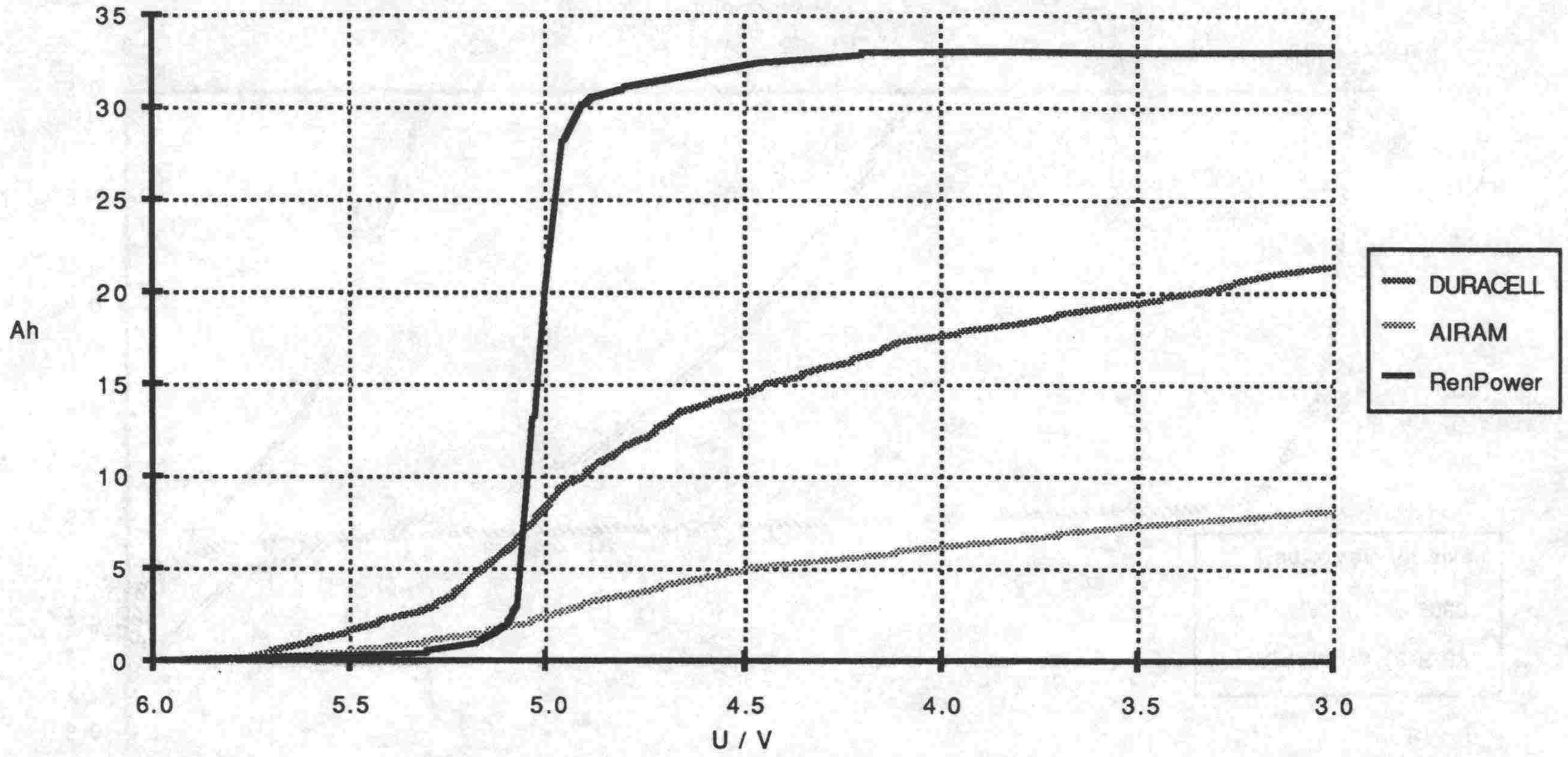

Figure 2. The accumulated ampere-hours as a function of voltage

8. SUMMARY AND CONCLUSIONS

8.1 General

In this section the principal matters contained in the various sections of the report are reviewed, and in addition some subjective views are put forward together with the authors' own opinions concerning the quality requirements for flashing signals, their shortcomings and opportunities for improvement.

Before any attempt can be made to achieve uniformity in the regulations of the Nordic countries, a clear summary must be produced of the measurement procedures in the different countries and the significance of the differences. When the desired form of the quality requirements has been arrived at, a separate bulletin should be issued concerning the various measurement procedures and methods, and this should also be brought to the attention of the manufacturers of flashing signals.

