

THE ASSESSMENT OF LIGHT SOURCES

**PART I GLARE FROM SMALL SOURCES:
DETERMINATION OF EFFECTIVE SIZE BY
SUBJECTIVE APPRAISAL OF MANY OBSERVERS**

**PART II THE COMPUTERISATION OF GONIO
PHOTOMETRIC MEASUREMENTS FOR
LUMINAIRE OUTPUT, DISTRIBUTION
AND GLARE CLASSIFICATION**

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[PLXBRE 002]

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PART I

GLARE FROM SMALL SOURCES:

DETERMINATION OF EFFECTIVE SIZE BY

SUBJECTIVE APPRAISAL OF MANY OBSERVERS

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SYNOPSIS

Discomfort glare from normal sources has been thoroughly researched over the last five decades and agreement has been reached by the CIE to express it by the Unified Glare Rating (UGR) formula:

$$\text{UGR} = 8 \log_{10} g$$

where : $g = (0.785 / E_i) \sum (L^2 \omega / p^2)$ (see Glossary)

Hardly any research, however, has been done on discomfort glare from *small* sources, so the definition of a small source was just not known. It was not known whether to define it as an effective solid angle, ω_s or area, A_s . Two hypotheses were put forward concerning the effective size of a small source:

Hypothesis # 1 ('constant omega' hypothesis)

The effective size of a small source has a solid angle, ω_s . Any source with an actual solid angle less than ω_s shall be considered a small source and will have an effective solid angle equivalent to ω_s when viewed off the line of sight (LoS). This solid angle, ω_s is a constant. i.e. it remains the same irrespective of distance from the source.

Hypothesis # 2 ('constant area' hypothesis)

The effective size of a small source has an area, A_s . Any source with a projected area less than A_s shall be considered a small source and will have an effective area equivalent to A_s when viewed off the line of sight (LoS). This area, A_s is a constant. i.e. its solid angle varies inversely proportional to the square of the distance from the source.

To investigate the two hypotheses *and* establish an effective size for the small source, observers were recruited and asked to set for a glare sensation of 'just uncomfortable' for both the normal *and* small source.

The normal source consisted of a 0.2m by 0.2m diffusing sheet ($\tau = 0.5$), lit from behind by a narrow reflector housing a 1000W incandescent lamp, and the small source consisted of just a clear 200W incandescent lamp. Both sources were presented to the observer through an opening in the front screen

which was transformable in shape to accommodate each source. Three different distances from the source/s were used for viewing, namely 1.37m, 2.29m and 3.94m, and all tests were done at E_i levels not exceeding 120 lux. Observers were asked to look at a point so as to have the line of sight (LoS) 16° vertically below the source.

For each source, distance of viewing, and E_i fixing (done by the experimenter), the observers set an E_d value to give a glare sensation of 'just uncomfortable'. From this, an E_d^2 / E_i value was calculated for each source and plotted against distance from the source. *The way in which the E_d^2 / E_i values varied with distance for the small source gave an indication to which hypothesis should be accepted.* Here is a brief proof:

Removing the summation term from the UGR formula (since only one source contributing to the glare) and acknowledging the position index, p as a constant in this particular experiment, the following can be derived:

$$\begin{aligned}
 g &= c L^2 \omega / E_i && \text{where } c = 0.785 / p^2 = \text{a constant} \\
 &= c (E_d^2 / \omega^2) \omega / E_i && \text{since } L = E_d / \omega \\
 &= c (E_d^2 / E_i) / \omega \\
 &= c (E_d^2 / E_i) R^2 / A && \text{since } \omega = A / R^2
 \end{aligned}$$

For 'constant omega' and unchanged glare i.e. $g = \text{constant}$, the quotient, E_d^2 / E_i would be constant irrespective of distance of viewing.

For 'constant area' (which is true for the normal source) and unchanged glare, i.e. $g = \text{constant}$, the quotient, E_d^2 / E_i would be inversely proportional to the square of the distance of viewing.

On analysing the results the values of E_d^2 / E_i were seen to vary inversely proportional to the square of the distance from the source for both the normal and small source **indicating a 'constant area' for the small source.**

The assessment of the effective size of the small source is made by comparing averaged E_d^2 / E_i settings for the normal and small source at each of the distances tested at. Since the observers set for a glare sensation

consistent for both the normal and small source independent of distance of viewing, the following can be said:

glare for the normal source, g_n = glare from small source, g_s

Ignoring constants and summation terms,

$$g_n = (E_d^2 / E_i)_n R^2 / A_n \quad (i) \quad \text{and} \quad g_s = (E_d^2 / E_i)_s R^2 / A_s \quad (ii)$$

Equating (i) and (ii) above, for the same distance, R the area, A_s can be expressed as:

$$A_s = [(E_d^2 / E_i)_s / (E_d^2 / E_i)_n] A_n$$

Since the value of A_n is known ($A_n = 0.04 \text{ m}^2$), a value for A_s or ω_s at each distance from the source can be determined.

The average effective area for the small source, A_s was calculated to be about 51 cm^2 which corresponds to a disc approximately 8cm in diameter. The area, A_s was found to be independent of both the sensitivity of the observer and the adaptation level, E_i . The 95% confidence interval associated with this area was [$43 \leftrightarrow 61 \text{ cm}^2$] which relates to a UGR variation of 1.2 units i.e. ± 0.6 units (For comparison, a variation of three units is a normally accepted step in glare from one level to another and so ± 1 units is an acceptable error)

Of the 76 observers tested, who were mostly between the ages of 18 and 30, a total of 37 were accepted for complying within limits to expected results for the *normal* source. All results and conclusions are based on the settings made by these observers. A glare sensation of 'just uncomfortable' on average related to a UGR value of about 23.5.

A certain degree of adaptation by the source was noticed on analyzing the results.

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GLOSSARY

Nomenclature

A_s ... the effective area of a small source from a glare perspective

CGI ... C.I.E Glare index

E_d ... direct vertical illuminance at the eye (lux) = ωL

E_i ... indirect vertical illuminance at the eye (lux) = πL_b

L ... the luminance of the luminous parts of each luminaire in the direction of the observer's eye (cd.m^{-2}).

L_b ... the background/field luminance (cd.m^{-2})

LoS ... Line of sight

lux, lx ... unit of illuminance (lumens / m^2)

n ... number of observers

N or n ... normal source

N/A ... not applicable

p ... the Guth position index (see Appendix 3)

$$1/p = [d^2 / (0.97d^2 + 2.3d + 4) - 0.1] \times \exp (-0.17s^2 / d + 0.013s^3 / d) + 0.09 \\ + (0.075 - 0.035 / d) / (1 + 3(s - 0.5)^2)$$

{ d ... forward distance of source/height, s ... sideways distance of source/height (forward means in the direction of the line of sight; sideways means perpendicular to it; and height means height above eye level) }

S or s ... small source

source ... glare source / lamp

UGR ... Unified Glare rating

ω ... the solid angle of the luminous parts of each luminaire at the observer's eye (st.r)

ω_s ... the effective solid angle of a small source from a glare perspective

Σ ... summation term for more than one source

Symbols for experimental data

1 or 1_1 ... 1.37m from the source

2 or 2_2 ... 2.29m from the source

4 or 4_4 ... 3.94m from the source

— — — ... 1.37m from the normal source

—— ——— ... 2.29m from the normal source

————— ... 3.94m from the normal source

..... ... 1.37m from the small source

—— • —— ... 2.29m from the small source

—— •• —— ... 3.94m from the small source

★ ... E_d 'up' (normal source)

✧ ... E_d 'down' (normal source)

♣ ... E_d 'up' (small source)

♠ ... E_d 'down' (small source)

♠ ... E_i 'up' (normal source)

♠ ... E_i 'down' (normal source)

♠ ... E_i 'up' (small source)

♠ ... E_i 'down' (small source)

1. INTRODUCTION

Research investigating glare from small sources has never been thoroughly undertaken. Many artificial lighting installations include small sources such as clear incandescent lamps, miniature spotlights and even candles as part of their make up. No methods, formula or tables, however, are available to monitor or express) the amount of *discomfort* glare experienced by a person of average glare sensitivity, when subjected to such sources. Under-estimations of the glare from small sources have led to glaring installations; on the other hand, over-estimations have led to unnecessary design modifications to limit the supposed glare.

An internationally accepted UGR formula,

$$\text{UGR} = 8 \log_{10} [(0.785 / E_i) \sum (L^2 \omega / p^2)] \quad (\text{see Glossary})$$

expressing discomfort glare in terms of an index is available for glare calculations on *normal* sources.

Unfortunately the UGR formula does not give realistic glare index predictions for *small* sources. Applying the formula yields indices which would suggest far more glare than is actually experienced. For example, it could predict very intolerable glare from an incandescent lamp installation which might be widely accepted.

For example, consider a 200W incandescent lamp with an intensity of 230 cd. The luminance of such a source is of the order of 5×10^6 cd. m⁻². The area of the filament would equate to 4.6×10^{-5} m², since $A=I/L$. (This could be pictured as a filament about 0.5mm by 9mm in projected dimensions) At a distance of say 4m, with an indirect illuminance of say, 150 lux, such a source, when viewed at say, 16° above the LoS, would be generally accepted as 'comfortable' from a glare perspective. However, plugging the associated values (i.e. $L = 5 \times 10^6$, $p^2 = 3.42$, $\omega = 2.875 \times 10^{-6}$, $E_i = 150$) into the UGR formula, yields a UGR of above 40. A UGR of anything above 30 is usually considered intolerable, so the formula clearly needs modifications for small sources.

The reason for the discrepancy lies with the human eye's inability to resolve the fine detail of a small filament when viewed off the line of sight (LoS). The small source therefore appears to an observer as a "blob" larger than its physical size and less bright (as Luminance = Intensity / Area), and hence less glaring than expected.

The apparent or effective size of the "blob" cannot be directly measured and differs from person to person. Research was therefore undertaken to determine the effective size of a small source through subjective appraisal of a number of observers. This effective size, if approved, can form a basis of design calculations, and will then be at the disposal of the lighting engineer. **It is not known whether the 'effective' size of a small source should be expressed in terms of an *area*, A_s , a *solid angle*, ω_s , or something different.**

Two hypotheses are presented concerning the effective size of a small source:

Hypothesis # 1 ('constant omega' hypothesis)

The effective size of a small source has a solid angle, ω_s . Any source with an actual solid angle less than ω_s shall be considered a small source and will have an effective solid angle equivalent to ω_s when viewed off the line of sight (LoS). This solid angle, ω_s is a constant. i.e. it remains the same irrespective of distance from the source.

Hypothesis # 2 ('constant area' hypothesis)

The effective size of a small source has an area, A_s . Any source with a projected area less than A_s shall be considered a small source and will have an effective area equivalent to A_s when viewed off the line of sight (LoS). This area, A_s is a constant. i.e. its solid angle varies inversely proportional to the square of the distance from the source.

The **objectives of the research** are as follows:

1. To determine which, if any, of the above two hypotheses is pertinent.
2. To determine the effective size of a small source at any distance from the source.

Other parameters of interest are:

3. The effect, if any, of the sensitivity of the observer on the effective size of the small source.

4. The effect, if any, of the adaptation level, E_i on the effective size of the small source.
5. The effect, if any, of the adaptation by the source itself on discomfort glare for both the normal and small source.

The research was confined to square, and substantially round, sources. i.e. tests on linear sources such as bare tungsten halogen and tubular fluorescent lamps were not carried out. All tests were restricted to off-the-LoS viewing at an angle of 16° vertically below the source, at distances less than 4m from the source and at E_i levels of 120 lux and less. Whenever the term 'glare' is mentioned in the text it refers to 'discomfort glare'.

The write-up begins by describing two tried-out experimental layouts and why the one was chosen over the other, and gives details of the procedure of glare testing of observers. It then goes on to explain how the objectives proposed to be fulfilled, which in turn helps the reader make as much sense as possible of the results. The results are then given and discussed, followed up by conclusions and recommendations.

2. PROCEDURE

2.1 Constructing the semi-enclosure

The initial stages of the study involved setting up an experimental work environment suitable for glare testing of observers. A semi-enclosure was created by the use of vertical screens, floor boards, walls, and roof. It was then painted a matt grey with an estimated reflectance, $\rho = 0.5$ (see Figure 5).

2.2 Circuitry

An incoming steady voltage supply was necessary for the purpose of the glare source testing. This was provided by a 230V single phase constant voltage regulator which fed two 8A variacs. Variac 1 was used for adjusting the intensity of the background lamp and variac 2 was used for adjusting the intensity of the glare source. The variacs were capable of delivering 260 V and thus providing the ability to overrun the lamps for higher background and glare source luminance (see Figure 1).

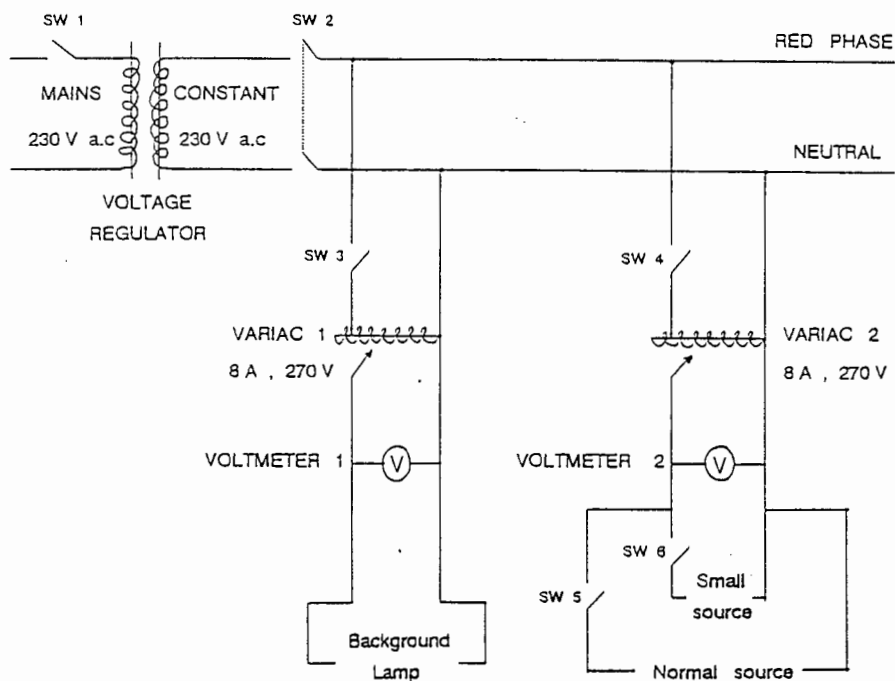


Figure 1. Circuit diagram of the improved experimental layout

2.3 The relative positioning of observer, lamps and semi-enclosure

Two different experimental layouts were used for the purpose of testing. The first (initial) set-up proved unsuccessful: many readings were inconsistent with accepted glare theory, and reproduceabilities in individuals readings were poor. A new (improved) set-up was then constructed in place of the initial one which proved to be most suitable for the purpose of glare testing. Both set-ups are discussed below but the findings and conclusions are almost exclusive to the improved set-up.

2.3.1 The initial experimental set-up

Initially the glare sources were hung from the roof 1.75m above the ground, 2.00m from the front screen and midway between the side screens. The small source consisted of a 200W clear incandescent lamp and the normal source was made possible by encompassing the small source with a 200mm cube diffuser. The background light consisted of a 500W incandescent lamp inside a wide diffusing reflector. It was positioned on the roof midway between the side screens and 3.25m from the front screen. A trolley, carrying the two variacs was available to the seated observer. (see Figure 2 for the initial experimental layout)

2.3.1.a Calibration of voltage versus illuminance for the initial set-up

Calibration of variac voltage and illuminance at the eye (both direct, E_d and indirect, E_i) were made at each of three distances from the source; namely 1.45m, 2.38m and 4.04m. i.e. for each background voltage fixing, V_b (spaced in steps of 10V) an E_i reading was obtained at each of the three distances. For each source voltage fixing, V_s (spaced in steps of 10V) an illuminance reading, E_{sum} was obtained representing the sum of direct illuminance, E_d and reflected illuminance, E_r . The direct illuminance was therefore established as:

$$E_d = E_{sum} - E_r$$

where E_r was determined by shielding the source from the lux meter and reading the illuminance at each voltage and distance.

The calibration was done with a Hagner Lux meter held at eye level and angled at 16° beneath the source, towards one of three targets in accordance to the distance of viewing (see Appendix 3 for calculations of target heights).

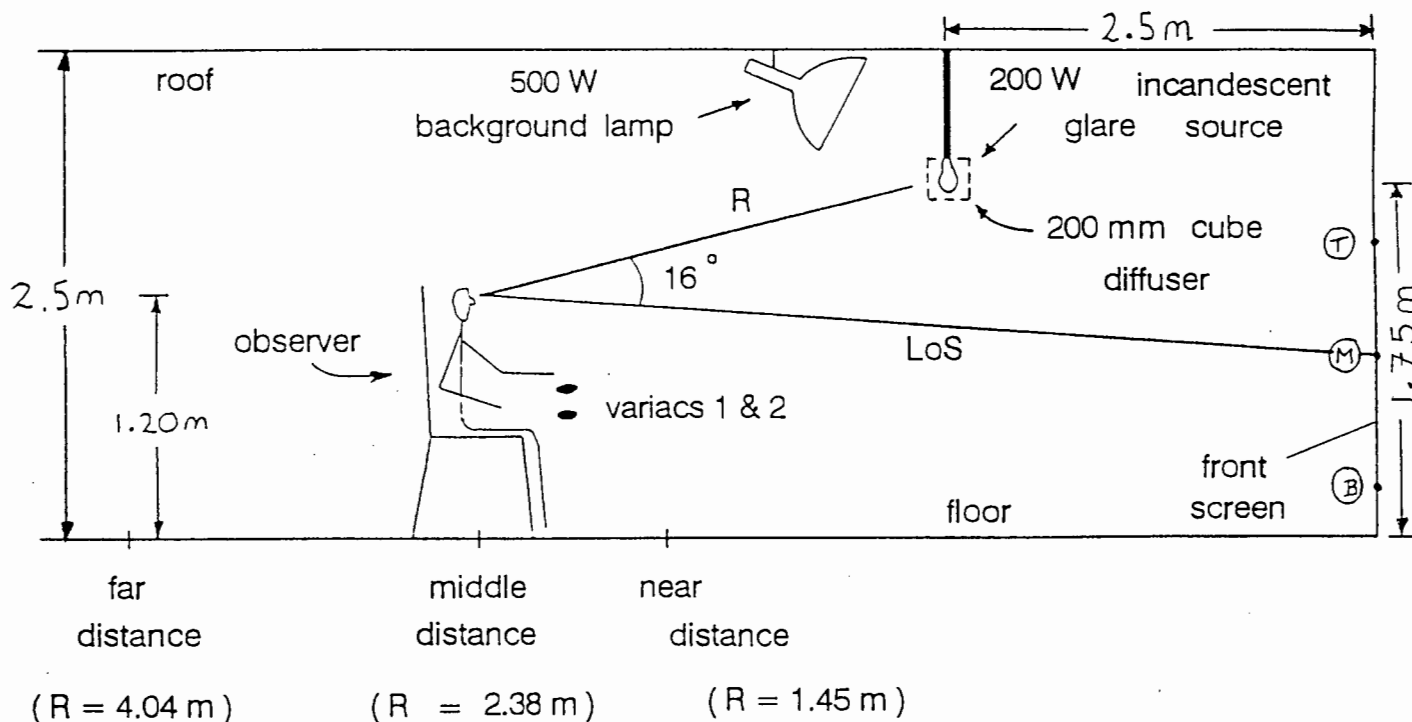


Figure 2. Side view of the original experimental layout with the glare sources held in between observer and front screen. The small source consisted of a 200W clear incandescent lamp and was interchangeable with a 500W incandescent lamp and reflector comprising the normal source. Two 8A, 270V variacs are shown: one to control the background light and the other to control the source being tested.

2.3.1.b Problems encountered with the initial set-up

- 1) A very non-uniform distribution of light was thrown onto the background screens from the background/field lamp with most of the light falling on the front screen. At the nearby distance the non-uniformity was not that severe, but at the far distance the visual solid angle of the brighter front screen was relatively small compared to the complete visual field involving the much less bright side screens and walls. As a result, for an unchanged background/field lamp voltage, the E_i at the far distance was significantly lower than the E_i at the near distance (see Figure 4 for comparison with the improved set-up discussed in section 2.3.2).
- 2) With the glare sources held in front of the screen, a significant proportion of the E_i was attributed to inter-reflections from the source off the background screens.
 - a) At the far distance from the source the highest source luminance was not sufficient to cause any discomfort to the insensitive glare observers. This was due to the relatively high E_i levels resulting from the source inter-reflections.
 - b) Because the adaptation level changed significantly with source luminance, changes to source luminance by observers had to be done very slowly for them to adapt adequately to changing surround luminance.

2.3.2 The improved experimental set-up

The problems associated with the initial set up were alleviated by moving the background/field lamp back to 3.5m from the front screen, and moving the glare sources *behind* the front screen.

A 200W incandescent lamp was still used as the small source and presented to the observer through a hole in the front screen, 70mm diameter and 1.75m above the ground (see Figure 3a for the improved experimental layout for the small source).

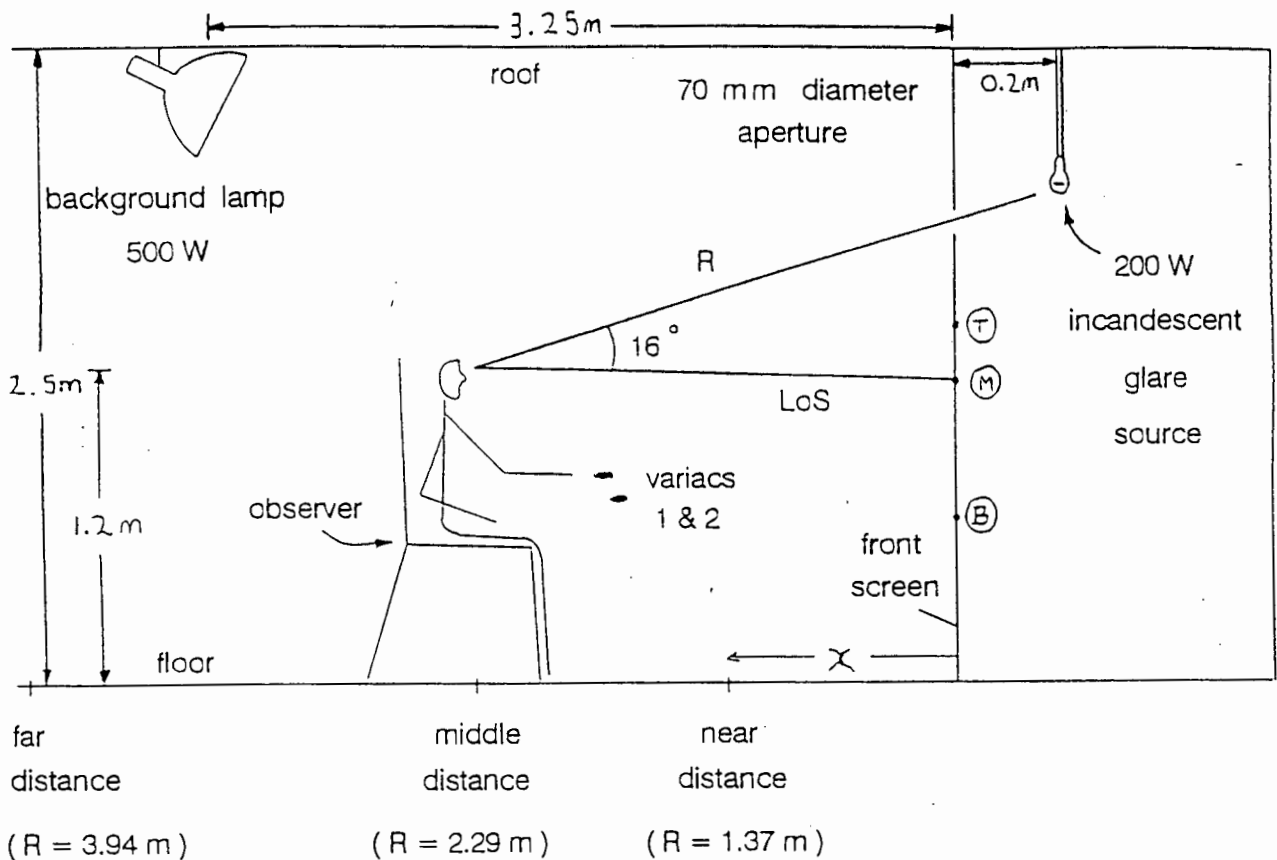


Figure 3a. Side view of the improved experimental layout showing the presentation of the small source behind the front screen. The source is made fully visible through a 70 mm diameter aperture in the front screen by an adjustable height mechanism. Two 8A, 270V variacs were used, one to control the background light and the other to control the source being tested.

The normal source consisted of a 200mm by 200mm diffusing sheet ($\tau = 0.5$), lit from the behind by a narrow reflector housing a 1000W incandescent lamp. The source was presented to the observer through a 200mm by 200mm opening in the front screen positioned similarly to that for the small source and interchangeable with the small source opening. (see Figure 3b for the improved experimental layout for the normal source).

Under this improved set-up negligible inter-reflected light contributed to the surround luminance.

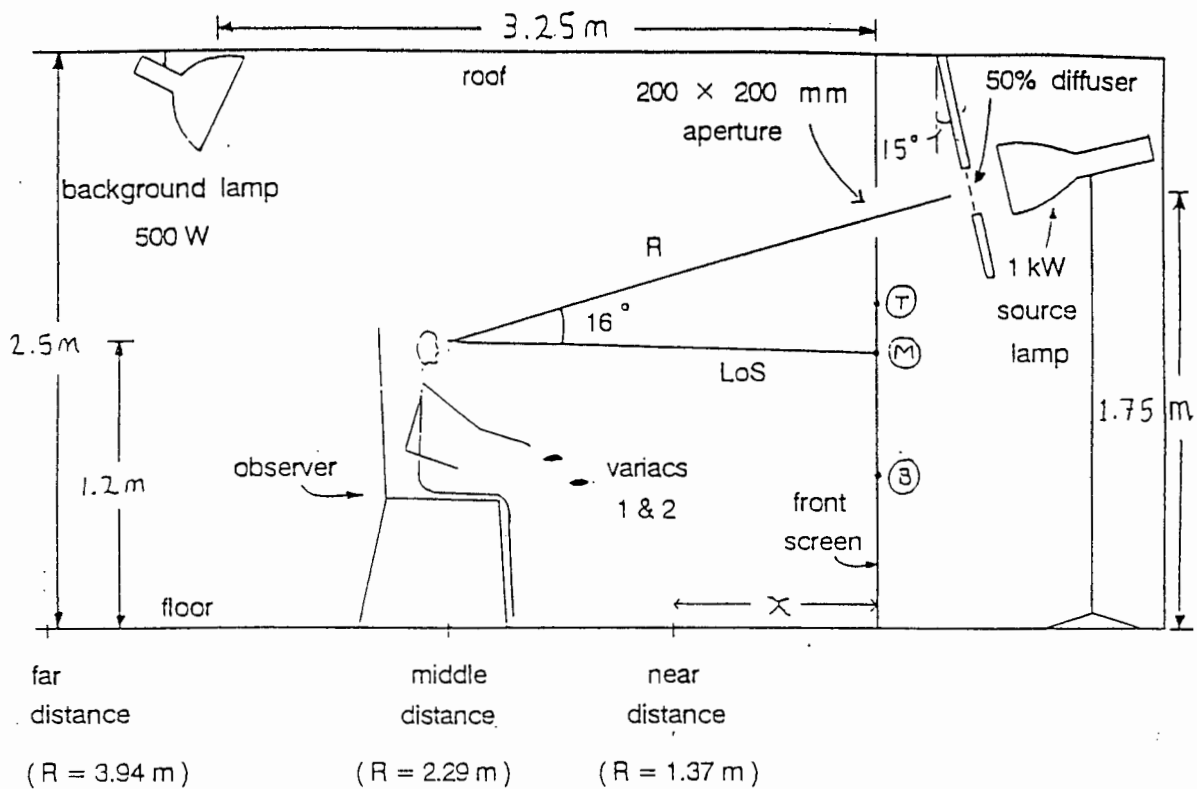


Figure 3b. Side view of the improved experimental layout showing the presentation of the normal source behind the front screen. The source is made fully visible through a 200mm by 200mm aperture in the front screen by an adjustable height mechanism. Two 8A, 270V variacs are shown: one to control the background lamp and the other to control the source being tested.

2.3.2.a Calibration of voltage versus illuminance for the improved set up

The calibration was done with the same Hagner lux meter angled vertically down at 16° from the source from distances of 1.37m, 2.29m and 3.94m from the source towards one of three new targets according to distance of viewing (see Appendix 3 for calculation of new target heights). Variac voltages were spaced in steps of 10V like before (refer to section 2.3.1.a). A set of improved set-up calibration curves are available in Appendix 3.

Note that *not* all the readings in Appendix 4 refer to this set. When a light bulb broke or blew a new set of calibrations had to be made.

2.3.2.b Higher uniformity of background luminance for the improved set-up

The more maintained indirect illuminance with distance for the improved set-up over the initial set-up is illustrated in Figure 4 for an arbitrarily chosen voltage, $V_b = 250V$. For the ideal situation of a perfectly uniformly lit hemisphere the graph would consist of a horizontal line. Iso-illuminance curves for the background screens in the improved set up are depicted in Figure 5 for an arbitrary voltage, $V_b = 250V$.

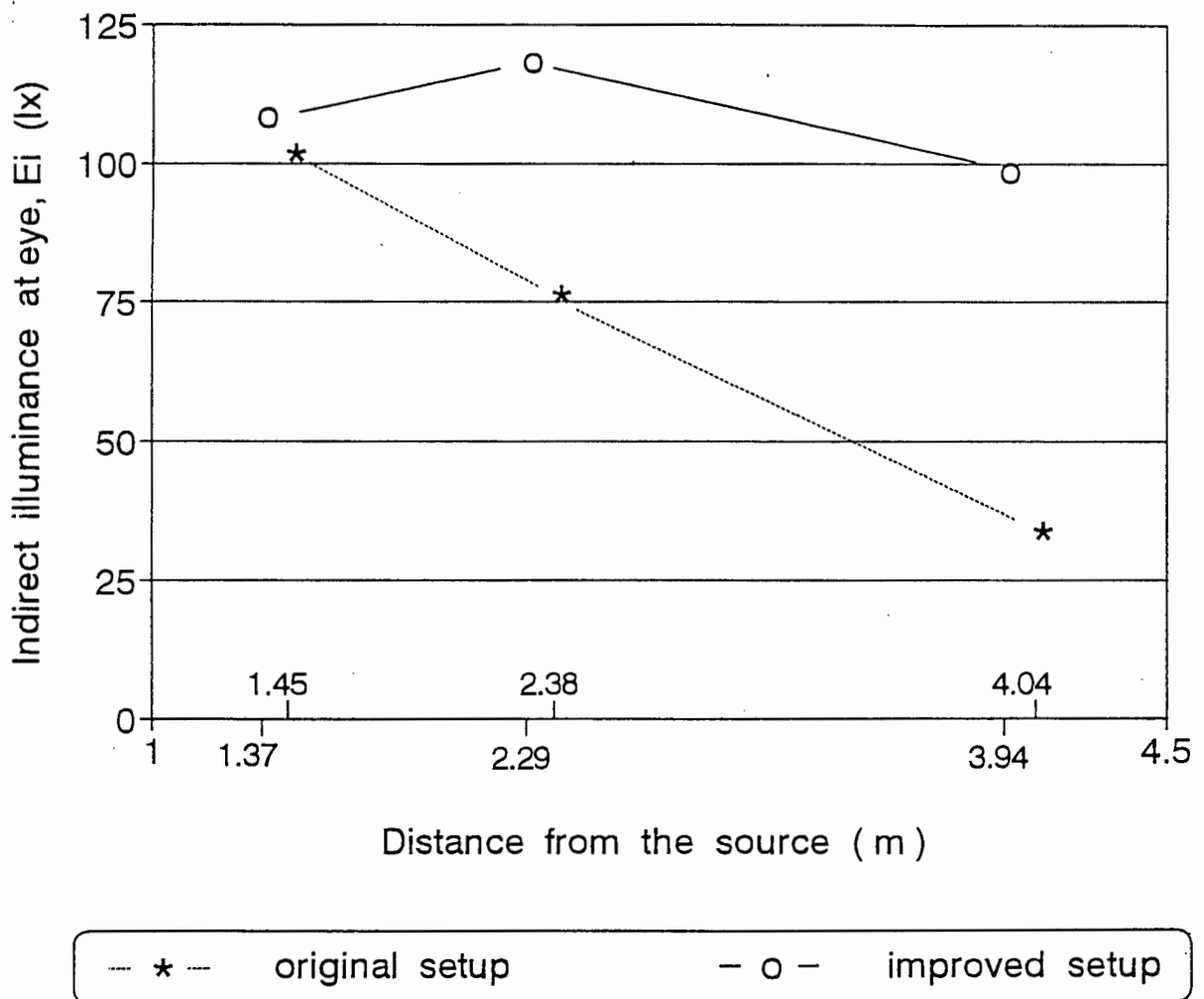


Figure 4. Comparison of the E_i variation with distance for the initial and improved layouts for an arbitrary voltage, $V_b = 230V$. It illustrates the more maintained indirect illuminance in the improved layout.

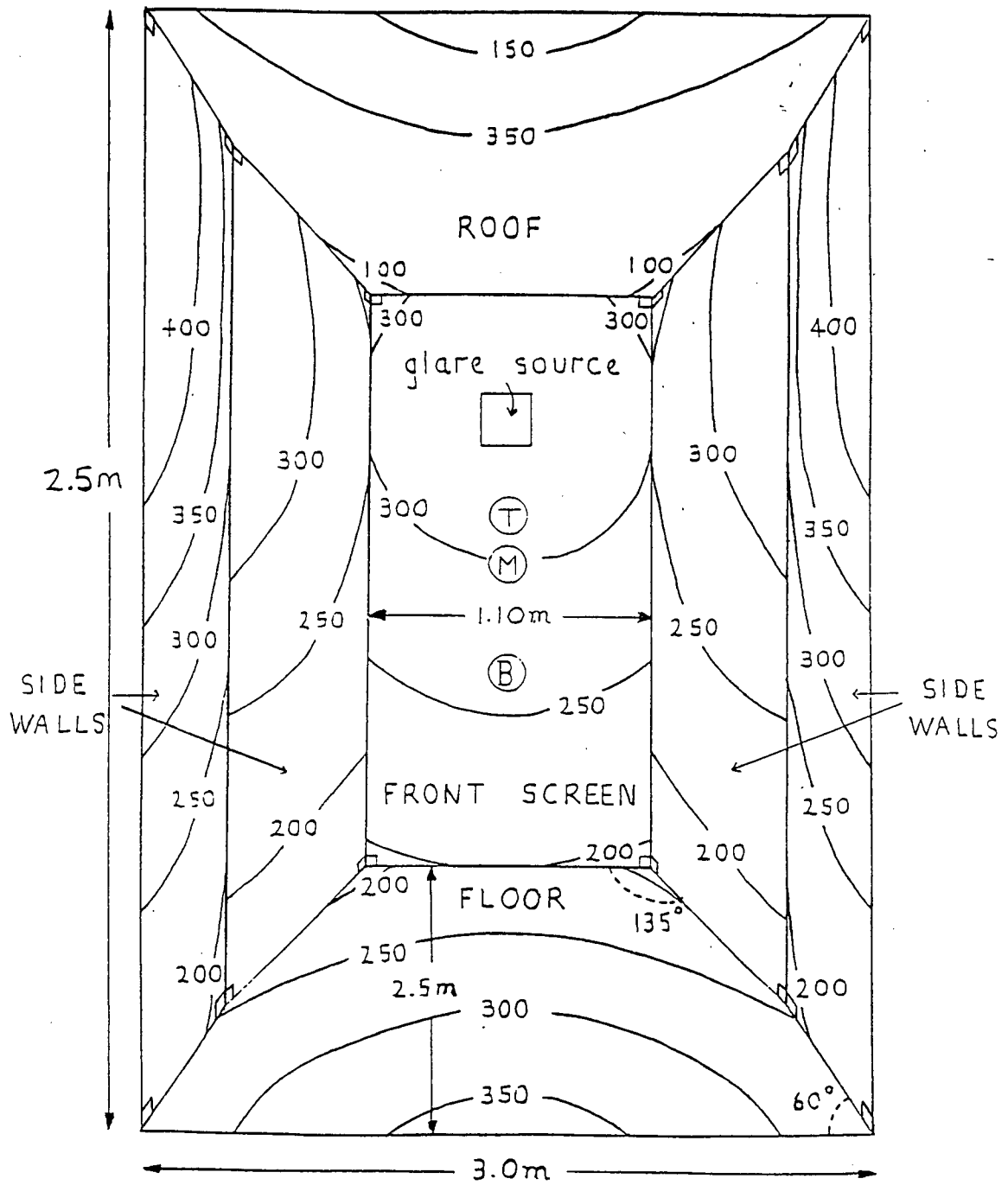


Figure 5. Front view of the background semi-enclosure for the improved layout with iso-illuminance curves in units of lux. The background light was provided by a 500W incandescent lamp and reflector at 230V, 3.25m from the front screen. The position of the glare source and three targets T, M and B (one for each distance of viewing) is shown. For conversion to luminance (cd./m^2), $L = \pi E / \rho$; where $\rho = 0.5$.

2.4 Details of the observers

A variety of observers, in terms of sex, age and race were recruited for their glare assessment and offered a small payment for their co-operation. Some observers had to be rejected for not conforming to widely accepted expectations (see Appendix 2 for details of the acceptance/rejection process). Observers were predominantly white with twice as many males as females. Of the 76 observers tested, 37 were accepted who did a total of 43 tests. Of the 37 observers, 32 were between the ages of 18 and 30, and the rest were members of staff being above the age of 30. (see Table 1)

Number of Tested Observers	76
Number of Accepted Observers	37
Aged < 30	32
Aged > 30	5
Total number of tests	43
Average Sensitivity (GI) \pm Std. Dev	23.4 \pm 5.2

Table 1. Observers' details

2.5 Types of glare testing : Buffer versus Direct

2.5.1 Buffer testing

For the buffer test two E_i settings ('up' and 'down') are made at each of the experimenter's E_d fixings. The settings should correspond to a specified degree of discomfort glare. The 'up' setting is made by increasing the surround luminance very slowly until the specified glare sensation is reached. The 'down' setting is made by decreasing the surround luminance extremely slowly until the specified glare sensation is reached. The importance of the very slow E_i adjustments is to allow the observer's eyes to adapt to the changing surround luminance. Because 'dark adaptation' is a far longer process than 'light adaptation' the *downward* buffer setting must be done even slower.

2.5.2 Direct testing

For the direct test two E_d settings ('up' and 'down') are made at each of the experimenter's E_i fixings. The settings should correspond to a specified degree of discomfort glare. The 'up' setting is made by increasing the source luminance slowly until the specified glare sensation is reached. The 'down' setting is made by decreasing the source luminance slowly until the specified glare sensation is reached.

2.6 Details of the glare tests carried out by the observers

2.6.1 Testing in the initial set-up

Both buffer and direct tests were carried out with observers setting for a specified sensation of BCD (borderline between comfort and discomfort), (Luckiesh and Guth, 1949). Tests were carried out on the *normal* source first, with BCD settings made at two or three of the distances from the source, and later evaluated. If after evaluation his / her settings more or less complied with accepted glare theory then he / she was called upon again at a later date to repeat the process on the small source. By carrying out this process one could get a fair indication about which hypothesis was acceptable. Since tests on the normal and small source were carried out on different days where one's sensitivity to glare may have varied, comparisons between the two could not be made to determine the effective size of the small source.

Experience showed that most observers concentration and / or tolerance to glare did not extend beyond half an hour, and so it was vital to get as much information as possible in those thirty minutes to fulfil the objectives of the research. Testing in the 'improved' set-up was configured to take care of this.

2.6.2 Testing in the improved set-up

The first improvement in the way of testing was to have an observer make settings on the *normal and small source* in the same thirty minute session. This way, the effective size of the small source as seen by each observer could be calculated by comparing readings for the normal and small source. For

comparisons to be made possible, testing had to be done at distances from the source common to both the normal and small source.

No time, with respect to the thirty minute constraint, was available for buffer tests to be carried out and were abandoned here-after.

Many observers from the initial set-up commented on the difficulty in setting the BCD sensation. It was decided that a more distinctive or noticeable sensation was more appropriate. A sensation of 'just uncomfortable' (see Literature Review, Appendix 1). In the direct 'up' test the observer simply turned up the source voltage slowly until the 'just uncomfortable' sensation was reached. In the direct 'down' test the observers were instructed to turn the source voltage down slowly until the glare was *just* not noticeable, and then asked to notch it up again until a 'just uncomfortable' sensation was experienced. All observers' settings were recorded, and those *accepted* ones are available in Appendix 4.

The fact that the testing was centred around a glare index slightly higher than that for BCD should not effect the evaluation of the effective size of the small source in any way because testing at this level was done on both the normal *and* small source.

3. EXPLANATION OF HOW THE OBJECTIVES PROPOSE TO BE FULFILLED

This section describes how certain values and ratios are determined, and gives proofs of what to expect for the two different hypotheses concerning small sources, namely ‘constant area’ and ‘constant omega’. It prepares the reader for the next section, which is the results, by describing exactly how the results were obtained and what they portray.

3.1 Calculation of the quotient E_d^2 / E_i

The two hypotheses outlined in section 1 need to be explored to assess which one, if any, is true for small sources, or whether something in between is more pertinent. Only those observers ascertained as being competent (see Appendix 2 for details of the acceptance / rejection process of observers) are used in the calculations which the results are centred around.

From each observer an average E_d setting was recorded for each E_i fixing at at least two of the three different distances from the source. For each $[E_d, E_i]$ pair, the quotient, E_d^2 / E_i was calculated and plotted against distance. A geometric average of E_d^2 / E_i was then calculated for each distance that the observer was tested at. [see Appendix 4 for all observers, or Figure 6 (excluding transparency), for just one observer’s plots, observer ‘X’]. The significance of the quotient E_d^2 / E_i is made clear in section 3.2 below.

3.2 The significance of the quotient E_d^2 / E_i in deciding amongst the hypotheses

Refer to the UGR formula for glare, $UGR = 10 \log_{10} g$

where $g = (0.785 / E_i) \sum (L^2 \omega / p^2)$

Since the angle between LoS and source is a constant 16° with no sideways displacement ever, the position index is a constant (see Appendix 3 for calculation of p^2). Now removing the summation term (since only one source contributing to the glare) the following can be stated :

$$\begin{aligned}
g &= c L^2 \omega / E_i && \text{where } c = 0.785 / p^2 \\
&= c (E_d^2 / \omega^2) \omega / E_i && \text{since } L = E_d / \omega \\
&= c (E_d^2 / E_i) / \omega && (1)
\end{aligned}$$

$$= c (E_d^2 / E_i) R^2 / A \quad \text{since } \omega = A / R^2 \quad (2)$$

3.2.1 Constant Area Hypothesis

For the ‘constant area’ hypothesis *which is true for normal sources* the area of the source, A is unchanged with distance of viewing. Referring to the derived formula of section 3.2, part (2), an unchanged sensation of glare with distance of viewing (i.e. g is constant) means that the quotient, E_d^2 / E_i is inversely proportional to the square of the distance from the source, R^2 since area, A is constant.

For the same E_d , E_i is inversely proportional to the distance squared, R^2 .

$$\begin{aligned}
\text{e.g.} \quad E_{i(4)} &= (3.94 / 1.37)^2 E_{i(1)} \\
&= 8.29 E_{i(1)}
\end{aligned}$$

$$\therefore E_{i(4:1)} = 8.29$$

$$\text{Similarly, } E_{i(2:1)} = (2.29 / 1.37)^2 = 2.79$$

$$\text{and, } E_{i(4:2)} = (3.94 / 2.29)^2 = 2.96$$

For the same E_i , E_d^2 is proportional to the distance squared, R^2 , which means that E_d is proportional to distance, R .

$$\begin{aligned}
\text{e.g.} \quad E_{d(1)} &= (3.94 / 1.37) E_{d(4)} \\
&= 2.88 E_{d(4)}
\end{aligned}$$

$$\therefore E_{d(1:4)} = 2.88$$

$$\text{Similarly, } E_{d(1:2)} = (2.29 / 1.37) = 1.67$$

$$\text{and, } E_{d(2:4)} = (3.94 / 2.29) = 1.72$$

where the subscripts, 1, 2 and 4 represent the distances, 1.37m, 2.29m and 3.94m respectively (see Figure 7 for a graphical illustration).

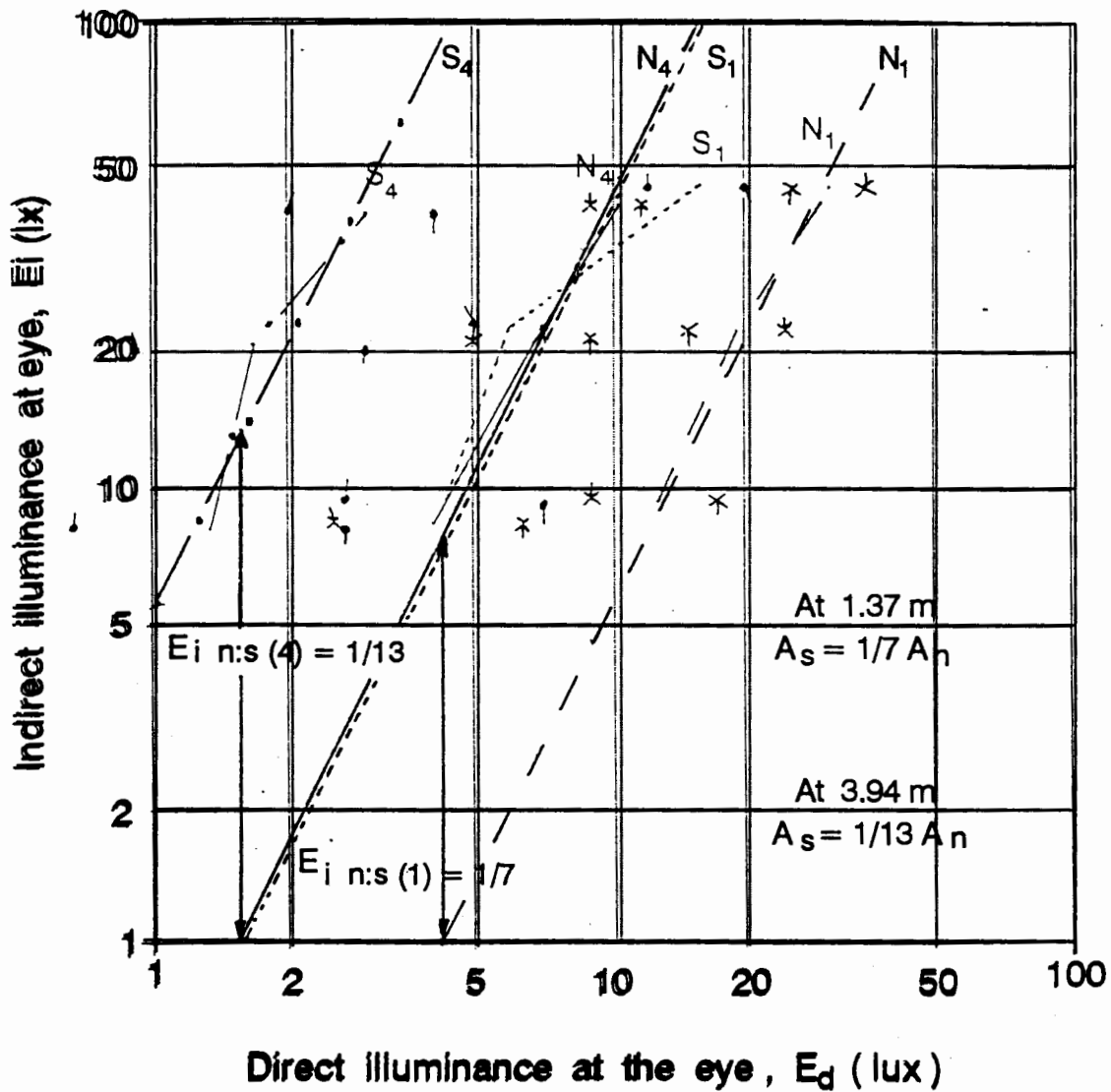


Figure 6. Observer 'X's plots of E_d versus E_i for the normal and small source at 1.37m and 3.94m from the source including a transparency of the least square fit graph lines of slope 2 with his assessment of A_s at 1.37m and 3.94m from the source.

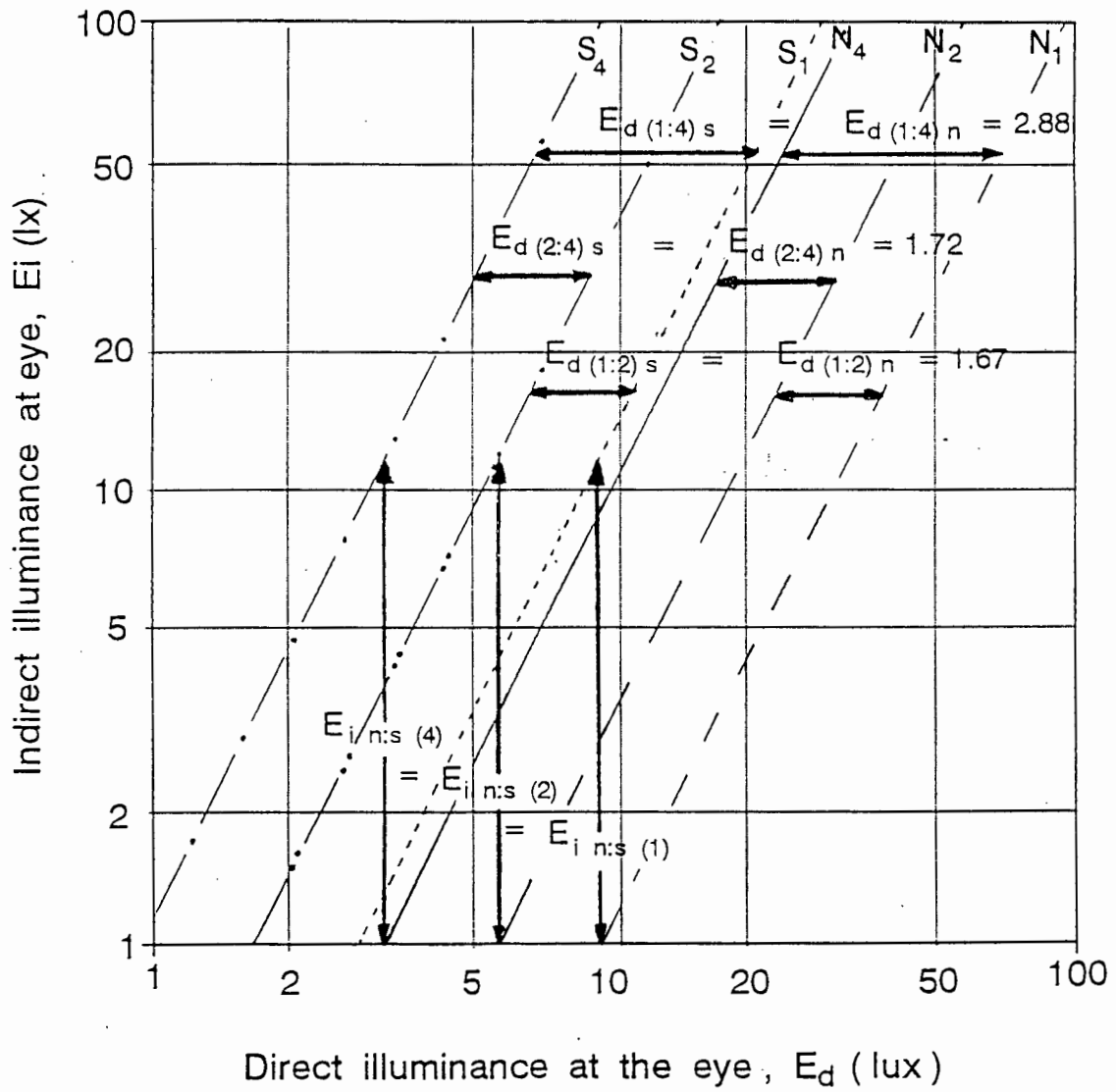


Figure 7. Graph of E_d versus E_i depicting 'constant area', and the size of the small source expressed as an area.

3.2.2 Constant omega hypothesis

For the 'constant omega' hypothesis the solid angle, ω is unchanged with distance of viewing. Referring to the derived formula of section 3.2, part (1), an unchanged sensation of glare with distance of viewing (i.e. g is constant) means that the value of the quotient E_d^2 / E_i is unchanged since ω is constant. i.e. the solid angle, ω remains constant with distance, R .

For the same E_d , E_i is unchanged with distance, R

$$\therefore E_{i(1)} = E_{i(2)} = E_{i(4)}$$

For the same E_i , E_d is unchanged with distance, R

$$\therefore E_{d(1)} = E_{d(2)} = E_{d(4)}$$

where the subscripts, 1, 2 and 4 represent the distances, 1.37m, 2.29m and 3.94m respectively.
(see Figure 8 for a graphical illustration).