8.2 The Colour of the Light

The regulations of the Roads and Waterways Administration for flashing road signals which are currently operative in Finland have the effect that the transmissivity of the lenses is rather low (as was noted in Section 2). In spite of this the re-definition of the colours of road flashers and lanterns is not necessary, since the colour regions defined are now the same as those recommended by the CIE.

One subject for investigation might be on what basis the use of separate filters is prohibited and the requirement for the use of solid-dyed lenses.

In addition it would be desirable to clarify the manner in which the colour is to be determined. The current regulations only state that the colour is to be determined at the recommended nominal voltage. There would perhaps be grounds for always making the colour determination with a flashing light where the determination relates to a flashing signal rather than a steady-burning lantern.

8.3 Luminous Intensity

If the quality requirements of the Roads and Waterways Administration are revised, it would be desirable at the same time to consider the patterns and widths of the intensity distribution required. For omnidirectional signals the "triangular" pattern of light distribution currently required is apparently not appropriate. Since the intensity distribution of an omnidirectional flasher is more readily made to resemble a sine curve than a triangle, the adoption of the former as the basis of the regulations too might be justified. At the same time a widening of the present distribution pattern could be considered, since in practice positioning of the flashers is not usually very accurate and a flasher may be inclined by 5...10°, greatly reducing its visibility. In the case of directional flashers, it should be considered why the required region is wider in the horizontal plane than in the vertical, although the positioning of the flashers is usually more accurate in just the horizontal plane.

The inclusion also in the Finnish regulations of a specification for warning signals emitting a steady-burning amber light would appear to be justified, since there are numerous applications for warning signals of this type too.

In addition the regulations should include clear instructions regarding warning signals intended for daytime use which are considerably more powerful than the flashers intended for use during hours of darkness.

8.4 Definition of the Effective Luminous Intensity

In the definition of the effective luminous intensity of flashes there do not appear to be any problems. If it is intended to achieve uniformity in the regulations of the Nordic countries, it would be natural to adopt the same method for calculation of the effective luminous intensity in all the Nordic countries.

The only problem is constituted by flashers working on the "double flash" principle. Here further research would be desirable on the method of defining the effective luminous intensity in order to establish a good basis for separate quality requirements for this type of flasher. It would appear that flashers which operate on the double-flash principle should be treated as a completely separate type of flasher.

8.5 Lighting-up and Extinguishing

The requirement in the quality requirements that a flasher shall not be extinguished as a result of a horizontally incident light of given magnitude should be reviewed. In particular, it should be determined what is an adequate requirement in respect of horizontally incident light, and on the other hand what is undesirable behaviour of a flasher when subjected to horizontal light should be clarified.

The rates of change of the ambient illumination are so great in the lux region in which the automatic lighting-up and extinguishing systems of warning devices should operate, that the Finnish and Swedish regulations could quite easily be made uniform.

Since in practice the measurements of the automatic lighting-up and extinguishing systems of the devices are made on clean, new flashers, it might be best to set the upper limit of the operating region at 300 lx, since in practice the lenses are always dirty to some extent, and with use also become scratched and cloudy, so that their transmission is reduced and the extinguishing illumination level tends to rise.

The lower limit of the operating region would perhaps be best increased to 100 lx, since as can be seen from the figures in Section 6 the 50 lx limit is located at a point on the curve where relatively small differences in the operation of the automatic system causes the flasher to light-up at an appreciably different time from that intended. In addition, in the course of measurements the impression has been gained that 100 lx would also otherwise be more suitable as the lower limit.

8.6 Operating Duration

The regulations of the Nordic countries differ in respect of the operating durations required for warning devices. It should be established what operating durations are sensible, since now batteries are available by which very long operating durations could be achieved. Considerations of maintenance and storage etc. may, however, favour shorter operating durations. In addition, it should be remembered that if longer operating durations are prescribed for flashers, then the efficiency of the flashers will fall because it will become necessary to use lamps which have an appreciably lower efficiency than those currently used.

In defining the desired operating duration for flashers, consideration should be given not only the service life of batteries and lamps, but also to the frequency of cleaning and other inspection rounds.

Since it is in any case necessary to visit warning flashers at intervals to clean off the dirt collected on their lenses, it is perhaps not appropriate to aim for the longest possible operating duration, because batteries and lamps can relatively easily be replaced at the same time without additional costs.

Possibly a regulation could be included in the quality requirements obliging the manufacturers of flashers to fit the flashers with an indicator by means of which it could be readily seen from the outside if the flasher was near the end of its operating duration.

This would be particularly important for accumulator-operated flashers, since these are required to have a mechanism to prevent the total discharge of the accumulators and which turns the flasher off suddenly. The indicator could take the form, for example, of some sort of signal light or a clear change in the repetition frequency of flashing (60 times/min...20 times/min).

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