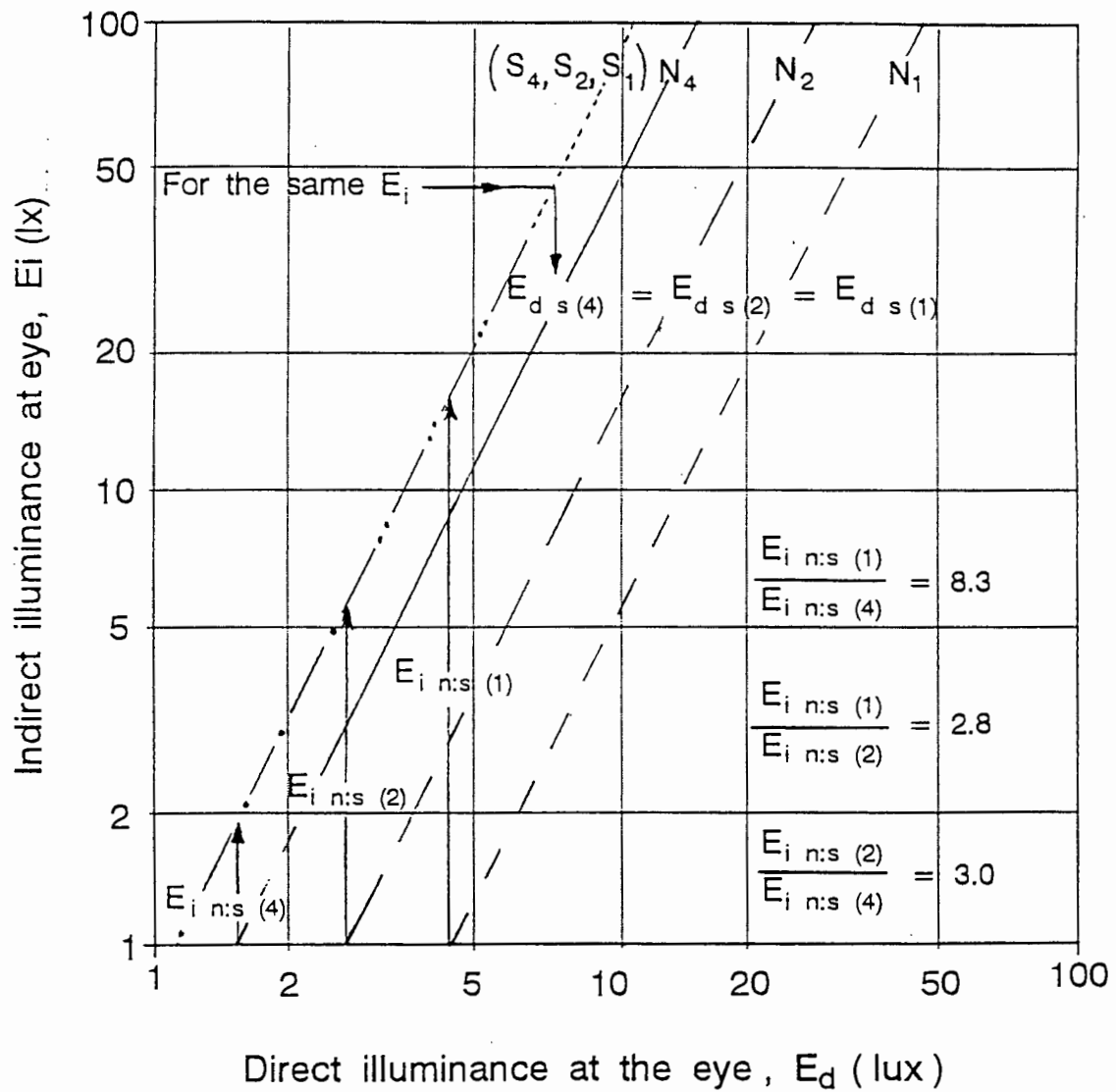


Figure 8. Graph of E_d versus E_i depicting 'constant omega', and the size of the small source expressed as a solid angle.

3.3 The assessment of the effective size of a small source from a glare perspective by comparisons with the normal source

The assessment of the limiting size of the small source is made by comparing averaged E_d^2/E_i settings for the normal and small source at each of the distances tested at. Since the observers set for a glare sensation consistent for both the normal and small source independent of distance of viewing, the following can be said:

glare for the normal source, g_n = glare from small source, g_s

$$\text{where } g_n = (E_d^2/E_i)_n R^2/A_n \quad (3) \quad \text{and} \quad g_s = (E_d^2/E_i)_s R^2/A_s \quad (5)$$

$$= (E_d^2/E_i)_n / \omega_n \quad (4) \quad = (E_d^2/E_i)_s / \omega_s \quad (6)$$

where subscript, 'n' represents the normal source and 's' the small source.

3.3.1 The effective size of a small source expressed as an area, A_s

Equating equations (3) and (5) in section 3.3

$$(E_d^2/E_i)_n R^2/A_n = (E_d^2/E_i)_s R^2/A_s \quad (7)$$

For each distance, R_x the area, A_s can be expressed as:

$$A_{s(x)} = [(E_d^2/E_i)_s / (E_d^2/E_i)_n]_{(x)} A_n \quad (8)$$

$$\text{i.e. } A_{s(1)} = [(E_d^2/E_i)_s / (E_d^2/E_i)_n]_{(1)} A_n$$

$$A_{s(2)} = [(E_d^2/E_i)_s / (E_d^2/E_i)_n]_{(2)} A_n$$

$$A_{s(4)} = [(E_d^2/E_i)_s / (E_d^2/E_i)_n]_{(4)} A_n$$

Now with the same E_i for normal and small source at the same distance, R_x the area, A_s can be expressed as:

$$A_s = [E_d^2 / E_d^2] A_n \quad (9)$$

And with the same E_d for normal and small source at the same distance, R_x the area, A_s can be expressed as:

$$A_s = [E_i / E_i] A_n \quad (10)$$

Since the value of A_n is known ($A_n = 0.04 \text{ m}^2$), a value for A_s at each distance from the source can be determined.

Referring to equation (10) above, **if A_s is constant over all distances like A_n is (i.e. if the ‘constant area’ hypothesis holds) then at each distance the ratio $E_i : E_i$ must be the same.**

$$\begin{aligned} \text{i.e.} \quad & E_{i \ n(1)} : E_{i \ s(1)} \\ & = E_{i \ n(2)} : E_{i \ s(2)} \\ & = E_{i \ n(4)} : E_{i \ s(4)} \end{aligned}$$

where the subscripts, 1, 2 and 4 represent the distances, 1.37m, 2.29m and 3.94m respectively. (see Figure 7 for a graphical illustration).

3.3.2 The effective size of a small source as expressed as a solid angle, ω_s

Equating equations (4) and (6) in section 3.3

$$(E_d^2 / E_i)_n / \omega_n = (E_d^2 / E_i)_s / \omega_s \quad (11)$$

For each distance, R_x the solid angle, ω_s can be expressed as:

$$\omega_{s(x)} = [(E_d^2 / E_i)_s / (E_d^2 / E_i)_n]_{(x)} \omega_n \quad (12)$$

i.e. $\omega_{s(1)} = [(E_d^2 / E_i)_s / (E_d^2 / E_i)_n]_{(1)} \omega_n$

$\omega_{s(2)} = [(E_d^2 / E_i)_s / (E_d^2 / E_i)_n]_{(2)} \omega_n$

$\omega_{s(4)} = [(E_d^2 / E_i)_s / (E_d^2 / E_i)_n]_{(4)} \omega_n$

Now with the same E_d for normal and small source at the same distance, R_x the solid angle, ω_s can be expressed as:

$$\omega_s = [E_d^2_s / E_d^2_n] \omega_n \quad (13)$$

And with the same E_d for normal and small source at the same distance, R_x the solid angle, ω_s can be expressed as:

$$\omega_s = [E_{i_n} / E_{i_s}] \omega_n \quad (14)$$

Since the value of A_n is known ($A_n = 0.04 \text{ m}^2$), a value for ω_s at each distance from the source can be determined since $\omega_n = A_n / R^2$

Referring to equation (14) above and making the substitution $\omega_n = A_n / R^2$, **if ω_s is constant over all three distances (i.e. if the constant omega hypothesis holds) then the ratio of $E_{i_n} : E_{i_s}$ would increase with the distance squared, R^2 since $\omega_s = [E_{i_n} / E_{i_s}] A_n / R^2$.**

e.g. $(E_{i_n} : E_{i_s})_1 = (3.94 / 1.37)^2 (E_{i_n} : E_{i_s})_4$

i.e. $(E_{i_n} : E_{i_s})_1 / (E_{i_n} : E_{i_s})_4 = 8.27$

Similarly, $(E_{i_n} : E_{i_s})_1 = (2.29 / 1.37)^2 (E_{i_n} : E_{i_s})_2$

i.e. $(E_{i_n} : E_{i_s})_1 / (E_{i_n} : E_{i_s})_2 = 2.79$

and $(E_{i_n} : E_{i_s})_2 = (3.94 / 2.29)^2 (E_{i_n} : E_{i_s})_4$

i.e. $(E_{i_n} : E_{i_s})_2 / (E_{i_n} : E_{i_s})_4 = 2.96$

where the subscripts, 1, 2 and 4 represent the distances, 1.37m, 2.29m and 3.94m respectively.

(See Figure 8 for a graphical illustration)

3.3.3 Averaging of the assessed size of the small source

3.3.3.a Averaging of the assessed small source size at each distance

After determining the average size of the small source at each distance for every observer, it is possible to calculate the geometric mean of the small source size at each distance and the standard deviation associated with it. It is also important to determine the 95% confidence interval associated with these calculated means to establish the range in size over which the true means almost certainly lie. i.e. with 95% probability. The pertaining formulae and associated t-distribution tables can be found in Appendix 3. (see section 4.3 for results)

3.3.3.b Averaging of the assessed small source size between distances

If the average sizes of the small source at each distance are approximately the same (either constant area or constant omega), it is reasonable to assume that the size (A_s or ω_s) is constant over that distance interval. In this case the geometric average of all the small source size assessments, irrespective of distance, is taken with standard deviation. It is also important to determine the 95% confidence interval associated with this calculated overall mean to establish the range in size over which the overall true mean almost certainly lies. i.e. with 95% probability. The pertaining formulae and associated t-distribution tables can be found in Appendix 3. (see section 4.3 for results)

3.3.4 Worked example : calculation of A_s at 1.37m and 3.94m for observer 'X'

3.3.4.a Plotting settings of E_d versus E_i on log-log paper for observer 'X'

Observer 'X's' E_d versus E_i readings, including both 'up' and 'down' settings, are plotted on log-log paper for distances of 1.37m and 3.94m for both the normal and small source, and shown in Figure 6 (excluding transparency). An average value for each E_d 'up' and E_d 'down' pair is calculated and plotted for each E_i level that the readings were taken at. These averaged points are then joined up at each distance with different lines to resemble the different distances. The denotions for these line types is given in the Glossary under 'Symbols for experimental data'.

3.3.4.b Calculation of average E_d^2 / E_i values at each distance for each source for observer 'X'

For each $[E_d, E_i]$ pair the quotient, E_d^2 / E_i is calculated for both the normal and small source at each distance. For each distance and source a geometric average of the E_d^2 / E_i value is computed which corresponds to the least square fit line of slope, $m=2$ through all the experimental points [see Figure 6 (transparency)]. i.e. any point (i.e. a hypothetical $[E_d, E_i]$ pair) on this 'normalised' $m=2$ graph line, would give an E_d^2 / E_i value equivalent to the average E_d^2 / E_i of the experimental settings (see least square fit Pascal program in Appendix 3 which works out exactly where the normalised line crosses the E_d vs E_i axes).

3.3.4.c Calculation of A_s at each distance for observer 'X'

The effective size of the small source at each distance is calculated here as an area, A_s .

Referring to Figure 6 (transparency) the assessed area, A_s at 1.37m and 3.94m are as follows:

$$A_{s(1)} = 1/7 A_n = 1/7 (0.04) \text{ m}^2 = 0.0057 \text{ m}^2$$
$$A_{s(4)} = 1/13 A_n = 1/13 (0.04) \text{ m}^2 = 0.0031 \text{ m}^2$$

The factors 1/7 and 1/13, relating to the ratios of the area of the small source to the normal source at distances of 1.37m and 3.94m respectively, were calculated as follows

[refer to equation (8) of section 3.2.1]:

$$(E_d^2 / E_i)_{n1} / (E_d^2 / E_i)_{s1} = 1/7$$

$$(E_d^2 / E_i)_{n4} / (E_d^2 / E_i)_{s4} = 1/13$$

and could also be read off the normalised graph of Figure 6.

$A_{s(1)}$ relates to a disk 8.5 cm in diameter and $A_{s(4)}$ relates to a disk 6.3 cm in diameter.

Proof: $A_{s(1)} = \pi r^2 = 0.0057 \text{ m}^2$

$$\therefore r = (0.0057 / \pi)^{1/2}$$

$$d = 2r = 0.085 \text{ m} = 8.5 \text{ cm}$$

$$A_{s(4)} = \pi r^2 = 0.0031 \text{ m}^2$$

$$\therefore r = (0.0031 / \pi)^{1/2}$$

$$d = 2r = 0.063 \text{ m} = 6.3 \text{ cm}$$

3.4 Calculation of observer sensitivities

Every observer's sensitivity to glare could be determined and expressed as a glare index as calculated from the UGR formula. By plugging each observer's averaged normal source E_d^2 / E_i per distance value into the broken down UGR formula of equation (2) in section 3.2:

$$\text{UGR} = 0.785 / p^2 (E_d^2 / E_i) R^2 / A \quad \text{where } p^2 = 3.42 \text{ (see Appendix 3)}$$

a glare rating at each distance for each observer was determined. The geometric average of all sensitivities at each distance and between distances was possible. When averaging between distances was made, each observer's average sensitivity was first determined, and then the 'average observer' was determined from the geometric average of all observers. (see section 4.4 for the results)

3.5 Calculation of the effective size of the source at varying E_i levels

The full experimental E_i range that the tests were conducted at was divided into six smaller E_i ranges (see Figure 18 and Table 5). From each observer, any $[E_d, E_i]$ pairs for the normal and small source found in the same E_i range were selected, and an A_s value was computed with that data using equation 8 in section 3.3.1. All the computed A_s values were grouped into their pertaining E_i range, and geometric averages for each range were determined. i.e. averaged A_s values were plotted at a geometrically averaged E_i level in each range. (see section 4.5 for results)

3.6 Investigation into Adaptation by the Source

3.6.1 Calculation of E_d versus E_i slopes at varying E_i ranges and distances for comparison

All plots of (on log-log paper) were studied and those ones with three or more $[E_d, E_i]$ pairs were selected for analyzing. The necessity of at least three $[E_d, E_i]$ pairs of settings at a given distance is to have at least two E_d vs E_i calculated slopes per distance in order to investigate the effect of adaptation level on slope. The significance of this relationship becomes apparent when the question of adaptation by the source is presented.

The slopes of E_d versus E_i denoted by 'm', are calculated as follows:

$$m = \log (E_i \text{ max} / E_i \text{ min}) / \log (E_d \text{ max} / E_d \text{ min})$$

3.6.2 Characteristics of the CGI formula

In Dr. Einhorn's paper, "Discomfort Glare: a formula to bridge differences" (Lighting Research and Technology, 1979), the following CIE Glare Index formula was proposed:

$$\text{CGI} = 8 \log 2 [((1 + E_d / 500) / (E_i + E_d)) \sum (L^2 \omega / p^2)]$$

where: CGI = CIE glare index

L = Luminance of a glare source in cd / m^2

p = Guth position index, developed by Luckiesh and Guth, 1949 (see Appendix 3)

E_d = direct vertical illuminance at the eye due to all sources in lux

E_i = indirect vertical illuminance at the eye due to inter-reflected light in lux = πL_b

$E_d + E_i$ = vertical illuminance at the eye in lux.

Comparing the CGI with the UGR formula, $\text{UGR} = \log [(0.785 / E_i) \sum (L^2 \omega / p^2)]$, it can be seen that the term, $[1 / (E_i + E_d)]$ allows for adaptation by the source. 'The E_d component of the denominator

avoids the anomaly of glare becoming infinite in the absence of indirect light where E_i approaches zero' (Einhorn, Lighting Research and Technology, 1979).

Hypothetical graphs of E_d versus E_i for the normal source at three distances and three glare indices, are illustrated in Figure 9, using the UGR formula, and in Figure 10, using the CGI formula. In comparing the two graphs the first obvious difference was the straight line UGR graphs of slope $m=2$ and the 'curved-to-the-right' CGI lines.

To investigate the existence of adaptation by the source, averaged E_d versus E_i slopes obtained *experimentally* (explained in section 3.6.a, and expressed in table 5) were compared with Figures 9 and 10. (see section 4.6 for a discussion of the comparison).

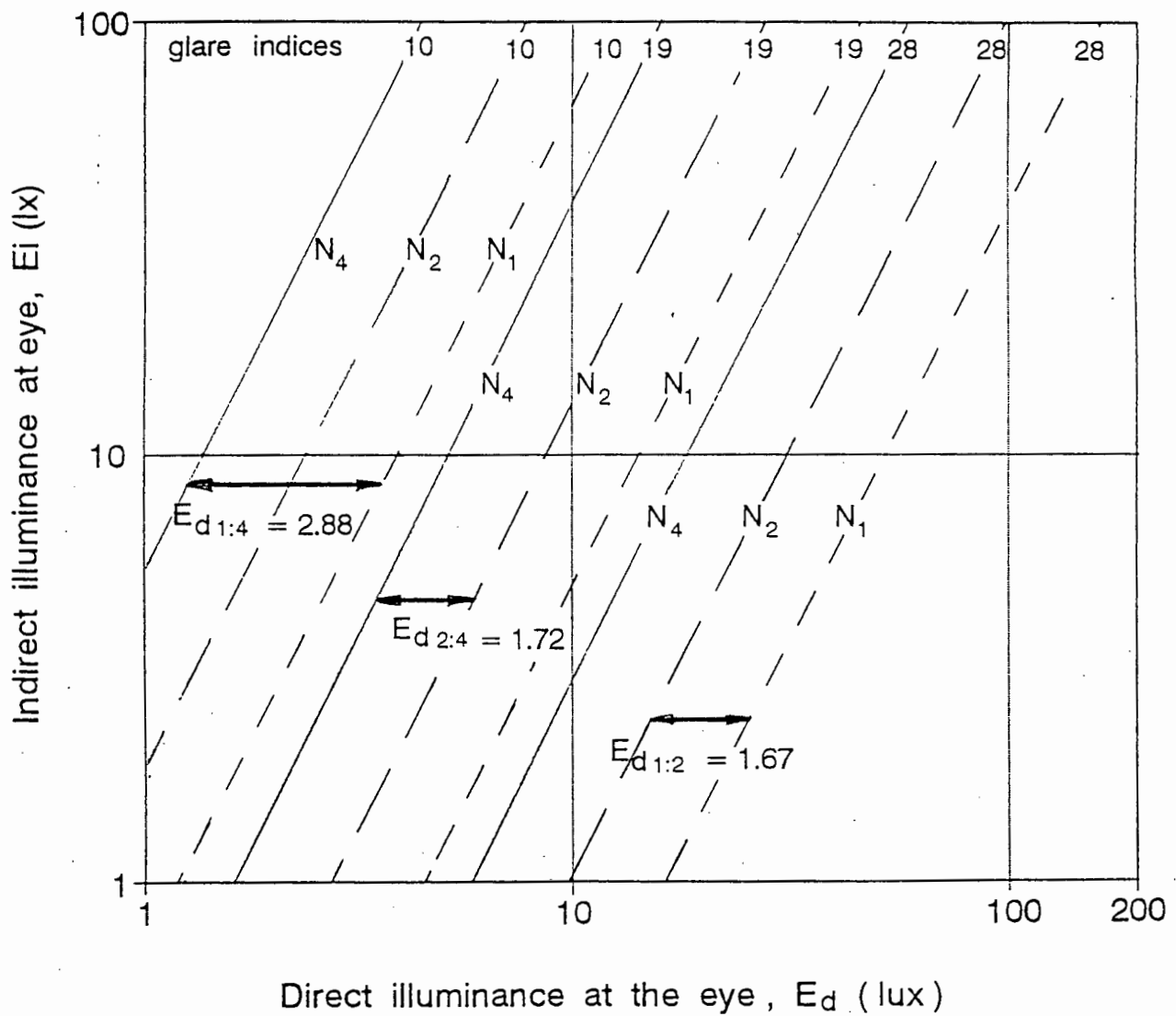


Figure 9. Graph of E_d versus E_i according to the UGR formula for the normal source at distances of 1.37m, 2.29m and 3.94m from the source for glare indices of 10, 19 and 28.

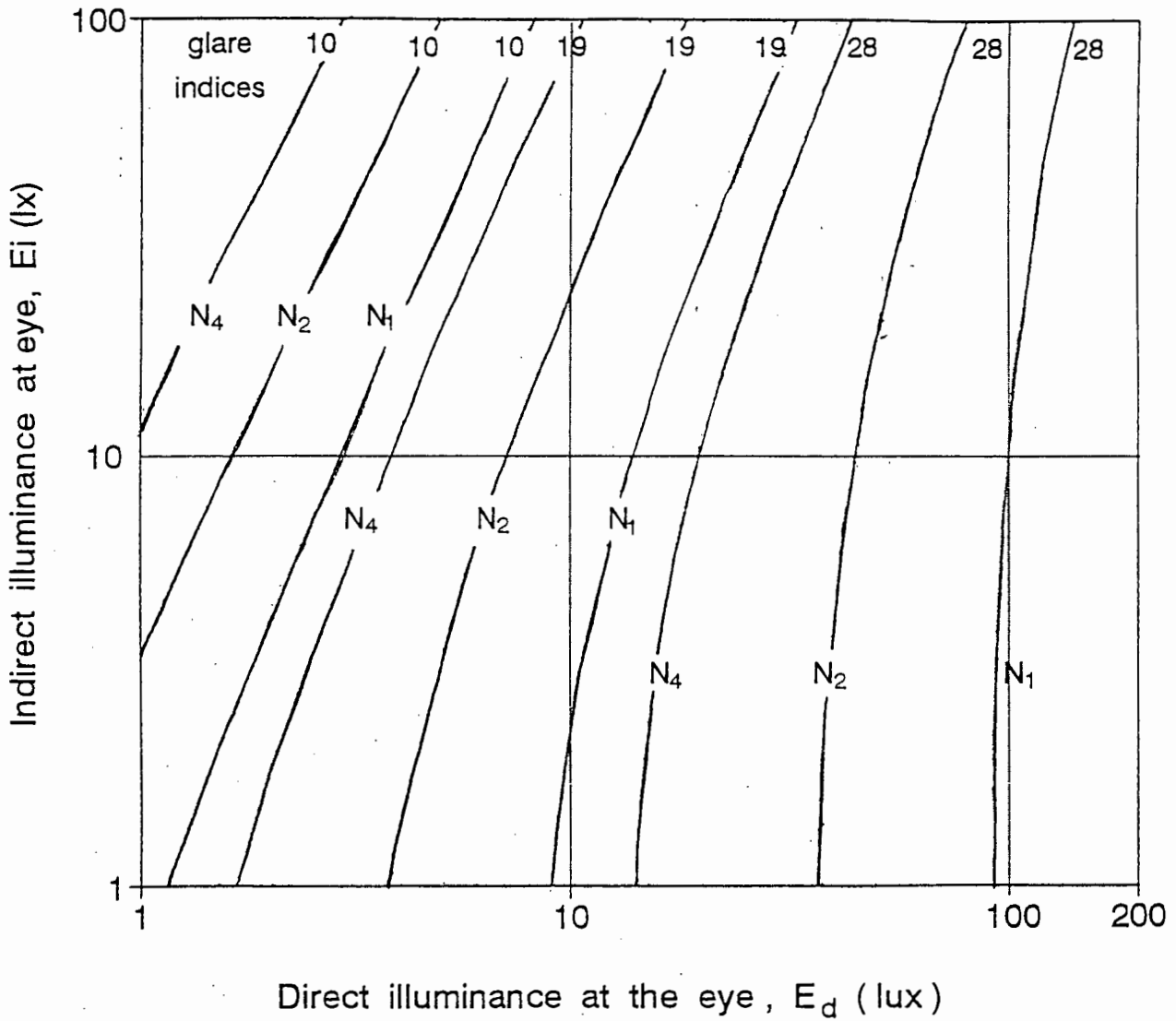


Figure 10. Graph of E_d versus E_i according to the CGI formula for the normal source at distances of 1.37m, 2.29m and 3.94m from the source for glare indices of 10, 19 and 28.

4. RESULTS

4.1 Comparison of E_d 'up' and 'down' pairs of settings

On analyzing all the E_d 'up' and E_d 'down' pairs of settings for each E_i setting, it was found that 76% of settings 'stopped short' of one another. i.e. most 'up' settings were less than their corresponding 'down' settings. 15% of settings were approximately the same. i.e. the 'up' and 'down' setting were within 10% of one another, and 9% of settings 'overran' one another. i.e. some 'up' settings were greater than their corresponding 'down' settings. Proportions of each occurrence are depicted in Figure 11. The reason for the high percentage of readings 'stopping short' is just not known but an explanation in terms of adaptation by the source is offered: When making E_d 'down' settings the observer experiences adaptation by the initially bright source and the sensation of comfort comes relatively soon. A few observers noted that after making their initial E_d 'up' setting the sensation of discomfort slowly subsided with time as they apparently became adapted by the source. Had the observers spent more time on making settings the percentage of readings 'stopping short' might have been lower.

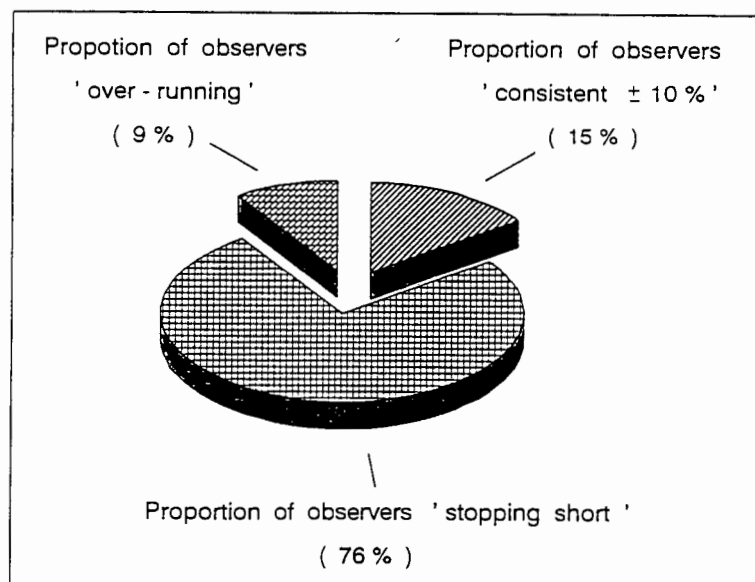


Figure 11. Pie chart showing different proportions of observers' relative E_d 'up' and E_d 'down' 'direct test' settings. Some readings stopped short of one another ($E_{d_{up}} < E_{d_{down}}$), some readings were the same or approximately the same ($E_{d_{up}} \approx E_{d_{down}}$), and some readings overran one other ($E_{d_{up}} > E_{d_{down}}$).

4.2 Values of E_d^2 / E_i versus Distance

Plots of E_d^2 / E_i versus distance were done for both the normal and small source. The values of E_d^2 / E_i in Figure 12(a) were obtained by calculations made from tests done exclusively at 1.37m and 3.94m from the source. The values of E_d^2 / E_i in Figure 12(b) were obtained by calculations made from tests done at 2.29m from the source and at either of, or both 1.37m and 3.94m from the source. By comparing the average of E_d^2 / E_i at 1.37 m and 3.94 m in Figure 12(a) it can be seen that E_d^2 / E_i decreases approximately with the square of the distance from the source, for both the normal and small source. It has been shown (see section 3.2.1) *that this variation of E_d^2 / E_i with distance indicates a “constant area” for the small source.* A large standard deviation in the values was evident, which merely represented the differences in sensitivity to glare of all the observers. A slightly bigger standard deviation was obtained for the small source. This could be attributed to the variation in the glare assessments of A_s made by different observers. A similar variation of E_d^2 / E_i from one distance to the next is seen in Figure 12(b), confirming the “constant area” hypothesis. The horizontal and vertical scales in Figures 12(a) and 12(b) was chosen in such a way that lines sloping down to the right at 45 correspond to ‘constant area’ and horizontal lines correspond to ‘constant omega’.

Explanation of scale choice:

For constant area E_d^2 / E_i goes down in proportion with the square or the distance.

Considering just Figure 12(a), $(R_4 / R_1)^2 = (3.94 / 1.37)^2 = 8.27$. Now the distance on the vertical scale corresponding to an E_d^2 / E_i ratio of 8.27 must be equivalent to the distance on the horizontal scale corresponding to a distance ratio of $(8.27)^{1/2}$.

The *experimental mean ratios* of E_d^2 / E_i between one distance and the next for both the normal and small source are shown in Figure 13, together with the standard deviations and 95 % confidence intervals (see Table 2 for tabulated values). Referring to Figure 13, $S_{2.4}$ for example, means the ratio of $[E_d^2 / E_i \text{ at } 2.29 \text{ m }]$ to $[E_d^2 / E_i \text{ at } 3.94 \text{ m }]$ for the small source. Similarly, $N_{1.2}$ means the ratio of $[E_d^2 / E_i \text{ at } 1.37 \text{ m }]$ to $[E_d^2 / E_i \text{ at } 2.29 \text{ m }]$ for the normal source.

The ratios that one would expect for either “constant omega” or constant area” are illustrated in Figure 13 (see section 3.1 for proof). It can be seen in Figure 13 (and shown in Table 2) that the ratios for “constant area” are all within one standard deviation of the ratios obtained experimentally for both the normal and small source. Although one standard deviation might not seem to be a reassuring interval of

likelihood, similar deviations from the 'constant area' ratios exist experimentally for both the small *and normal* source. For example, experimental E_d^2 / E_i ratios between the near and far distance, and between the near and middle distance, are slightly higher than the 'constant area' E_d^2 / E_i ratios for both the normal and small source. The experimental E_d^2 / E_i ratio between the middle and far distance, however, is slightly lower than the 'constant area' E_d^2 / E_i ratio for both the normal and small source.

These slight deviations from 'constant area' can also be seen by observing the trend in deviations from '45°-constant-area-lines' of Figures 12(a) and (b) for both the normal and small source. Between the near and far distance, and between the near and middle distance, the average slope is slightly steeper than 45° but the average slope between the middle and far distance is slightly shallower than 45°.

The unexpectedly high E_d^2 / E_i ratio between distances of 1.37m and 2.29m for the normal source ($N_{1:2} = 4.09$, compared to an expected ratio of $N_{1:2} = 2.79$), *also seen for the small source* ($S_{1:2} = 3.65$) is discussed in section 4.6.

E_d^2 / E_i ratios between distances						
	Experimental				Predicted	
	Average ratio	Standard deviation	95 % Confidence limits	n	'constant area'	'constant omega'
$N_{1:4}$	9.5	7.0 ↔ 13.1	8.5 ↔ 10.7	31	8.27	N/A
$S_{1:4}$	10.6	7.2 ↔ 15.4	9.2 ↔ 12.1	31	8.27	1
$N_{2:4}$	2.7	2.1 ↔ 3.6	2.3 ↔ 3.2	13	2.96	N/A
$S_{2:4}$	2.5	1.5 ↔ 4.1	1.8 ↔ 3.4	13	2.96	1
$N_{1:2}$	4.1	2.7 ↔ 6.3	3.1 ↔ 5.4	12	2.79	N/A
$S_{1:2}$	3.7	2.3 ↔ 5.7	2.8 ↔ 4.8	12	2.79	1

Where n = number of observers, N = normal source, S = small source
 subscripts 1, 2 and 4 represent distances 1.37m, 2.29m and 3.94m respectively
 e.g. $S_{2:4}$ represents the E_d^2 / E_i ratio between 2.29m and 3.94m for the small source

Table 2. Comparison of experimental, calculated 'constant omega' and calculated 'constant area' E_d^2 / E_i ratios between one distance and the next for both the normal and small source.

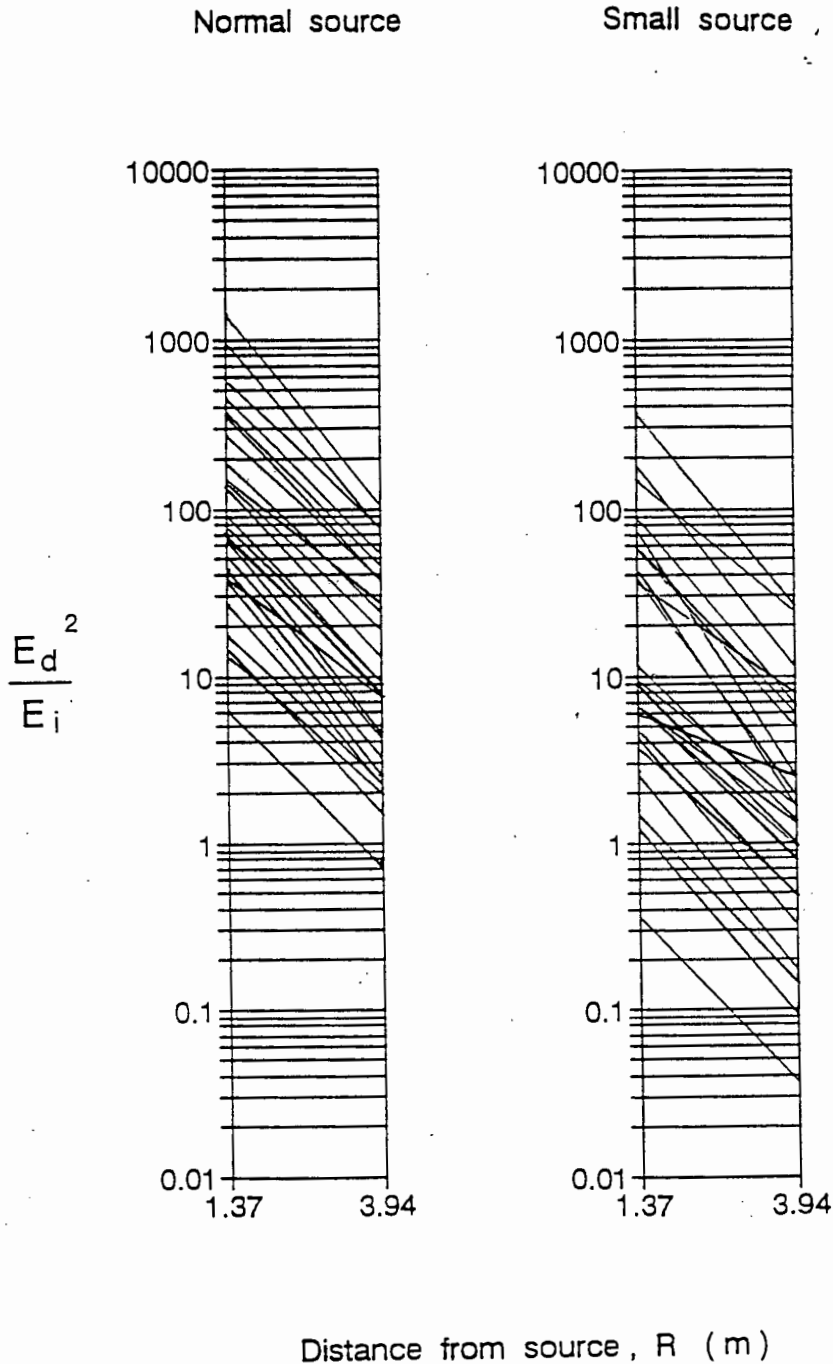


Figure 12a. Comparison of the variation of E_d^2/E_i with distance from the normal and small source. The values were obtained by calculations made from tests done exclusively at 1.37 m and 3.94 m from the source. Horizontal lines would support the “constant omega” hypothesis and lines sloping down to the right at 45° to the horizontal would support the “constant area” hypothesis.

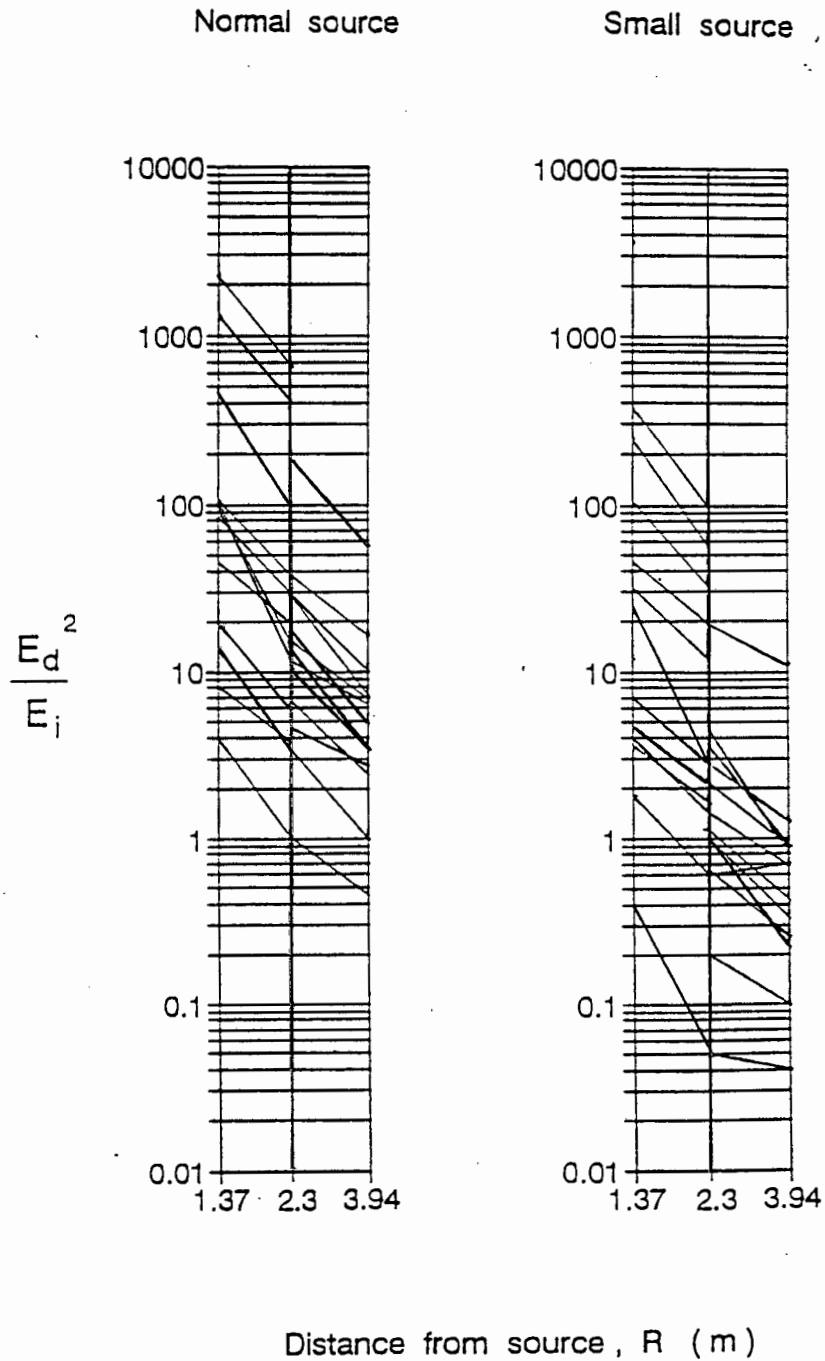
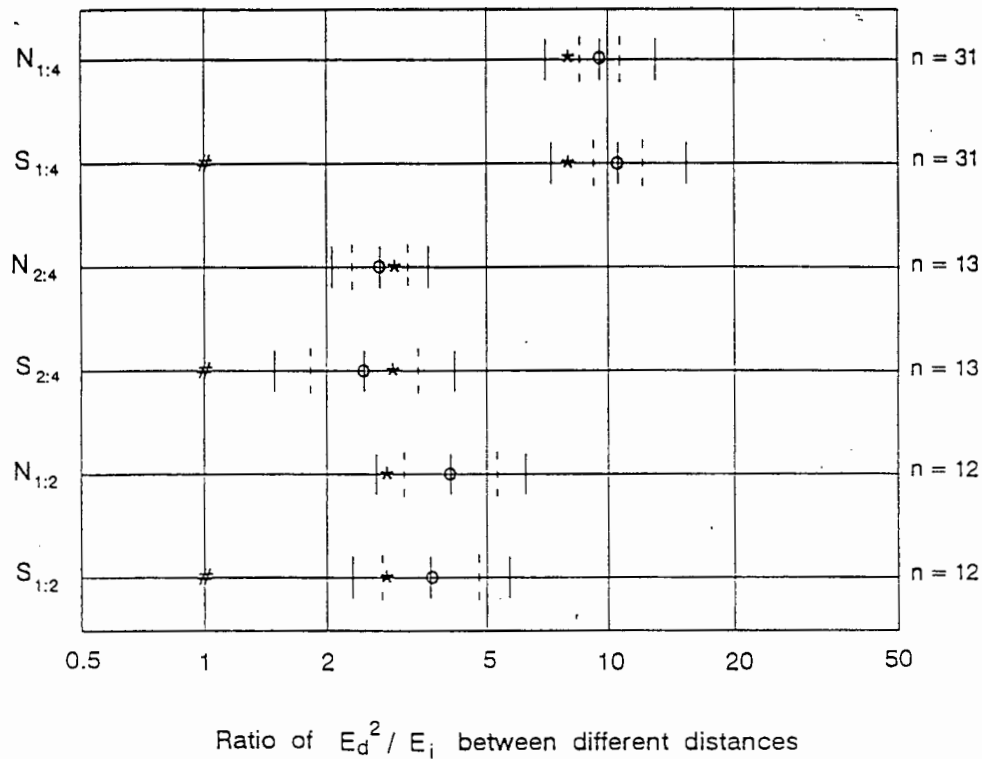


Figure 12b. Comparison of the variation of E_d^2/E_i with distance from the normal and small source. The values were obtained by calculations made from tests done at 2.29 m from the source and at either of, or both, 1.37 m and 3.94 m from the source. Horizontal lines would support the “constant omega” hypothesis and lines sloping down to the right at 45° to the horizontal would support the “constant area” hypothesis.



Mean	
ϕ Experimental ratio	95 % confidence interval standard deviation
# = ratio for constant omega	* = ratio for constant area
N = normal source	1 = 1.37 m
S = small source	2 = 2.29 m
n = no. of observers	4 = 3.94 m

Figure 13. Comparison of experimental, calculated ‘constant omega’, and calculated ‘constant area’, E_d^2 / E_i ratios between one distance and the next, for both the normal and small source. For example, $S_{2:4}$ represents the ratio of the mean E_d^2 / E_i at 2.29m to the mean E_d^2 / E_i at 3.94m for the small source. Standard deviations and 95 % confidence intervals are also shown together with E_d^2 / E_i ratios supporting each of two hypotheses.

4.3 Assessment of A_s

Individual observer's glare assessment of A_s was determined at each of the distances that they were tested at, by the method described in section 3.2.1. These values of A_s for each observer are plotted against their corresponding distances from the source and connected by lines to distinguish one observer from the next (see Figure 14).

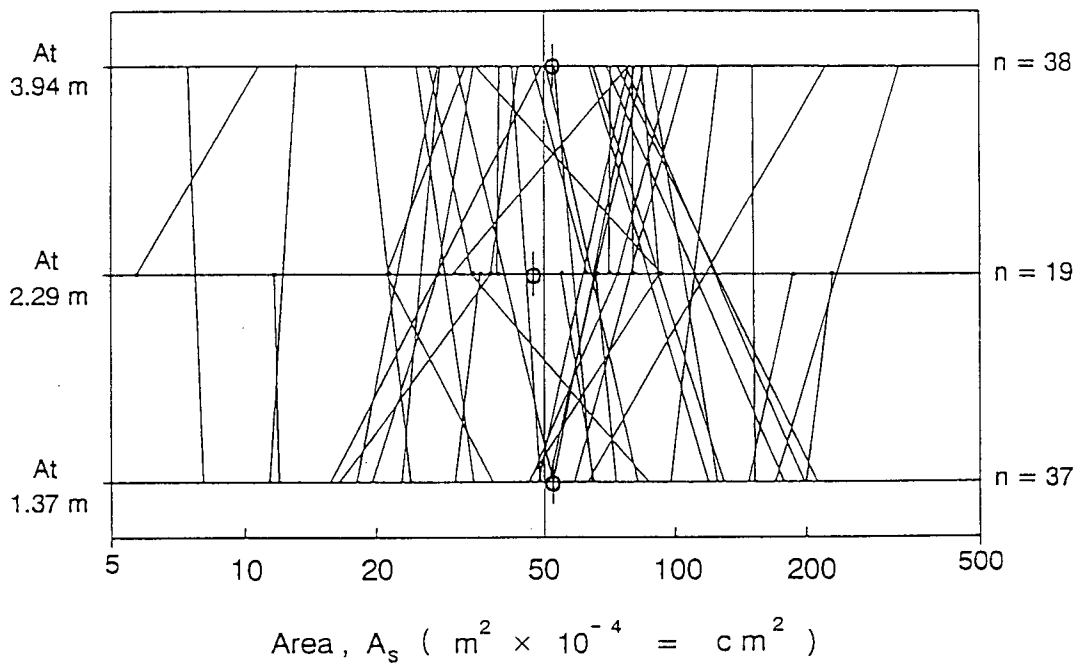


Figure 14. Individual observers' glare assessment of A_s , linked at pertaining distances. The small dots indicate that an assessment was made at that distance, and lines link the dots for each observer. Vertical lines support the "constant area" hypothesis and lines sloping up to the right at 45° support the "constant omega" hypothesis. The values to the right of the diagram refer to the number of separate assessments of A_s made at that particular distance.

Vertical lines would support 'constant area', and the vertical and horizontal scales were chosen in such a way, that lines sloping up to the right at 45° would support 'constant omega'.

Explanation of scale choice:

For 'constant omega' the area is proportional to the square of the distance, since $\omega = A / R^2$.
e.g. $R^2 = (R_4 / R_1)^2 = (3.94 / 1.37)^2 = 8.27$. Now the distance on the horizontal scale corresponding to an area ratio of 8.27 must be equivalent to the distance on the vertical scale corresponding to a distance ratio of $(8.27)^{1/2}$.

Although some lines do slope *up* to the right, a similar proportion slope *down* to the right.

The overall trend of the lines is in the vertical direction which means that the values of A_s at each of the three distances are approximately the same. This is verified by noting the three mean values of A_s depicted in Figure 14, which are within 10 % of one another.

95 % confidence intervals and standard deviations were calculated for the values of A_s at each distance from the source (see Figure 15 and Table 3). The statistics were made from 38, 19 and 37 separate assessments of A_s at 3.94m, 2.29m and 1.37m from the source, respectively.

The 95 % confidence interval and standard deviation for the 1.37m values were slightly larger than the 95 % confidence interval and standard deviation associated with 3.94m, despite working with practically the same number of assessments. i.e. $n = 37$ and $n = 38$ respectively. The reason for this could be due to the slight deviations in distance of the seated observers from the prescribed distance from the source. i.e. some observers' eyes might have been in front of the prescribed mark and some might have been behind it. Deviations closer to the source would have a more marked effect on the change of glare experienced, than the same deviations further from the source.

The 19 assessments of A_s at the 2.29 m distance had the widest 95 % confidence interval on account of the relatively few assessments made. i.e. 19 compared with 37 and 38.

	At 3.94 m	At 2.29 m	At 1.37 m	Overall averaged assessment
No. of A_s assessments	38	19	37	94
Average A_s	52.7	47.5	52.2	51.4
Standard deviation limits	24 ↔ 115	20 ↔ 115	21 ↔ 128	22 ↔ 119
95 % confidence limits	41 ↔ 68	31 ↔ 73	41 ↔ 70	43 ↔ 61

All A_s values are in $m^2 \times 10^{-4}$ (= cm^2)

Table 3. Average glare assessment of A_s at 1.37m, 2.29m and 3.94m and an overall average of A_s

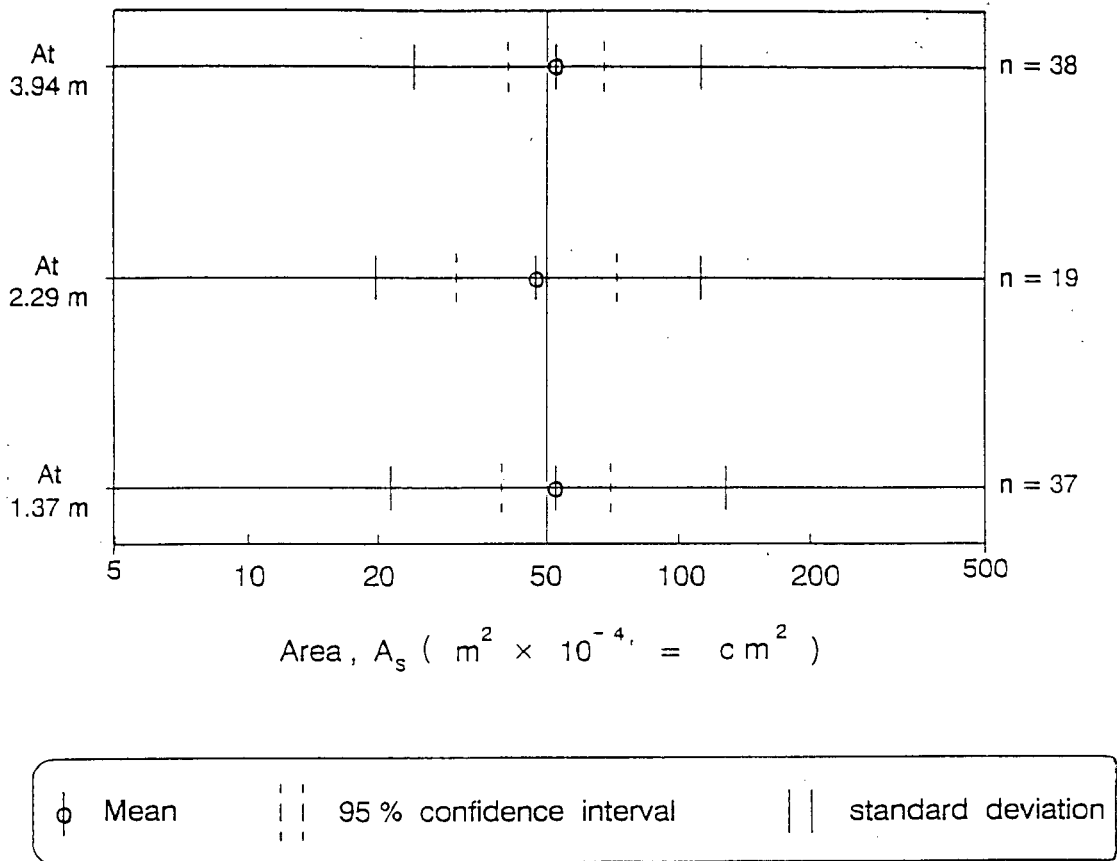


Figure 15. A statistical representation of Figure 14 without the individual plots. The mean effective area, A_s at each of the three distances from the source are shown together with the standard deviations and 95 % confidence intervals. The values to the right of the diagram refer to the number of separate assessments of A_s , made at that particular distance and used in computing the statistics.

All values of A_s irrespective of distance were then averaged together to get an overall mean value of A_s . Averaging between distances was done only *after* the ‘constant area’ hypothesis for small sources was considered to be correct. A total therefore of $94 = (38 + 19 + 37)$ values were used to compute this mean together with a 95 % confidence interval and standard deviation (see Figure 16 and Table 3). This overall confidence interval is significantly narrower than either of the 95 % confidence intervals associated with the different distances separated as expected.

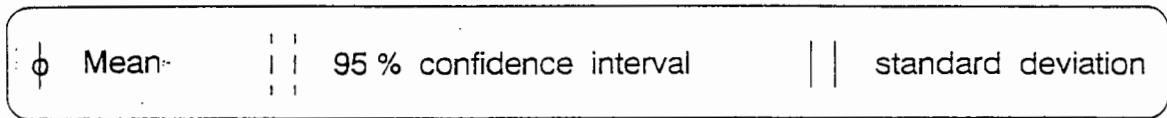
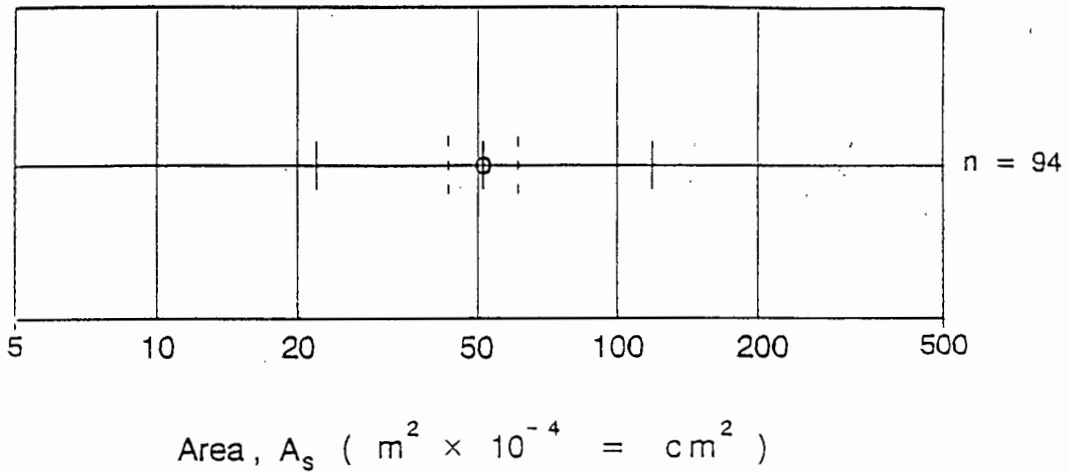


Figure 16. Since the effective area, A_s remained substantially the same with distance of viewing, an average was taken from assessments of A_s at all three distances. This average, with standard deviation and 95 % confidence interval, is shown. The value $n = 94 = (38 + 19 + 37)$ represents the number of assessments of A_s used in computing the statistics.

The overall confidence interval corresponds to a glare index range of 1.2 units as calculated from the UGR formula.

Proof: Referring to Table 3 the 95% confidence limits for 94 assessments of A_s are:

$$A_s \text{ (lower limit) } = 43.3 \text{ m}^2 \times 10^{-4}$$

$$A_s \text{ (upper limit) } = 61.0 \text{ m}^2 \times 10^{-4}$$

Now referring to the UGR formula for glare,

$$\begin{aligned} \text{UGR} &= 8 \log_{10} [0.785 / E_i \sum (L^2 \omega / p^2)] \\ &= 8 \log_{10} (0.785 / E_i \sum [L^2 (A / R^2) / p^2]) && \text{since } \omega = A / R^2 \\ &= 8 \log_{10} (0.785 / E_i \sum [(I^2 / A^2) (A / R^2) / p^2]) && \text{since } L = I / A \\ &= 8 \log_{10} (0.785 / E_i \sum [I^2 / (A \cdot R^2 p^2)]) \end{aligned}$$

it can be seen that a change in area from the upper limit to the lower limit relates to an increase in glare,

$$\begin{aligned} \Delta UGR \text{ of: } \quad \Delta UGR &= 8 \log_{10} (61.0) - 8 \log_{10} (43.3) \\ &= 8 \log_{10} (61.0 / 43.3) \\ &= 1.2 \text{ G.I units} \end{aligned}$$

i.e. Average UGR \pm 0.6 units

For comparison, one unit is considered to be the least detectable step from a glare perspective and three units is a normally accepted step (TC-3. 13, 1991).

4.4 A_s versus Sensitivity for all observers

Each observer's assessment of A_s at different distances were plotted against their sensitivity to glare [see Figure 17 (a, b and c)]. Their sensitivities are represented as UGR indices calculated from the observers' settings for the normal source. The average observer in terms of sensitivity and assessment of A_s was then obtained by averaging over the three distances. This average together with the standard deviations in both the A_s and GI directions is depicted in Table 4. The assessment of A_s appeared to be independent of sensitivity.

	At 3.94 m	At 2.29 m	At 1.37 m	Overall averaged assessment
Average A _s	52.7	47.5	52.2	51.4
A _s Standard deviation limits	24 ↔ 115	20 ↔ 115	21 ↔ 128	22 ↔ 119
Average Sensitivity (GI)	22.6	22.4	24.7	23.4
Sensitivity Standard deviation limits	17.9 ↔ 27.3	16.8 ↔ 28.0	19.4 ↔ 30.0	18.2 ↔ 28.6

Table 4. Average sensitivity of all observers expressed as a glare index

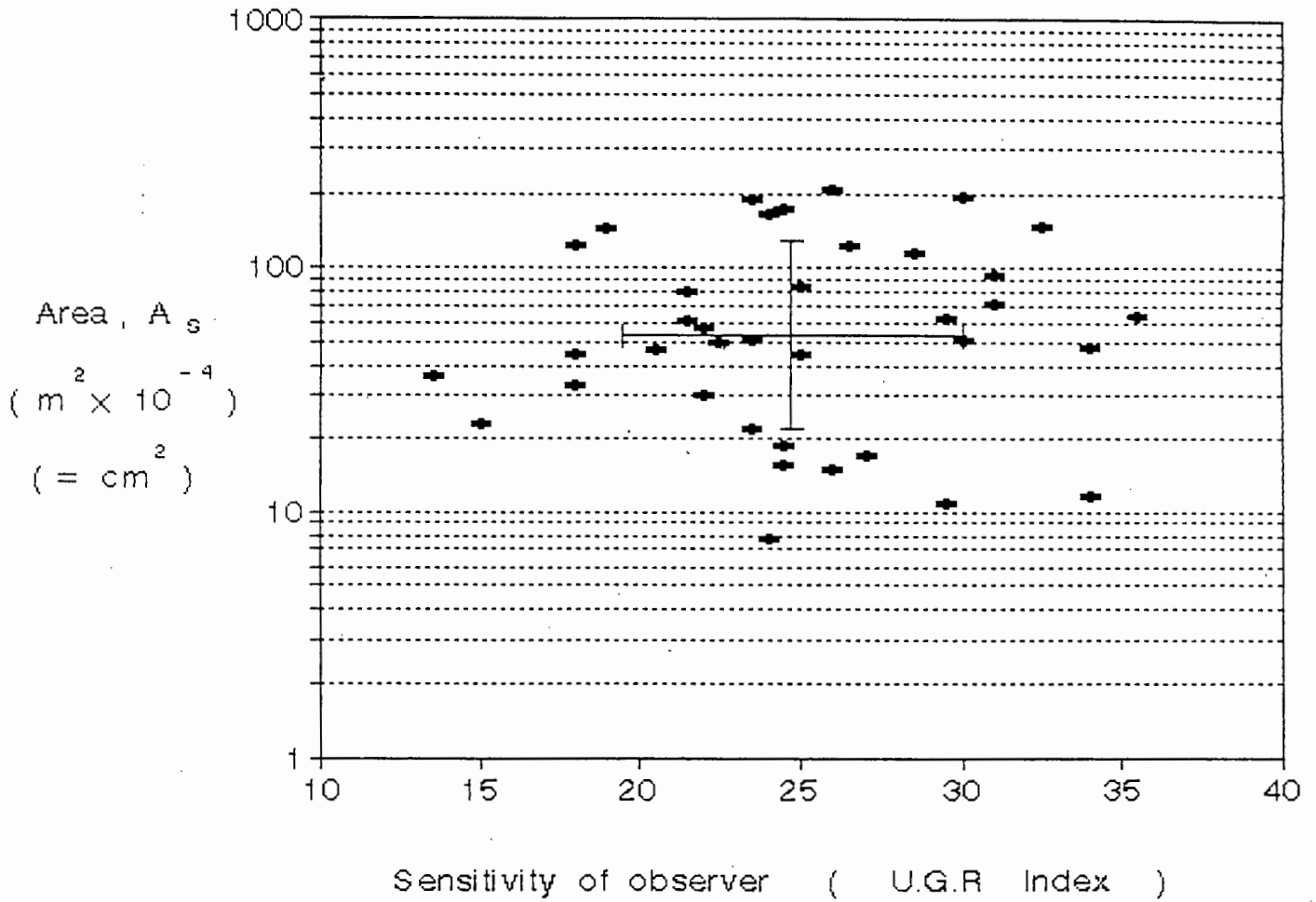


Figure 17a. Points on the graph correspond to individual observers of varying sensitivity and their glare assessment of A_s at 1.37m from the source. Sensitivities are represented as UGR glare indices, calculated from the observers' settings for the normal source. The average observer together with standard deviations in both the G.I. and A_s directions is indicated.

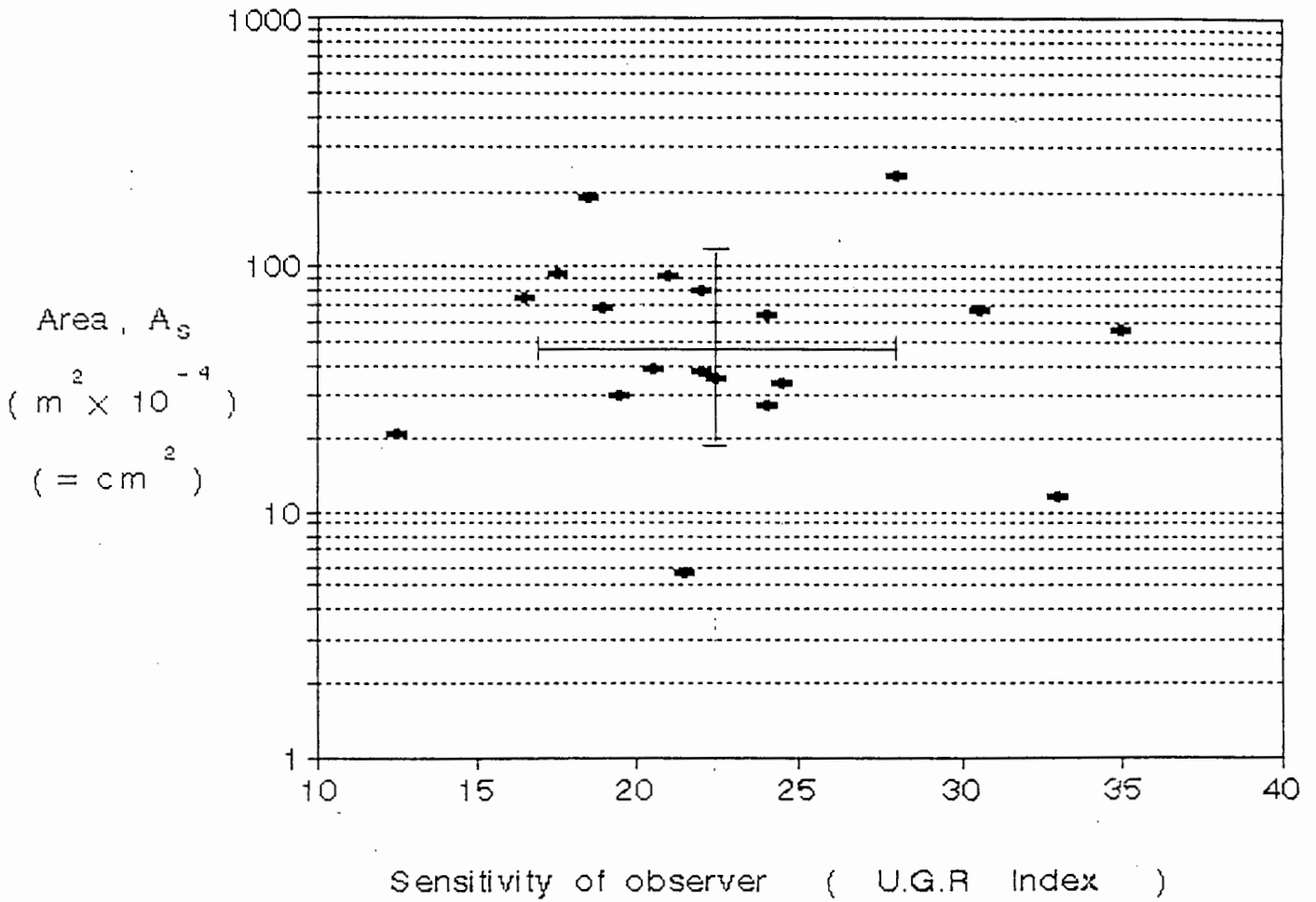


Figure 17b. Points on the graph correspond to individual observers of varying sensitivity and their glare assessment of A_s at 2.29m from the source. Sensitivities are represented as UGR glare indices, calculated from the observers' settings for the normal source. The average observer together with standard deviations in both the G.I. and A_s directions is indicated.

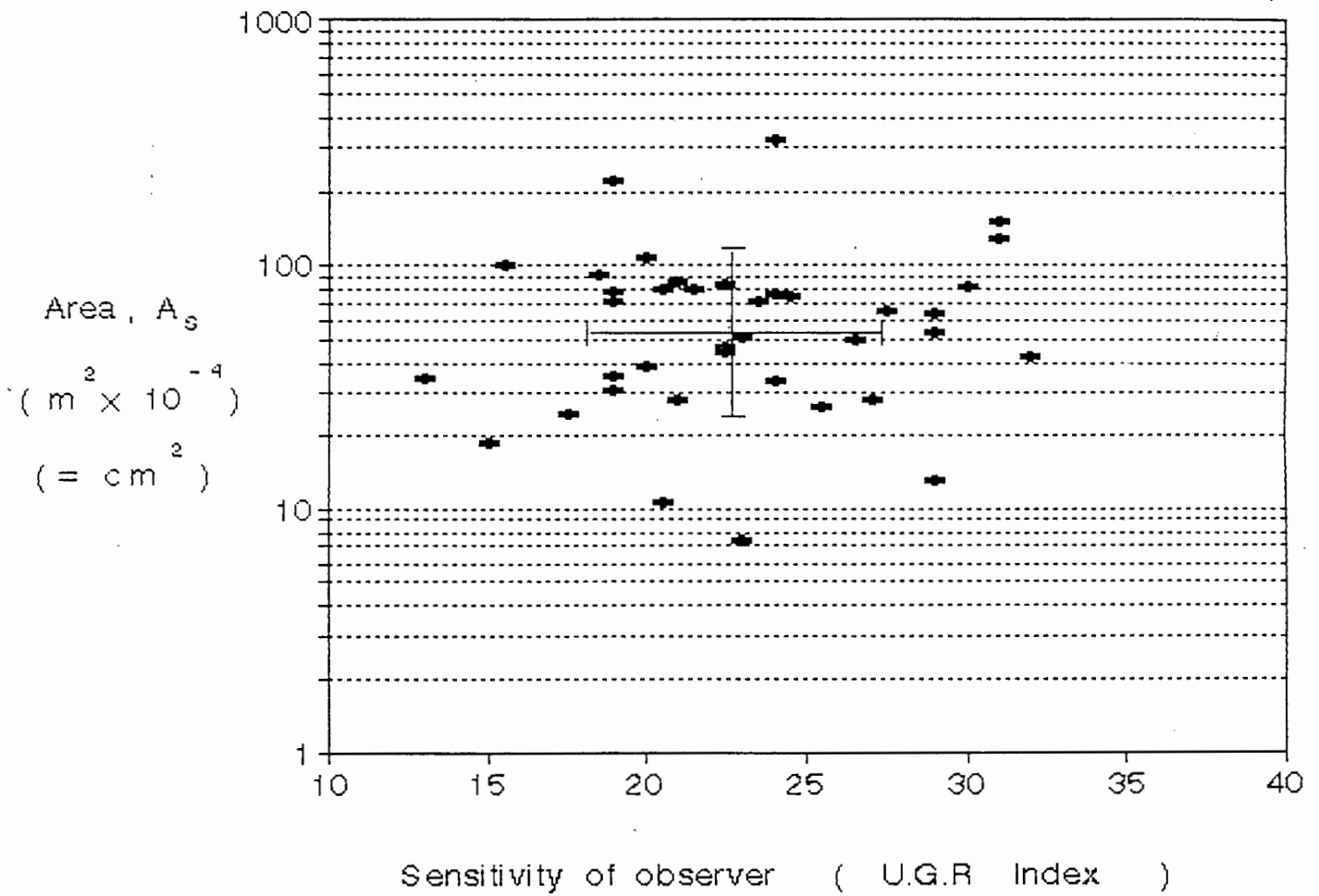


Figure 17c. Points on the graph correspond to individual observers of varying sensitivity and their glare assessment of A_s at 3.94m from the source. Sensitivities are represented as UGR glare indices, calculated from the observers' settings for the normal source. The average observer together with standard deviations in both the G.I. and A_s directions is indicated.

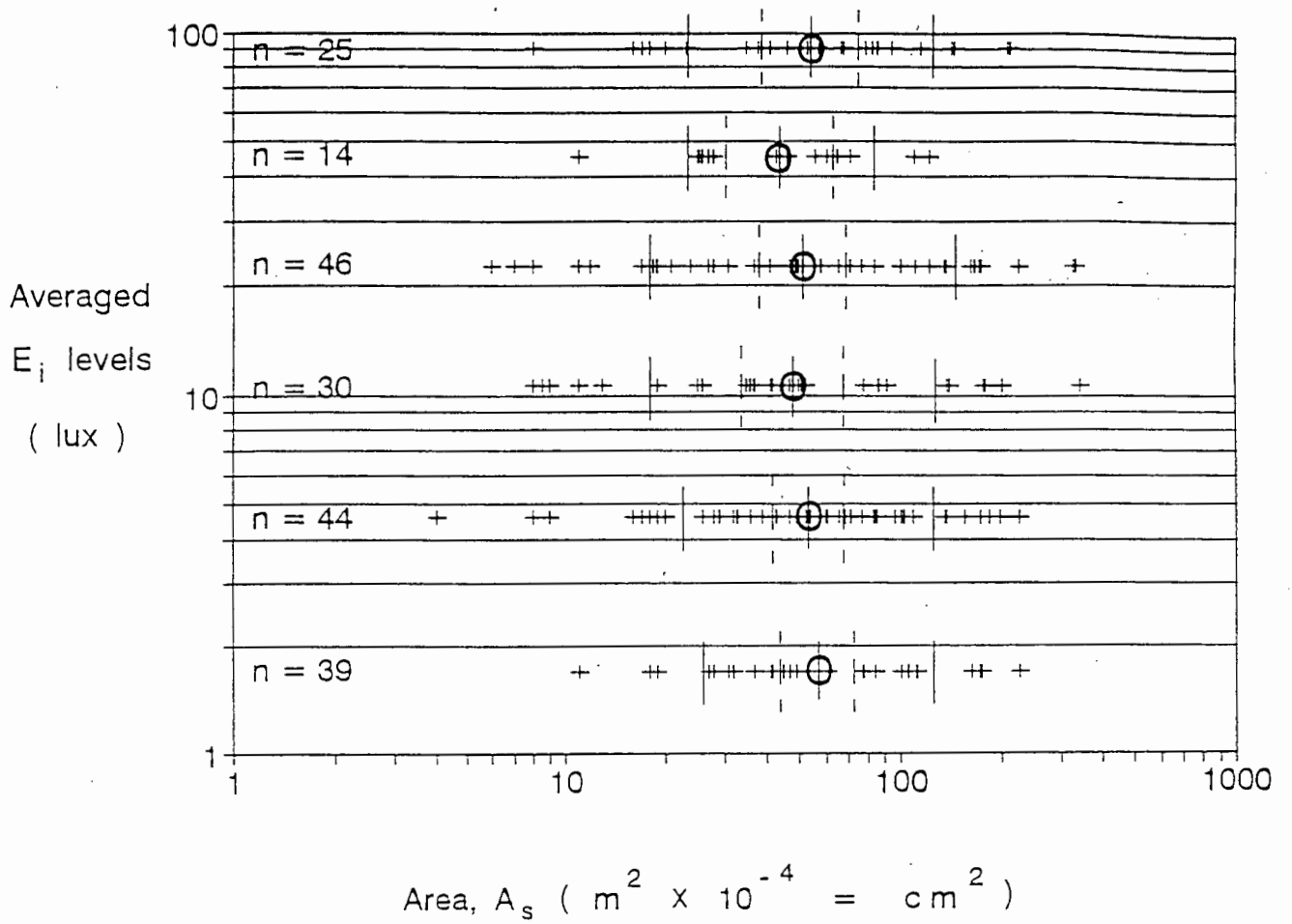
4.5 A_s versus Adaptation Level

To investigate whether or not the adaptation level, namely E_i , had an effect on the assessment of A_s , individuals' assessments of A_s at different E_i levels were plotted (see Figure 18) together with standard deviations and 95% confidence intervals. Only E_i levels common to the normal *and* small source at the same distance from each source were used in the evaluation. The full experimental E_i range was divided into six separate E_i ranges (see Table 5) with an average A_s determined for each range combining all distances tested at. Averaging between distances was allowed once the verification in the 'constant area' hypothesis was established. It can be seen that the adaptation level had no apparent affect on the average observer's assessment of A_s .

E_i levels (lux)	1 ↔ 3	3 ↔ 7	7 ↔ 16	16 ↔ 32	32 ↔ 64	64 ↔ 128
No of assessments	39	44	30	46	14	25
Average A_s	56	52	47	50	43	53
Standard deviation	25 ↔ 122	22 ↔ 123	18 ↔ 125	17 ↔ 144	22 ↔ 83	23 ↔ 123
95 % confidence interval	43 ↔ 72	40 ↔ 68	32 ↔ 68	36 ↔ 69	29 ↔ 63	38 ↔ 75

All A_s values are in $m^2 \times 10^{-4}$ (= cm^2) rounded off to nearest cm^2

Table 5. Individual observer's glare assessment of A_s at different E_i levels



ϕ Mean ||| 95 % confidence interval || standard deviation

Figure 18. Individual observer's glare assessment of A_s at six different averaged E_i levels at each distance tested at. Shown are average A_s assessments at each E_i level, together with standard deviations and 95 % confidence intervals.

4.6 Indications of Adaptation by the Source

[E_d , E_i] pairs obtained *experimentally* were used in determining average E_d versus E_i slopes on two dimensional logarithmic paper for three different E_i ranges and two distances for both the normal and small source to explore the adaptation by the source possibility (see section 3.6). Average slopes for a low, medium and high E_i range were determined for the near and far distance (see Table 6). It can be seen that in all cases (both sources and both distances) the slopes of the E_d versus E_i lines flatten with increase in E_i range. This same feature exists in the CGI graph suggesting a degree of adaptation by source found experimentally.

	E_i range (lux)	Average slopes of E_d vs E_i graphs	
		At 3.94 m	At 1.37 m
Normal source	1 ↔ 10	2.1 (n = 12)	2.4 (n = 16)
	6 ↔ 27	1.5 (n = 10)	1.8 (n = 15)
	23 ↔ 83	1.4 (n = 9)	1.6 (n = 14)
Small source	1 ↔ 12	2.4 (n = 14)	2.5 (n = 18)
	5 ↔ 35	1.8 (n = 16)	1.6 (n = 17)
	23 ↔ 102	1.3 (n = 19)	1.4 (n = 16)

where n = the number of observers

Table 6. Averaged E_d versus E_i slopes at varying E_i levels

No significant / consistent trend in change of slope between the near and far distance was apparent for the small source, although the trend in change of slope between the near and far distance (like that for the CGI graph) was found to exist for the normal source.

Referring to Figure 13 and / or Table 2, the unexpectedly high E_d^2 / E_i ratio between distances of 1.37m and 2.29m for the normal source ($N_{1:2} = 4.09$, compared to an expected ratio of $N_{1:2} = 2.79$), *also seen for the small source* ($S_{1:2} = 3.65$), suggest a degree of adaptation by the source. Here is an offered explanation:

At the near distance (1.37m) the solid angle of the sources are at their experimental largest and occupy a relatively large proportion of the visual field. This is particularly true in the case of the normal source, which is obviously bigger, and happens to have the larger E_d^2 / E_i ratio out of the two (i.e. $N_{1:2} > S_{1:2}$). The observers are comfortable with higher than expected source brightness since they become adapted by the source. i.e. they set for higher E_d than expected which means a higher E_d^2 / E_i value than expected.

Referring to Table 2 again it can be seen that the $N_{1:4}$ and $S_{1:4}$ ratios (9.5 and 10.6 respectively) are also in excess of 14% of the expected ratio of 8.27. This again supports the adaptation by the source suggestion in the above paragraph, and yet this time $N_{1:4} < S_{1:4}$.

In section 4.1 a suggestion of adaptation by the source was put forward to explain the 'stopping short' of E_d settings.

5. CONCLUSIONS AND RECOMMENDATIONS

The findings show conclusively that the small source has a constant effective area and not a constant effective solid angle as seen by the average observer when viewed off the line of sight at distances below 4m. Statements about the effective size of the small source at distances exceeding 4m can not be made.

The area, A_s was found to be approximately 0.005 m^2 (50 cm^2), which corresponds to a disk approximately 8cm in diameter. The 95 % confidence interval associated with this mean relates to a UGR interval of 1.2 units, i.e. a variation from the mean of ± 0.6 units. The area, A_s was found to be independent of the surround brightness (indirect illuminance, E_i) and the sensitivity of the observer.

It can be concluded that pearl (frosted) incandescent lamps with a projected area less than 50 cm^2 are not less glaring than clear incandescent lamps of the same intensity when viewed off the line of sight.

A certain degree of adaptation by the source itself was seen to exist for both the normal and small source.

Assuming the 94 subjects/observers involved in the study were more or less representative of the average observer of a much larger population in terms of sensitivity to glare, a UGR of 23.5 relates to a sensation of "just uncomfortable".

A recommendation is made to all interior lighting engineers to assume an effective area for small sources of 50 cm^2 when designing lighting layouts involving small sources in rooms where the distances between person and source does not exceed 4m.

Two suggestions may be made involving further research on glare from small sources:

Firstly, It may be suggested that similar glare tests be carried out on linear (long and thin) sources, such as bare halogen lamps, where the one dimension of the projected area is less than 8cm. In this way the effective size of thin linear sources when viewed off the LoS may be determined.

The other suggestion is that further tests be conducted at distances greater than 4m from the source to see whether or not the 'constant area' hypothesis extends to bigger distances.

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APPENDIX 1

[Literature review]

A1 LITERATURE REVIEW

The term “glare” in the CIE vocabulary normally refers to a “condition of vision” which includes two separate psycho-physical effects. These are:

1. *Discomfort* glare, which causes discomfort without necessarily impairing the vision of objects and details.
2. *Disability* glare, which impairs the vision of objects without necessarily causing discomfort.

‘Although they can occur in combination, these two forms of glare are quite different phenomena. Disability glare depends mainly on the quality of light falling on the eye and is relatively unaffected by the luminance of the source or by time. Discomfort glare on the other hand, is mainly attributed to source luminance and manifests itself in the form of a head-ache or fatigue by a person subjected to it over long periods’ (TC-3.4, 1981). ‘The evaluation of discomfort glare is an important design criteria in illuminating engineering’ (Guth, 1966). and ‘the limitation of discomfort glare is one of the major quality aspects of any lighting installation’ (TC-3.4, 1981). It is generally agreed (TC-3.4, 1981) that discomfort glare produced by an individual source basically depends on four main parameters :

- L Source luminance in the direction of the observer’s eye and exceeding a “threshold” of $500/750 \text{ cd.m}^{-2}$
- ω The solid angle subtended by the source at the observer’s eye
- θ The angular displacement of the source from the observer’s line of sight, LoS
- L_b The general field/background luminance controlling the adaptation level of the observer’s eye

(see Figure A over page for graphical illustration)

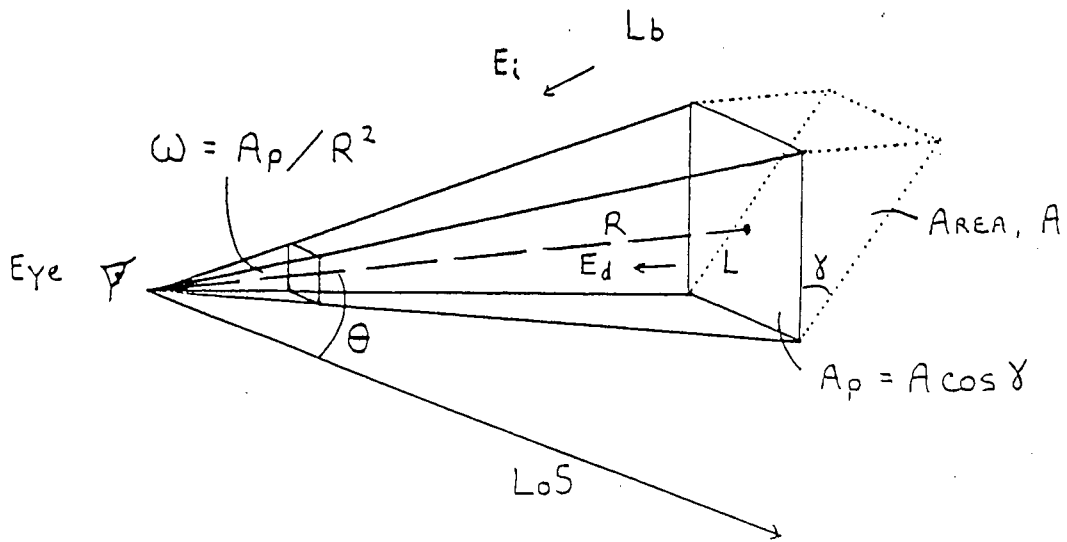


Figure A. Parameters effecting the discomfort glare from an individual source.

The subjective sensation of discomfort glare experienced by the observer can be related to the four factors by a general expression of the following type:

$$G = [L^a \cdot \omega^b] / [L_b^c \cdot p^d] \quad (1)$$

where G is a quantity expressing the sum of subjective sensations, and a , b , c and d are suitable weighting exponents. The position index, p is a complex function of the displacement angle, θ , which takes separate account of its vertical and azimuth components (see Appendix 3).

Since the 1950s many researchers around the world have tried to establish suitable values of the exponents in equation (1). It is agreed that the exponents a and d must be the same to satisfy Guth's position index formula. i.e. $a = d$. In all cases of research the exponent a was found to be bigger than the exponents, b and c . i.e. the source luminance was found to have more influence on discomfort glare than did either the background/field luminance or the size of the source. The comparative magnitudes of the exponents b and c , however, was an area of much controversy amongst different researchers.

It is generally agreed (Einhorn, 1969) that the field/background luminance will increase as the size or number of sources in an installation increases; assuming an unchanged source luminance. The question

arises: 'Does the degree of discomfort glare increase or decrease with an increase in size or number of luminaires. Ratios of $b:c < 1$ suggest that the degree of discomfort glare would decrease: i.e. glare is contra-variant with size. Ratios of $b:c > 1$ suggest that the degree of discomfort glare would increase; i.e. glare is co-variant with size. A ratio of $b:c = 1$ suggests that the degree of discomfort glare is unchanged i.e. glare is invariant with size (Einhorn, 1969).

In addition to calculating G, it is necessary to relate this to the subjective degree of discomfort experienced by the "average observer".(TC-3.4. 1981) 'Since comfort and discomfort are sensations, their appraisal can be made only by those who experience such sensations'.(Luckiesh and Guth, 1949). As sensitivity to discomfort glare varies from person to person, the number of observers must be large enough to provide adequate statistical data (TC-3.4, 1981).

In Guth's visual comfort probability (VCP) method (1966) a hundred observers were used to state individually whether they considered the installation acceptable, i.e. at or above the borderline between comfort and discomfort (BCD). The percentage of the group stating "yes" was taken as the VCP rating of the installation under appraisal.

Different methods of conducting glare tests have been used over the years and in all cases the observer was either required to make adjustments of parameters under his/her control or to comment on adjustments made by the experimenter. Adjustments made by the observer often took the form of 'direct' and/or 'buffer' tests. A 'direct' setting is made by adjustments of the source intensity until a specified degree of discomfort glare is reached, with the background/field luminance previously set by the experimenter. A 'buffer' setting is made by adjustments of the background/field luminance until a specified degree of discomfort glare is reached, with the source intensity previously set by the experimenter.

Luckiesh and Holliday (1949) developed a scale of comfort-discomfort or "degrees of sensation" from a scarcely noticeable sensation to a painful and intolerable sensation. Their observers were exposed to the source intermittently for one second duration spells and asked to express their sensation of glare by means of a number from 0 - 9, where a "0" corresponded to a scarcely noticeable sensation and a "9" corresponded to an intolerable sensation.

Hopkinson and Petherbridge (1950) described four precise degrees of discomfort glare to their observers. The four criterion were:

- A - Just intolerable ----- change over point between intolerable and uncomfortable glare
- B - Just uncomfortable ----- change over point between uncomfortable and merely distracting glare.
- C - Just acceptable ----- change over point between distracting and acceptable glare
- D - Just imperceptible ----- the change over point where glare from the sources is just no longer noticeable; the sources themselves are still noticeable, but they merge into the general field of view in such a way that they no longer form any source of attraction.

The observer was then asked to make a setting of the physical factor under his/her control - the general brightness in the room to reproduce a particular degree of glare. This was termed the 'multiple criterion' technique. Some observers were rejected as the experiment proceeded because of their inability to make consistent appraisals of glare under constant conditions in a "control experiment" (Hopkinson et al, 1950).

Luckiesh and Guth (1949) decided to confine the criterion to a single sensation which could be defined by the experimenter and which could be interpreted by the subjects as a relatively definite sensation. Furthermore, it was desirable to establish a criterion which was meaningful from a practical viewpoint. It was decided that the sensation at the borderline between comfort and discomfort (BCD) would fulfill these primary requisites. They termed this the BCD sensation.

In 1979, Einhorn proposed an international CGI formula for discomfort glare that would bridge discrepancies in results from past research. The formula took account of the increase in glare experienced when glare sources are added in a room in spite of the corresponding increased adaptation levels, i.e. co-variance.

$$CGI = 8 \log 2 [((1 + E_d / 500) / (E_i + E_d)) \sum (L^2 \omega / p^2)]$$

where: CGI = CIE glare index

- L = Luminance of a glare source in the direction of the observer's eye in cd / m^2
 p = Guth position index, developed by Luckiesh and Guth, 1949 (see Appendix 3)
 E_d = direct vertical illuminance at the eye due to all sources in lux
 E_i = indirect vertical illuminance at the eye due to inter-reflected light in lux = πL_b
 L_b = the background/field luminance in cd / m^2
 $E_d + E_i$ = vertical illuminance at the eye in lux.
 ω = the solid angle of the luminous parts of each luminaire at the observer's eye (st.r)
 Σ = summation term for more than one source

E_d was included in the adaptation function ($E_d + E_i$) in the denominator to avoid an anomaly in very dark rooms: 'glare does not become infinite in a candle-lit cave, where E_i approaches zero'.
 (Einhorn, 1979)

The CIE committee (TC 3.13, 1991) were of the opinion that further research was needed surrounding the proposed CGI formula and that E_d could be omitted. This would simplify the calculations without significant loss of accuracy. The CIE Unified Glare Rating (UGR) formula was then accepted in 1995.

$$\text{UGR} = 8 \log_{10} [(0.785 / E_i) \Sigma L^2 \omega / p^2]$$

'Discomfort glare from small sources is determined by intensity rather than luminance and so the UGR system should not be used for sources smaller than 0.003 steradians' (CIE TC 3.13, 1991). This has been overcome until now by agreeing on a minimum size for calculating source luminance e.g. $\omega = 10^{-3}$ which means a glare luminance definition for very small sources of:

$$L = 1000 I / R^2$$

instead of $L = I / (\omega R^2)$ where R is the distance of the source from the eye.

'Whether the transition from a normal to a small source should be expressed as a minimum *area* rather than a minimum *solid angle*, $\omega = 10^{-3}$, is not yet known. **The precise transition point or region warrants further research.** The principle ought to be accepted meanwhile'.

(Lighting Research & Technology, Vol.11, No.2, 1979).

APPENDIX 2

[The acceptance / rejection process]

A2. THE ACCEPTANCE / REJECTION PROCESS

All those people tested had to be categorized as either acceptable or unacceptable glare observers. The sorting out process was based entirely on observations made on the normal source since it is known what to expect for the normal source from past research and expressed by the UGR formula.

Comparisons were made between *experimental* normal source settings and *expected* normal source settings independent of sensitivity. Any observer whose settings of E_d versus E_i did not comply with **all** the selection criteria listed below were rejected, else they were accepted.

A2.1 Selection Criteria

A2.1.1 Relationship of E_d versus E_i at any one distance

At any distance from the source a setting consists of adjusting the E_d at a particular E_i for a glare sensation of 'just uncomfortable' and repeating the process at different E_i fixings. Now referring to the UGR derivation (see section 3.2) it can be seen that for $g = \text{constant}$ and $R = \text{constant}$, any E_i variation should be countered by an E_d variation whereby the square of the E_d variation is equivalent to the E_i variation.

Pairs of E_d versus E_i settings at a particular distance, when plotted on log-log paper and joined up, should yield a straight line of slope, $m=2$ (see Figure B). Experimentally, however, straight line graphs of slope, $m=2$ rarely appear. Making consistent glare assessments is not easy and slight deviations must be tolerated. A tolerance in the average slope was introduced in deciding on whether to accept or reject:

Past researchers have implicitly predicted values of $m=3.5$ and so a cut off $m \leq 5$ was chosen as the upper limit. Values of $m \leq 1$ could not be tolerated because this would suggest that E_i has as much or more effect on glare than E_d which has never been found in any research. Figure B graphically depicts the bounds of acceptance and rejection and gives a mathematical definition of the slope.

$$m = \log (E_{i \max} / E_{i \min}) / \log (E_{d \max} / E_{d \min})$$

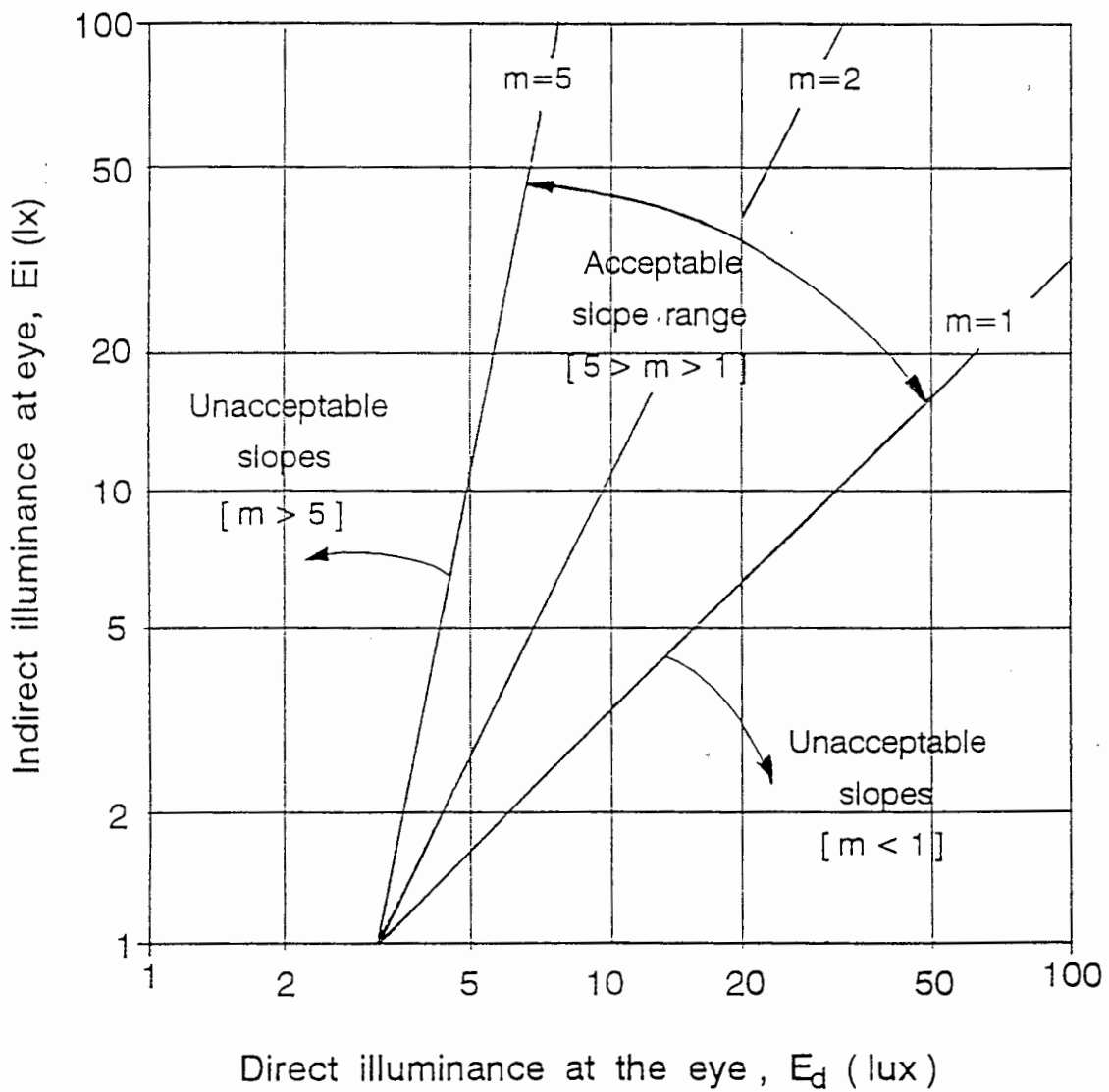


Figure B. Illustration of the acceptable and unacceptable slopes of E_d versus E_i

A2.1.2 Variation of E_d^2 / E_i with distance

As proved in section 3.2.1 the ratio of E_d^2 / E_i at 1.37m to E_d^2 / E_i at 3.94m should be theoretically 8.29 which corresponds to an E_d ratio of 2.88 for the same E_i at each distance. An upper and lower limit had to be chosen as the cut off ratios for acceptance or rejection (refer to Figure C). The following limits were chosen:

$$E_{d\ 1:4} \text{ (upper limit)} = 2.88 \times (2.88)^{1/2} = 4.89$$

$$E_{d\ 1:4} \text{ (lower limit)} = 2.88 / (2.88)^{1/2} = 1.70$$

The factor $(2.88)^{1/2}$ was chosen for use on the $E_{d\ 1:4}$ ratios because it is approximately equivalent to the $E_{d\ 1:2}$ and $E_{d\ 2:4}$ ratios. If a factor greater than this was chosen as the lower limit then one could have the scenario of the middle distance ($R = 2.29\text{m}$) setting sitting *outside* the range of the 1.37m and 3.94m settings and still being accepted.

Similarly,

$$E_{d\ 1:2} \text{ (upper limit)} = 1.67 \times (1.67)^{1/2} = 2.16$$

$$E_{d\ 1:2} \text{ (lower limit)} = 1.67 / (1.67)^{1/2} = 1.29$$

And,

$$E_{d\ 2:4} \text{ (upper limit)} = 1.72 \times (1.72)^{1/2} = 2.26$$

$$E_{d\ 2:4} \text{ (lower limit)} = 1.72 / (1.72)^{1/2} = 1.31$$

Observers with ratios outside these limits were rejected.

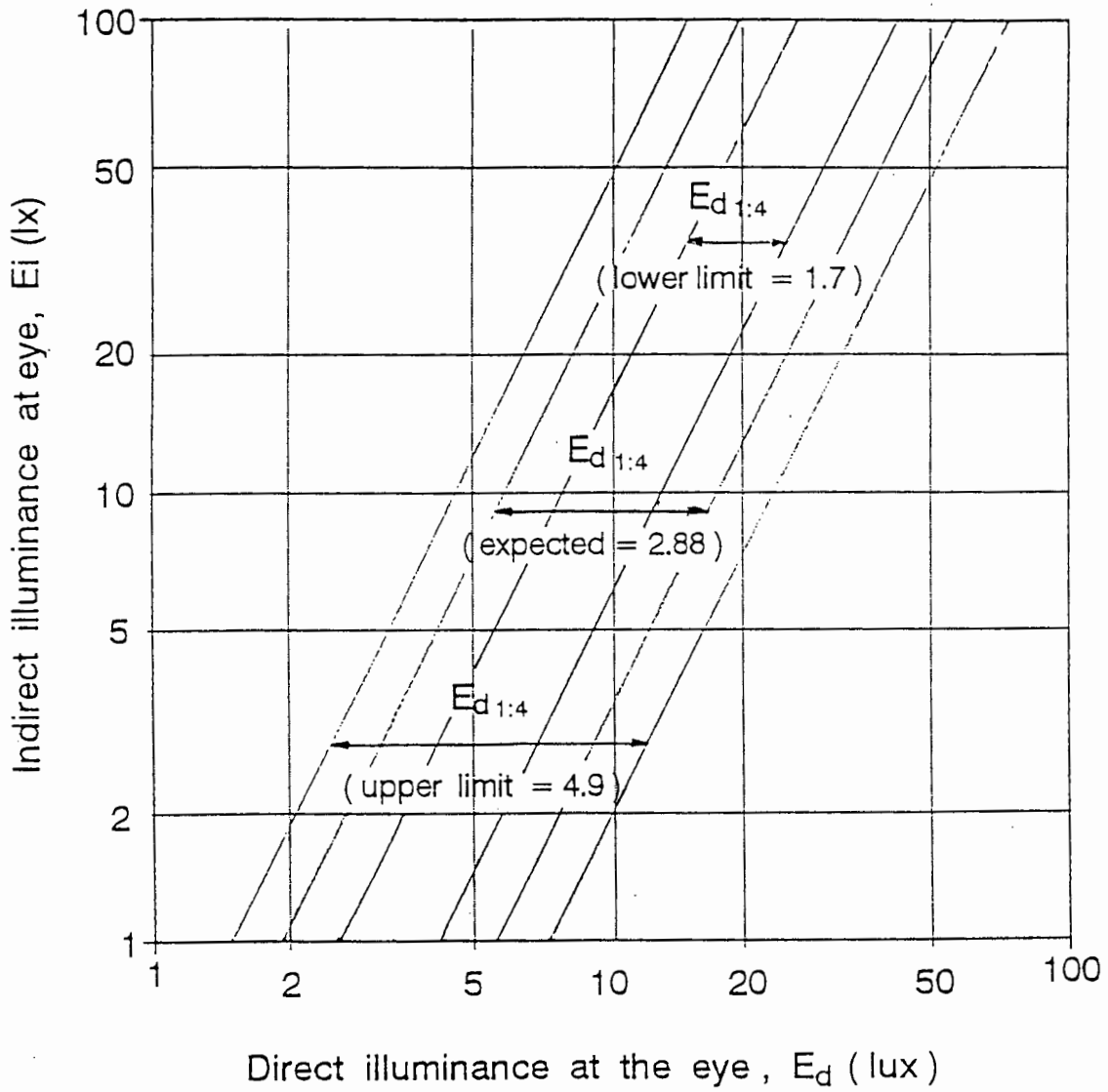


Figure C. Acceptable and unacceptable ratios of E_d^2 / E_i between distances of 1.37m, 2.29m and 3.94m from the source.

A2.1.3 Comparison of E_d^2 / E_i between the normal and small source at common distances

How the effective area of the small source varies with distance is not known and is a main objective of the research. What one can assume though is that the effective area of the small source does not exceed that of the normal source when viewed at the same distance (or at any distance for that matter). i.e. the average E_d^2 / E_i value for the small source should not exceed that of the normal source when viewed at the same distance.

Proof: glare from normal source = glare from small source

$$g_n = (E_d^2 / E_i)_n R^2 / A_n = g_s = (E_d^2 / E_i)_s R^2 / A_s$$
$$\therefore (E_d^2 / E_i)_n > (E_d^2 / E_i)_s \quad \text{since } A_n > A_s$$

Observers were only rejected if their *average* small source E_d^2 / E_i setting at a particular distance was greater than their *average* normal source E_d^2 / E_i setting at the same distance. In the ‘normalized’ $m=2$ plots of E_d vs E_i (see Figure D), a line to the right of another corresponds to a higher average E_d^2 / E_i value.

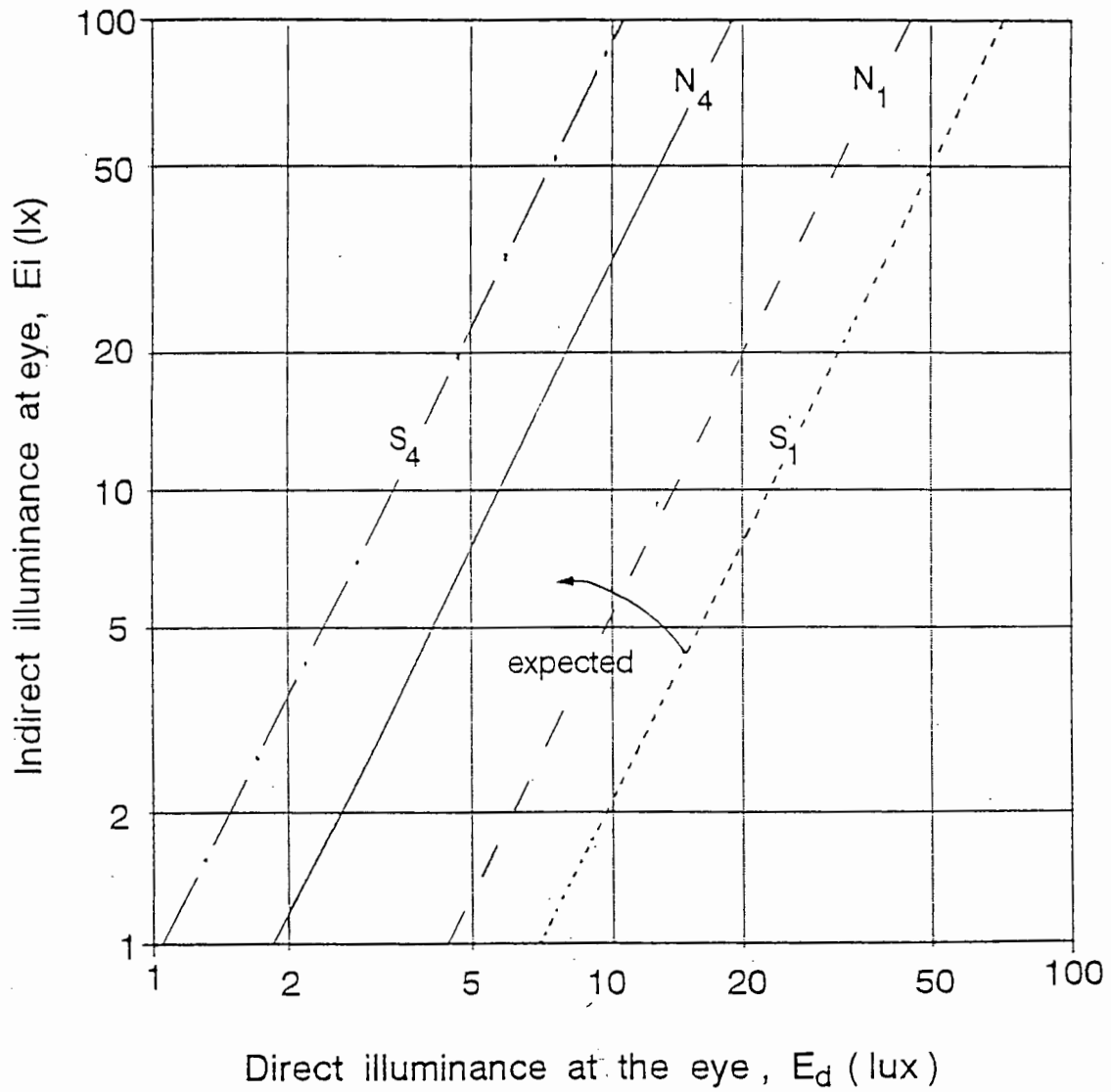


Figure D. Acceptable and unacceptable relative positioning of averaged E_d versus E_i settings at any distance, between the normal and small source.

A2.2 Examples of 'just accepted' and 'just rejected' observations

Below are 3 examples of 'just accepted' and 'just rejected' observations. The corresponding readings, the E_d^2 / E_i averages and the E_d vs E_i plots are given at the end of each section.

A2.2.1 'just accepted' observations

1. Karl Prince, 28/06/95

His spacing of averaged E_d settings for common E_i levels between distances for the normal source were relatively large but still within the accepted upper limits outlined in section 5.1.2.

$$\begin{aligned} \text{i.e. } E_{d\ 1:2} &= 1.94 < 2.16 = E_{d\ 1:2} \text{ (upper limit)} \\ E_{d\ 2:4} &= 2.20 < 2.26 = E_{d\ 2:4} \text{ (upper limit)} \\ E_{d\ 1:4} &= 4.27 < 4.89 = E_{d\ 1:4} \text{ (upper limit)} \end{aligned}$$

2. Chris Wes Garth Taylor, 19/07/95

His slopes of E_d vs E_i for the normal source were relatively high but still below the accepted upper limit outlined in section A2.1.1.

$$\begin{aligned} \text{i.e. His slope of } E_d \text{ vs } E_i \text{ at } 1.37\text{m} &= 4.55 < 5 = \text{upper limit} \\ \text{His slope of } E_d \text{ vs } E_i \text{ at } 3.94\text{m} &= 4.78 < 5 = \text{upper limit} \end{aligned}$$

3. Roy Michael, 2/08/95

His slopes of E_d vs E_i for the normal source were relatively low but still above the accepted lower limit outlined in section A2.1.1.

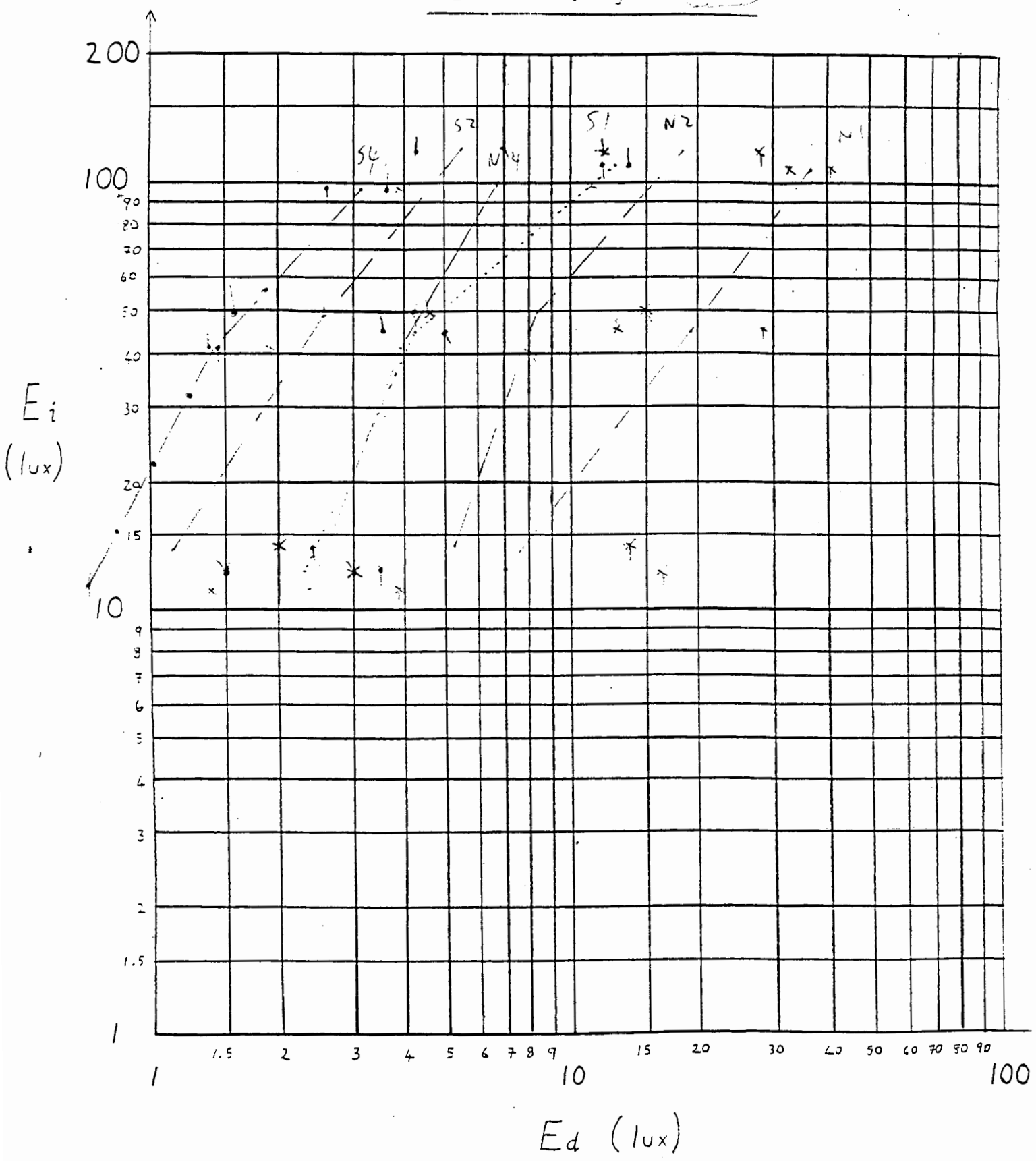
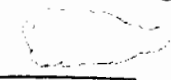
$$\begin{aligned} \text{i.e. His slope of } E_d \text{ vs } E_i \text{ at } 1.37\text{m} &= 1.21 > 1 = \text{lower limit} \\ \text{His slope of } E_d \text{ vs } E_i \text{ at } 3.94\text{m} &= 1.04 > 1 = \text{lower limit} \end{aligned}$$

NAME — Kart Prince

DATE — 28/06/95

'just uncomfortable'

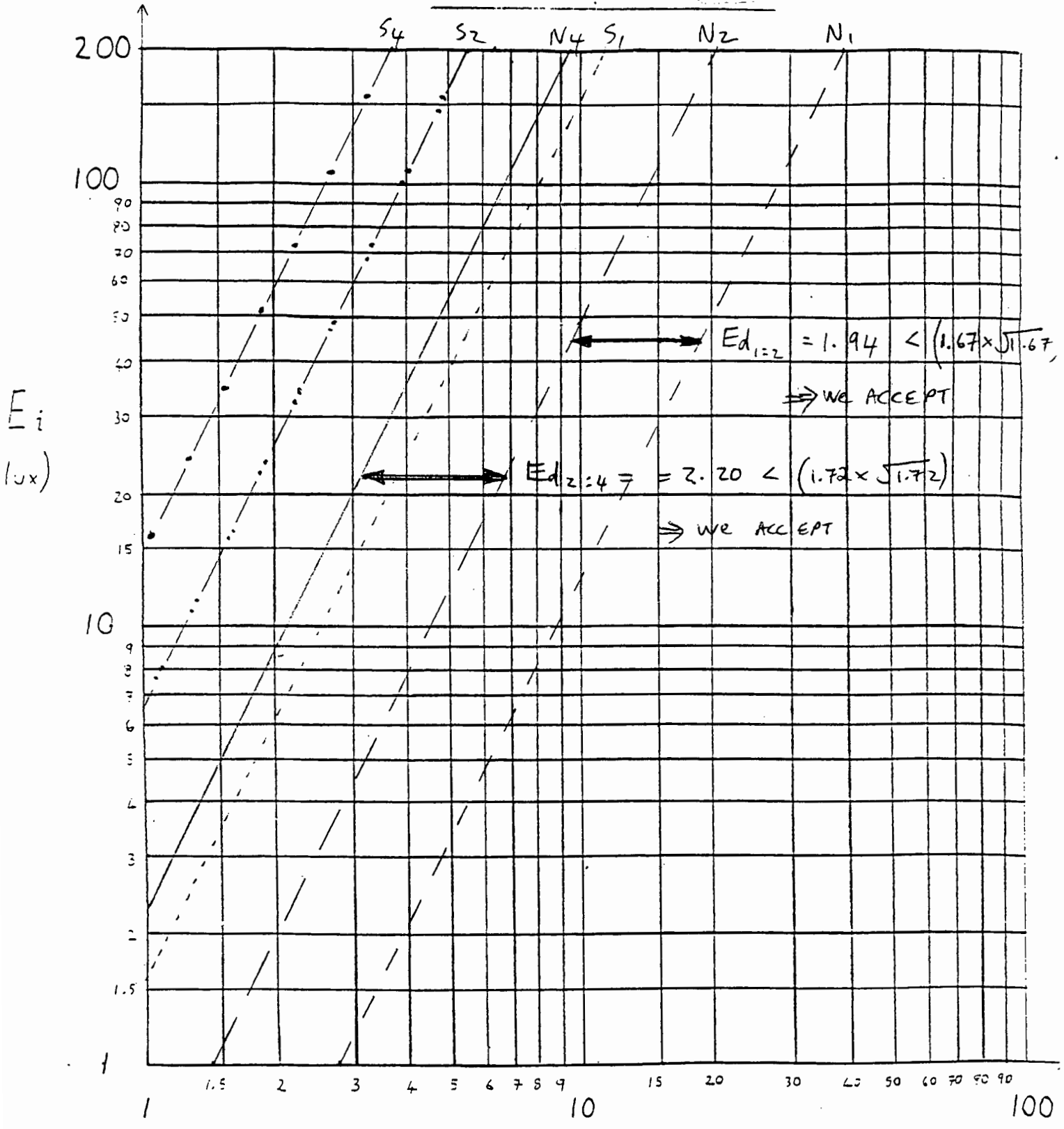
E_d vs E_i for



<u>Small</u>		<u>Normal</u>	
.....	1.37m	-----	1.37m
— . . —	2.3 m	—— —	2.3 m
—— . ——	3.94 m	————	3.94 m

DATE 28/06/95 North Prince

E_d vs E_i for just uncomfortable



<u>Small</u>		<u>Normal</u>	
.....	1.37m	-----	>1-37m
— .. —	2.3 m	—— —	2.3 m
— . —	3.94 m	————	3.94 m

Name: Chris Wes Garth Taylor Date: 19/07/95 Time: 11 a.m

Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i	Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E
N ₁	D ↗	80	1,2	150	32	853	S ₁	D ↗	80	1,2	140	10	83,3
	↗	110	6	170	51	655		↗	110	6	210	52	451
	↓	110	6	206	100	1667		↓	110	6	250	100	1667
	↘	80	1,2	204	96,7	7792		↘	80	1,2	210	52	2253
	Geometric Average 1641							Geometric Average 613					

N ₄	D ↗	80	1	155	5	64	S ₄	D ↗	80	1	160	2,5	6,25
	↗	110	5,5	210	15,5	43,7		↗	110	5,5	260	15	40,9
	↓	110	5,5	255	30	164		↓	110	5,5	265 ⁺	18 ⁺	60 ⁺
	↘	80	1	250	28,5	812		↘	80	1	260	15	225
	Geometric Average 138.9							Geometric Average 43.1					

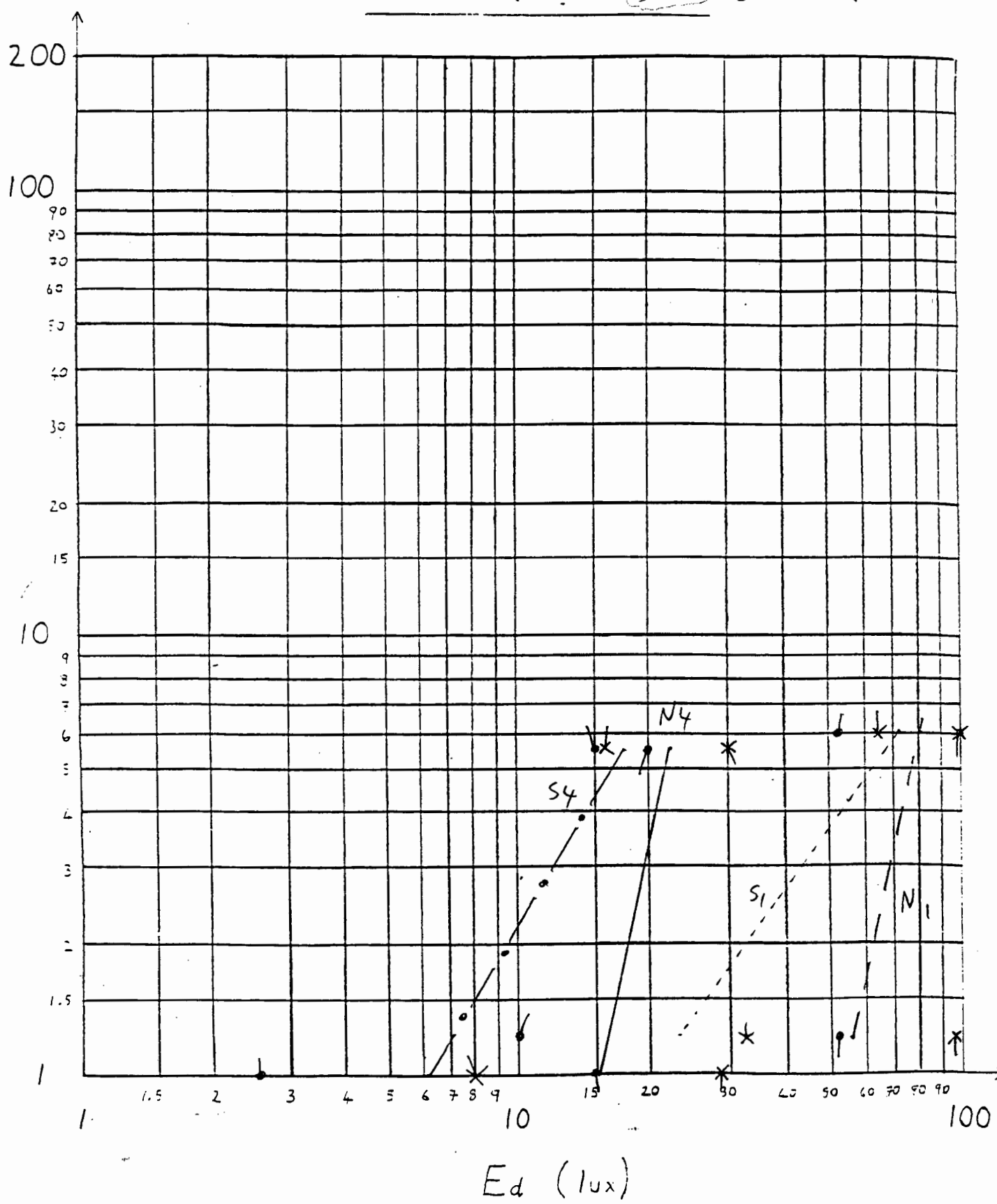
slope of E _d vs E _i		<p>for N₁ = 4.55 < 5 ⇒ ACCEPTABLE (we must accept)</p>											
slope of E _d vs E _i		<p>for N₄ = 4.78 < 5 ⇒ ACCEPTABLE (we must accept)</p>											

NAME - CHRIS WES GARTH TAYLOR

DATE - 19/07/95

E_d vs E_i for [circled] 'just uncomfortable'

E_i
(lux)



Small

Normal

.....

1.37m

[circled] 1.37m

- . -

2.3m

2.3m

— . —

3.94m

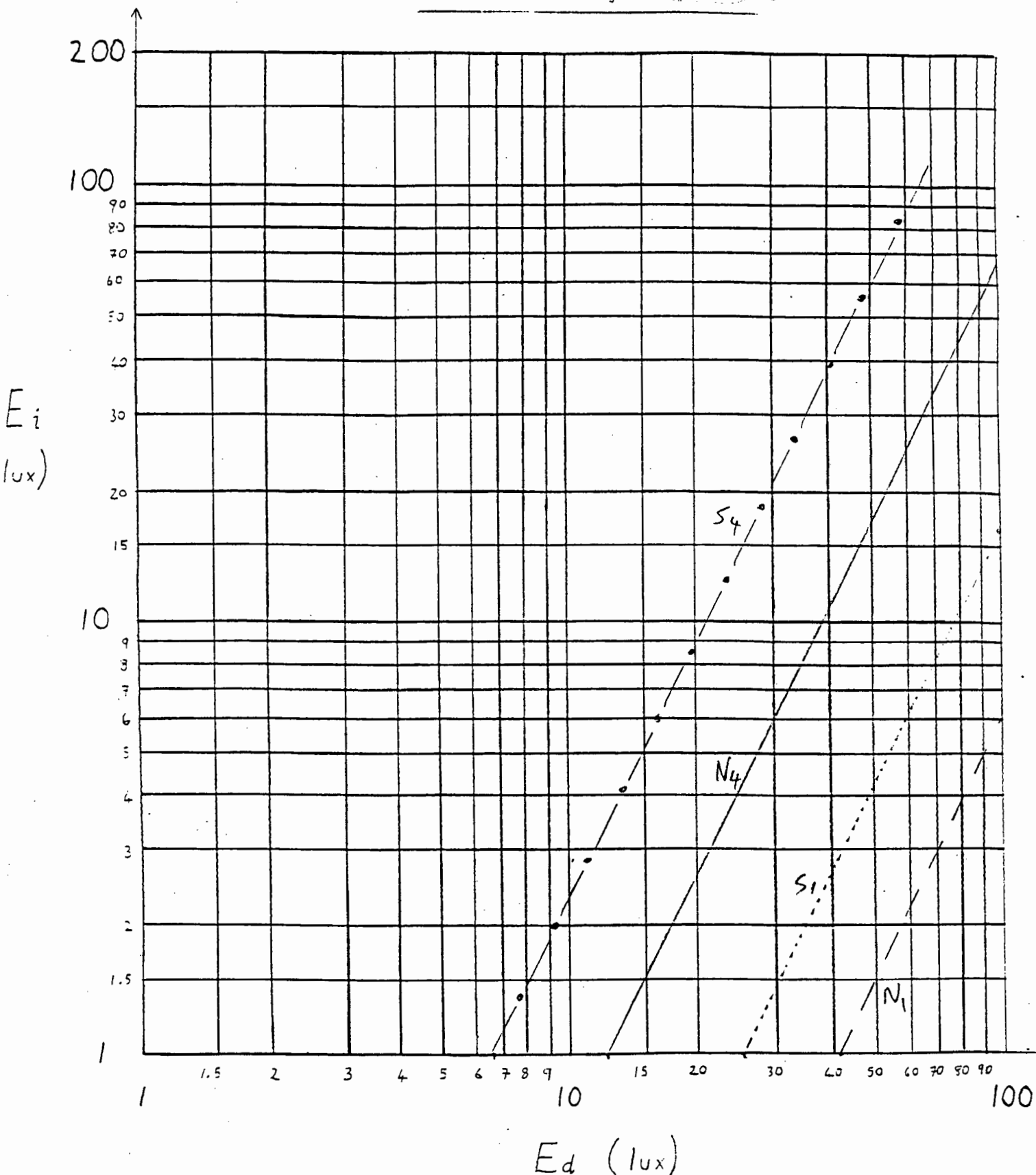
— . —

3.94m

E_d (lux)

NAME — Chris Wes Gauth Taylor
 DATE — 19/07/95

E_d vs E_i for 'just uncomfortable'



	<u>Small</u>		<u>Normal</u>
.....	1.37m	-----	 1.37m
— . . —	2.3 m	—— —	2.3 m
— . —	3.94 m	————	3.94 m

Name: Roy Michael

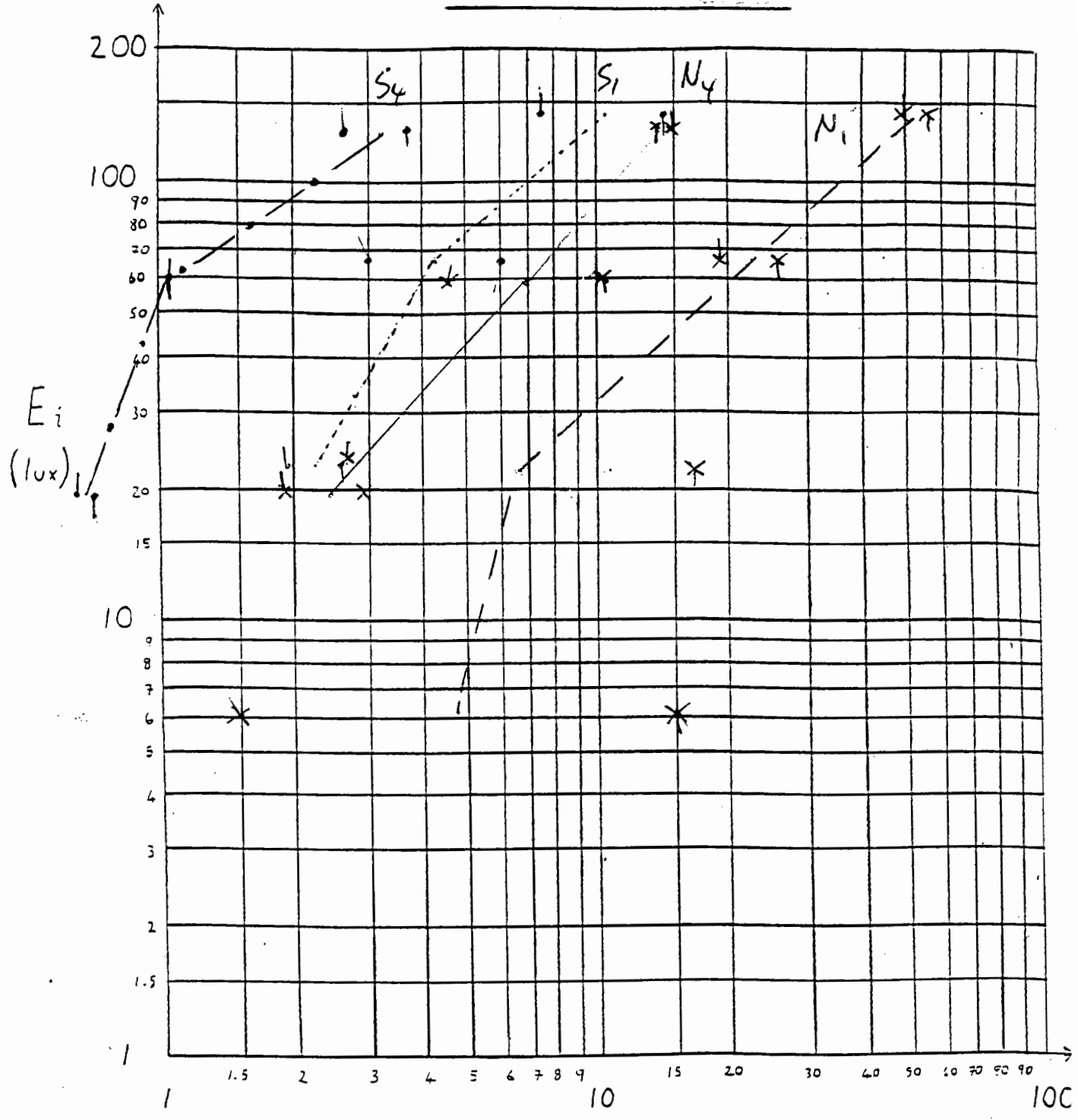
Date: 2/08/95

Time: 4 pm

Source	Buf/dir	V_b	E_i	V_s	E_d	E_d^2/E_i	Source	Buf/Dir	V_b	E_i	V_s	E_d	E_d^2/E
N_1	D ↗	110	6	70	1,5		S_1	D ↗	150	22	89	1.9	
	↗	150	22	85	3			↗	200	66	102	3	
	↗	200	66	145	33			↗	250	138	125	7.5	
	↗	250	138	170	61			↘	250	138	145	14	
	↘	250	138	185	84			↘	200	66	118	6	
	↘	200	66	155	44			↘	150	22	94	2,15	
	↘	150	22	135	25								
	↘	110	6	122	15								
N_4	D ↗	150	19,5	100	1,9		S_4	D ↗	150	19,5	112	9,65	
	↗	200	59	145	4,4			↗	200	59	130	1.05	
	↗	250	127	200	14,8			↗	250	127	162	2.7	
	↘	250	127	195	13,5			↘	250	127	175	3.7	
	↘	200	59	180	14,2			↘	200	59	130	1.05	
	↘	150	19,5	130	2,9			↘	150	19,5	115	9,7	
Average slope ^{of} E_d vs E_i													
for $N_4 = 1.04 > 1 \Rightarrow$ we must ACCEPT													
Average slope ^{of} E_d vs E_i													
for $N_1 = 1.21 > 1 \Rightarrow$ we must ACCEPT													

DATE — 2/08/95

E_d vs E_i for just uncomfortable



		E_d (lux)	
	<u>Small</u>		<u>Normal</u>
.....	1.37m	-----	1.37m
- . . -	2.3m	-----	2.3m
-----	3.94m	-----	3.94m
b	Buffer Up	⊗	Buffer Up
q	Buffer Down	⊙	Buffer Down
•	Direct Up	x	Direct Up
◐	Direct Down	x	Direct Down

A2.2.2 'just rejected' observations

1. Moira van der Linde, 26/10/95

Her average value of E_d^2 / E_i at 1.37m for the small source was greater than her corresponding normal source value.

$$\text{i.e. } (E_d^2 / E_i)_{s1} = 115.2 > 47.1 = (E_d^2 / E_i)_{n1}$$

2. Rob MacLachen, 28/10/95

Her spacing of averaged E_d settings for common E_i levels between distances of 1.37m and 2.29m from the normal source, was slightly greater than the acceptable upper limit outlined in section 5.1.2.

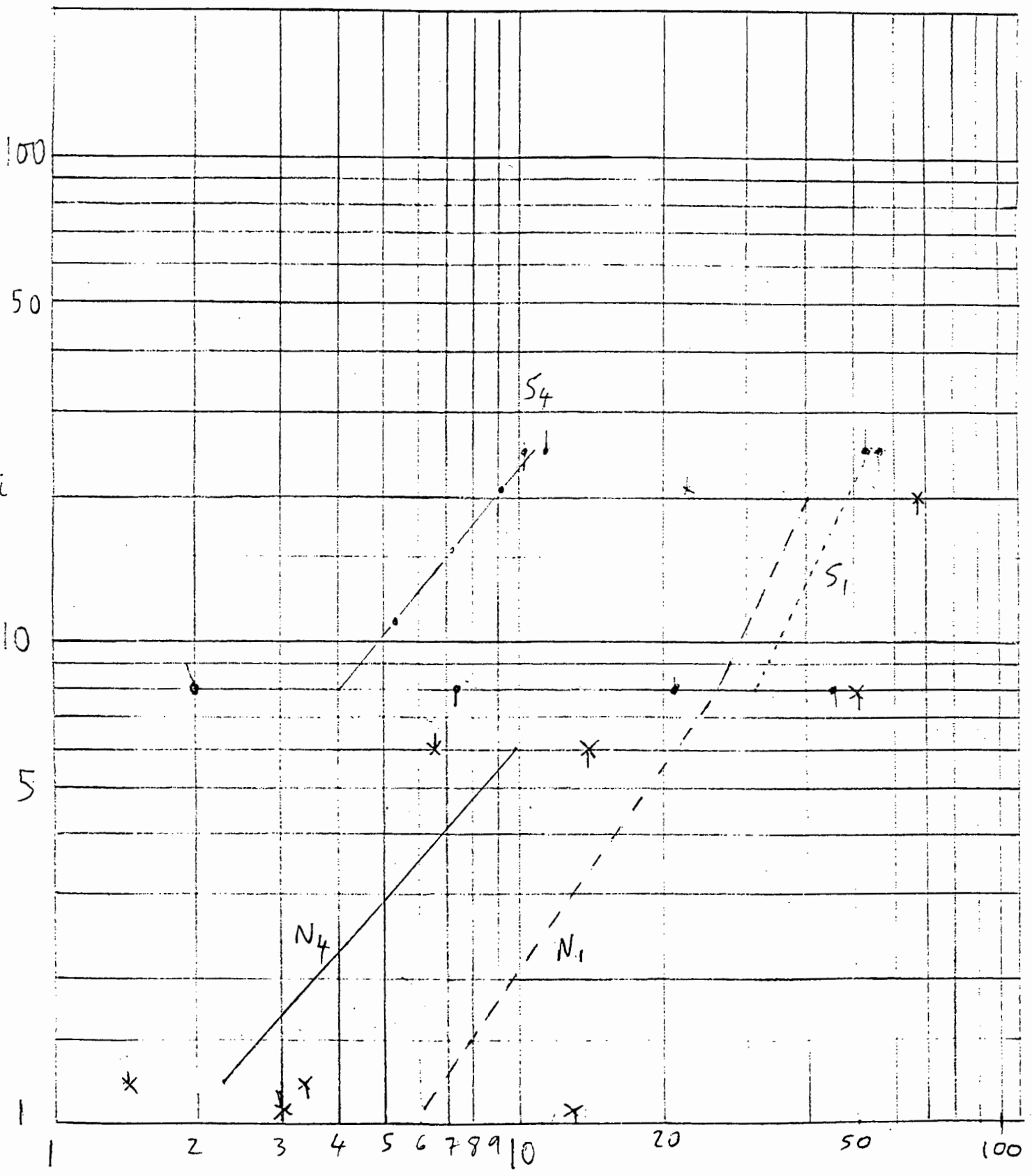
$$\text{i.e. } E_{d\ 1:2} = 2.24 > 2.16 = E_{d\ 1:2} \text{ (upper limit)}$$

3. Jono Bordillon, 30/03/95

His spacing of averaged E_d settings for common E_i levels between distances of 2.29m and 3.94m from the normal source, was slightly smaller than acceptable lower limit outlined in section 5.1.2.

$$\text{i.e. } E_{d\ 2:4} = 1.28 < 1.31 = E_{d\ 2:4} \text{ (lower limit)}$$

M. V. d. Linde 26/10/95



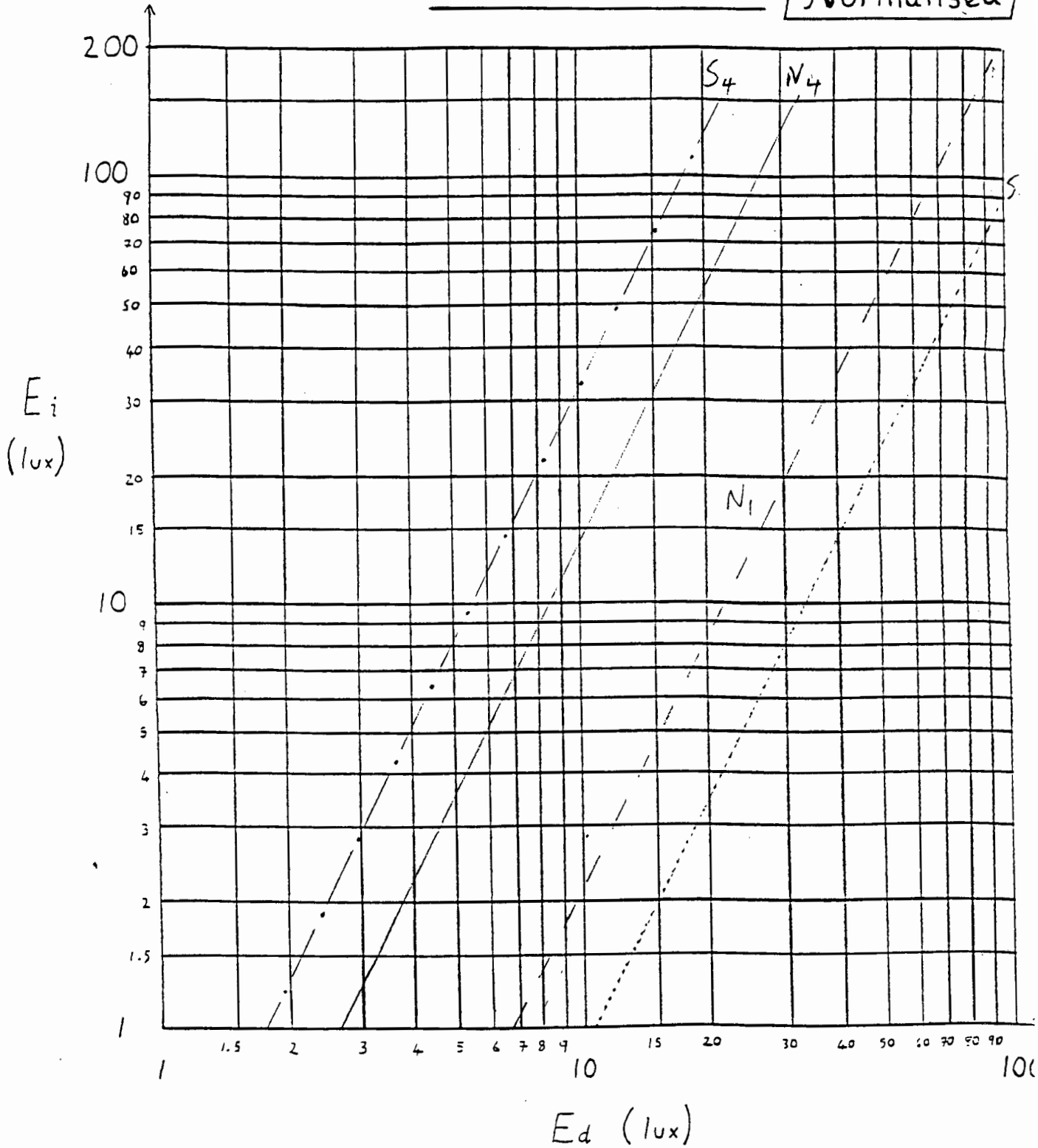
E_d

DATE —

26/10/95

E_d vs E_i for BCD

Normalised



<u>Small</u>		<u>Normal</u>	
.....	1.3 m	— — —	1.3 m
— . . —	2.3 m	— — —	2.3 m
— . —	4 m	— — —	4 m
⊂	Buffer Up	⊗	Buffer Up
⊃	Buffer Down	⊘	Buffer Down
↙	Direct Up	×	Direct Up
↘	Direct Down	×	Direct Down

Name: R. MacLachen Date: 28/10/95 Time: 10.00.

Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i	Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i
S ₁	D ↗	100	8	180	30	113	N ₂	D ↗	70	13	192	10	76.
	↗	130	25	275	67	180		↗	90	5	195	12	28.8
	↘	130	25	205	49	92.2		↘	110	14	250	30.4	66.0
	↘	100	8	202	45	253		↘	110	14	265 ⁺	50	179.
	↘	70	1.2	180 (200)	30	750		↘	90	5	231	22.6	102
	↗	70	1.2	175	27	608		↘	70	1.3	215	17.3	230
Geometric Average													92.1
S ₂	D ↗	90	5	172	10	20	N ₁	D ↗	70	12	195	30	750
	↗	115	17	224	28	46.1		↗	100	8	230	56	392
	↘	145	17	235	33	64.1		↘	100	8	216	45	253
	↘	90	5	220	26	135		↘	70	1.2	190	27	008
Geometric Average													46.1
						$\frac{E_d^2(1)}{E_i} = \frac{461.15}{92.19} = 5.00$							
						$\therefore \frac{E_d^2(2)}{E_i}$							
						For same E _i , $\frac{E_d(1)}{E_d(2)} = \sqrt{5.0} = 2.24$							
						Acceptable $\frac{E_d(1)}{E_d(2)}$ range = $\frac{1.67}{\sqrt{1.67}} \Leftrightarrow 1.67 \times \sqrt{1.67}$							
						= 1.29 \Leftrightarrow 2.16							
						since 2.24 > 2.16							
						we must REJECT							

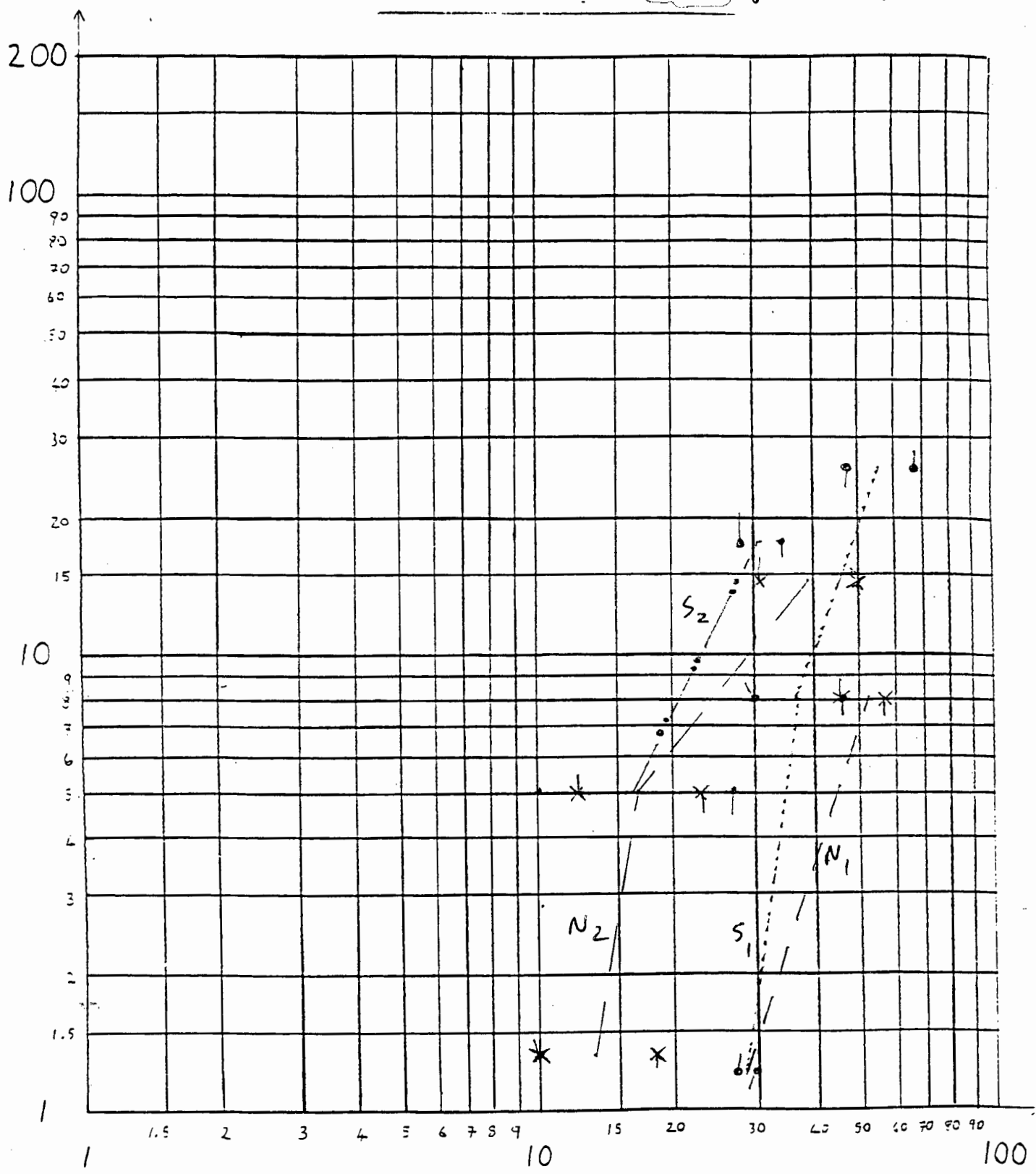
DATE —

R. MacLachlan


28/10/95

E_d vs E_i for  'just uncomfortable'

E_i
(lux)



E_d (lux)

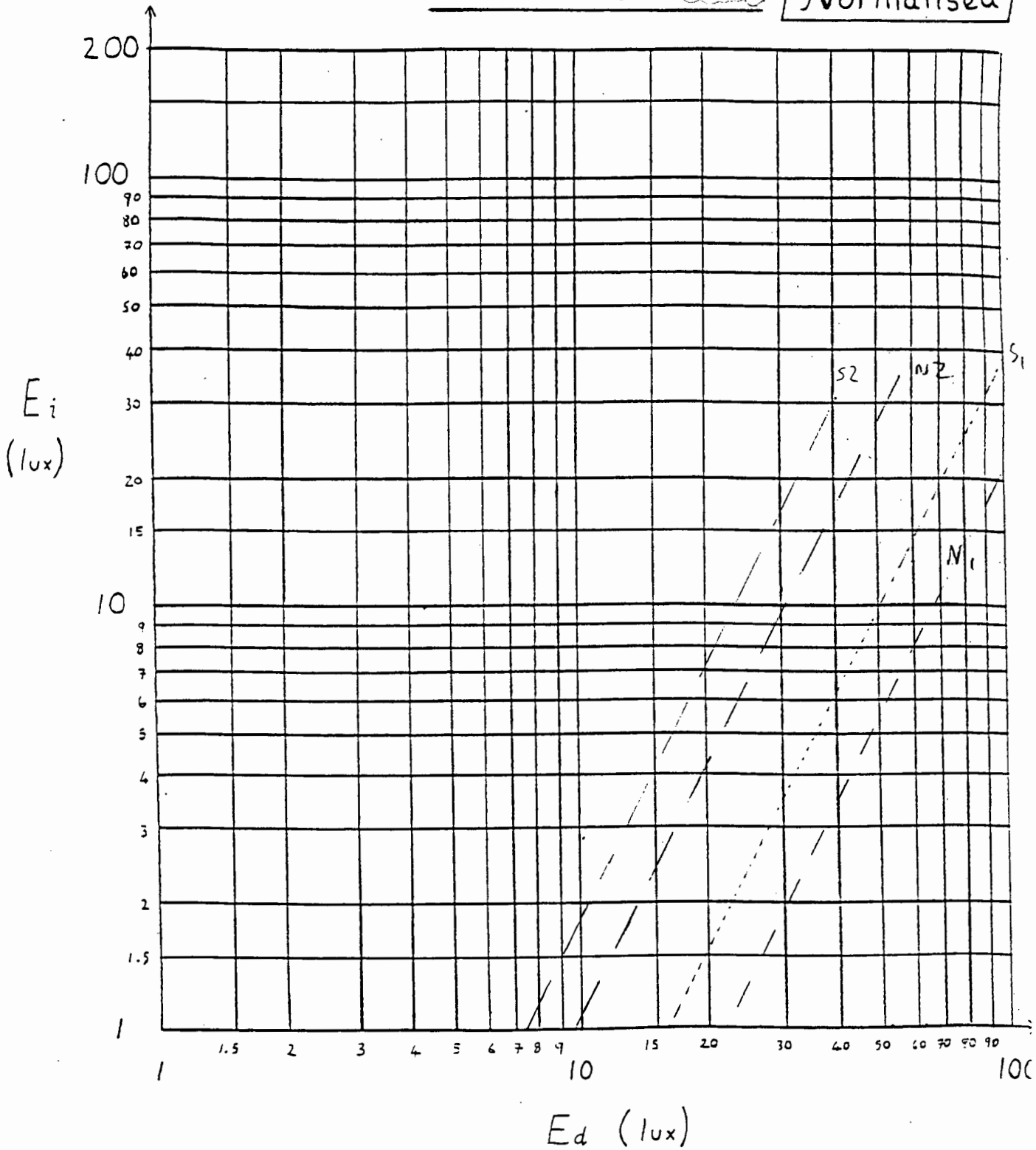
	<u>Small</u>		<u>Normal</u>
.....	1.37m	- - - -	 1.37m
— .. —	2.3 m	— — —	2.3 m
— . —	3.94 m	— — —	3.94 m

DATE

22/10/95

E_d vs E_i for

Normalised

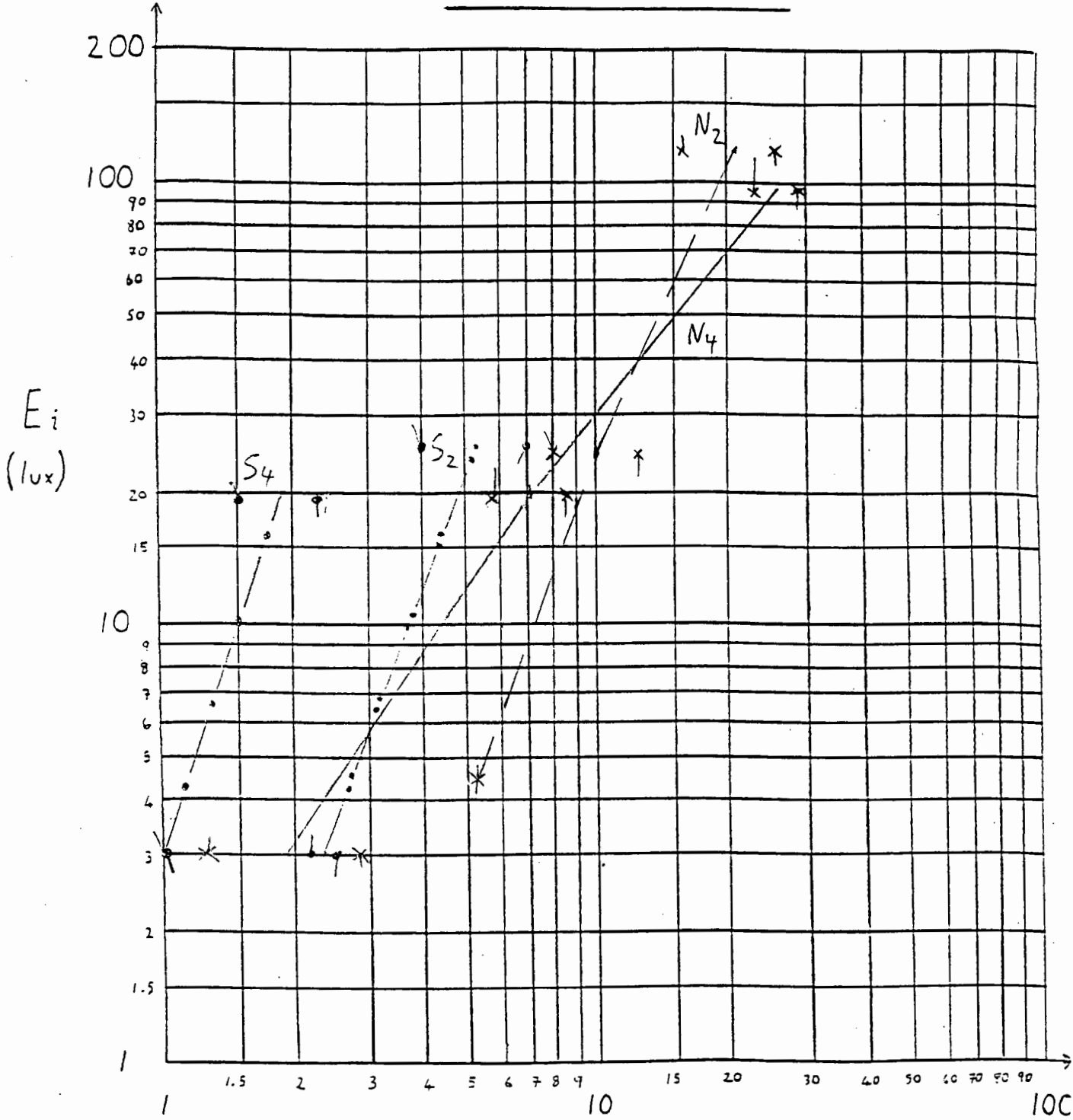


<u>Small</u>		<u>Normal</u>	
.....	1.37m	-----	1.37m 1.37m
— . . —	2.3 m	—— —	2.3 m
—— . ——	3.94 m	————	3.94 m
o	Buffer Up	⊗	Buffer Up
q	Buffer Down	⊙	Buffer Down
•	Direct Up	x	Direct Up
◐	Direct Down	x	Direct Down

DATE —

30/03/95

E_d vs E_i for BCD



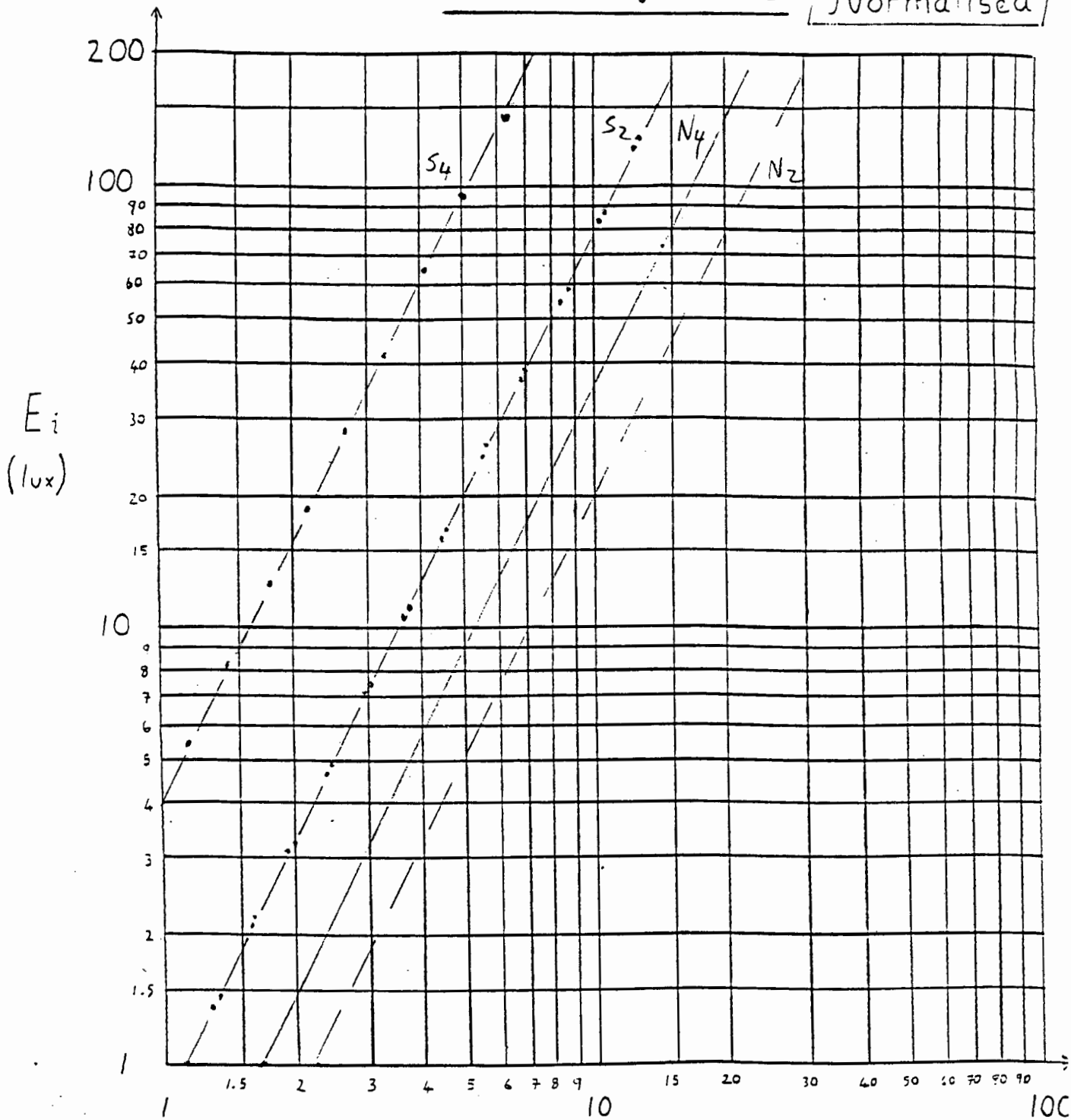
E_d (lux)

	<u>Small</u>		<u>Normal</u>
.....	1.3 m	— — —	1.3 m
— . . —	2.3 m	— — —	2.3 m
— . —	4 m	— — —	4 m
o	Buffer Up	⊗	Buffer Up
⊙	Buffer Down	⊗	Buffer Down
•	Direct Up	x	Direct Up
●	Direct Down	x	Direct Down

DATE — 30/03/95

E_d vs E_i for BCD

Normalised



E_d (lux)

<u>Small</u>		<u>Normal</u>	
.....	1.3 m	— — —	1.3 m
— .. —	2.3 m	— — —	2.3 m
— . —	4 m	— — —	4 m
⊙	Buffer Up	⊗	Buffer Up
⊙	Buffer Down	⊗	Buffer Down
⊙	Direct Up	x	Direct Up
⊙	Direct Down	x	Direct Down

A2.3 Potentially biased observers

The author's and the author's supervisor's results were not included in the final results on the grounds that they might be biased. Those readings of theirs which were found to fit the 'acceptance criteria' can be found at the end of this section for interest. Their corresponding E_d vs E_i plots and calculated averaged E_d^2 / E_i values for each source and distance are also given. Note that some of these readings were taken in the 'initial' set-up (see section 2.6.1) where buffer tests were also carried out. Their average sensitivity and assessment of A_s is given in Table 7 below.

	Einhorn	Paul
No. of A_s assessments	7	10
Average A_s	117	39
Standard deviation limits for A_s	77 ↔ 179	22 ↔ 71
95 % confidence limits for A_s	78 ↔ 173	26 ↔ 60
Average sensitivity (G.I.)	26.7	24.1
Standard deviation sensitivity limits	23.0 ↔ 30.9	23.2 ↔ 25.1

All A_s values are in $m^2 \times 10^{-4}$ (= cm^2) rounded off to nearest cm^2

Table 7. The average glare assessment of A_s as seen by the experimenter and supervisor of the research

The Author's Results

Name: B. PAUL

Date: 13/02/95

Time: 9:00

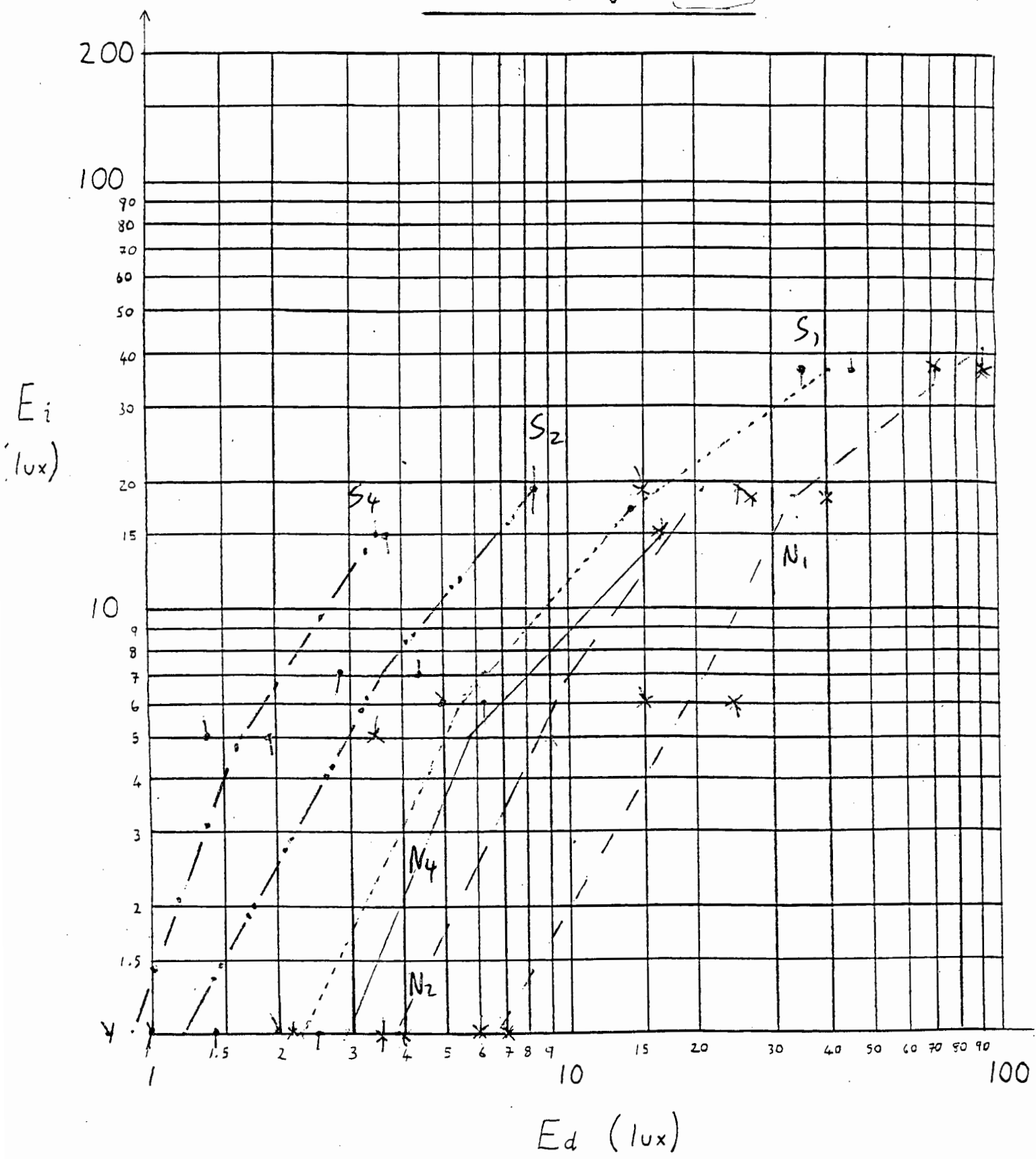
Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i	Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i
N ₄	D ↗	80	1	125	2,1	4,41	N ₂	D ↗	80	1	112	3,5	12.2
	↗	110	5	140	3,3	2,18		↗	110	7	144	10	14.2
	↗	140	15	215	17	19.3		↗	140	19	160	15	11.8
	↘	140	15	215	17	17.3		↘	140	19	180	24	30.3
	↘	110	5	180	9	16.2		↘	110	7	145	10	14.29
	↘	80	1	145	3.8	14,84		↘	80	1	117	4	16
	Geometric Average = 9.71							Geometric Average = 15.58					

Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i	Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i
N ₁	D ↗	80	1	105	7	49	S ₂	D ↗	80	1	104	1	1
	↗	110	6	125	15	37.5		↗	110	7	140	4,3	2,64
	↗	140	17	155	36	108		↗	140	19	165	8,6	3,89
	↗	170	36	200	92	235		↘	140	19	170	9,6	3,33
	↘	170	36	185	71	140		↘	110	7	125	2,8	1,12
	↘	140	17	130	18	38.1		↘	80	1	110	1,4	1.96
	↘	110	6	140	24	96		Geometric Average = 2.05					
	↘	80	1	100	6	36		Geometric Average = (73.6)					

Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i	Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i
S ₄	D ↗	80	1	119	0,8	0,84	S ₁	D ↗	80	1	100	2	4
	↗	110	5	125	3,2	0.4		↗	110	6	120	5	4.17
	↗	140	15	200	5,9	1.38		↗	140	17	145	12	12.7
	↘	140	15	170	3,2	0,83		↘	170	36	200	44	53.8
	↘	110	5	150	1,9	0,72		↘	170	36	190	36	36
	↘	80	1	130	1	1		↘	140	17	150	14	11.5
	Geometric Average = 0,77							Geometric Average = 7.08					
						Geometric Average = (10,96)							

NAME — B. F. MULL
 DATE — 13/02/95

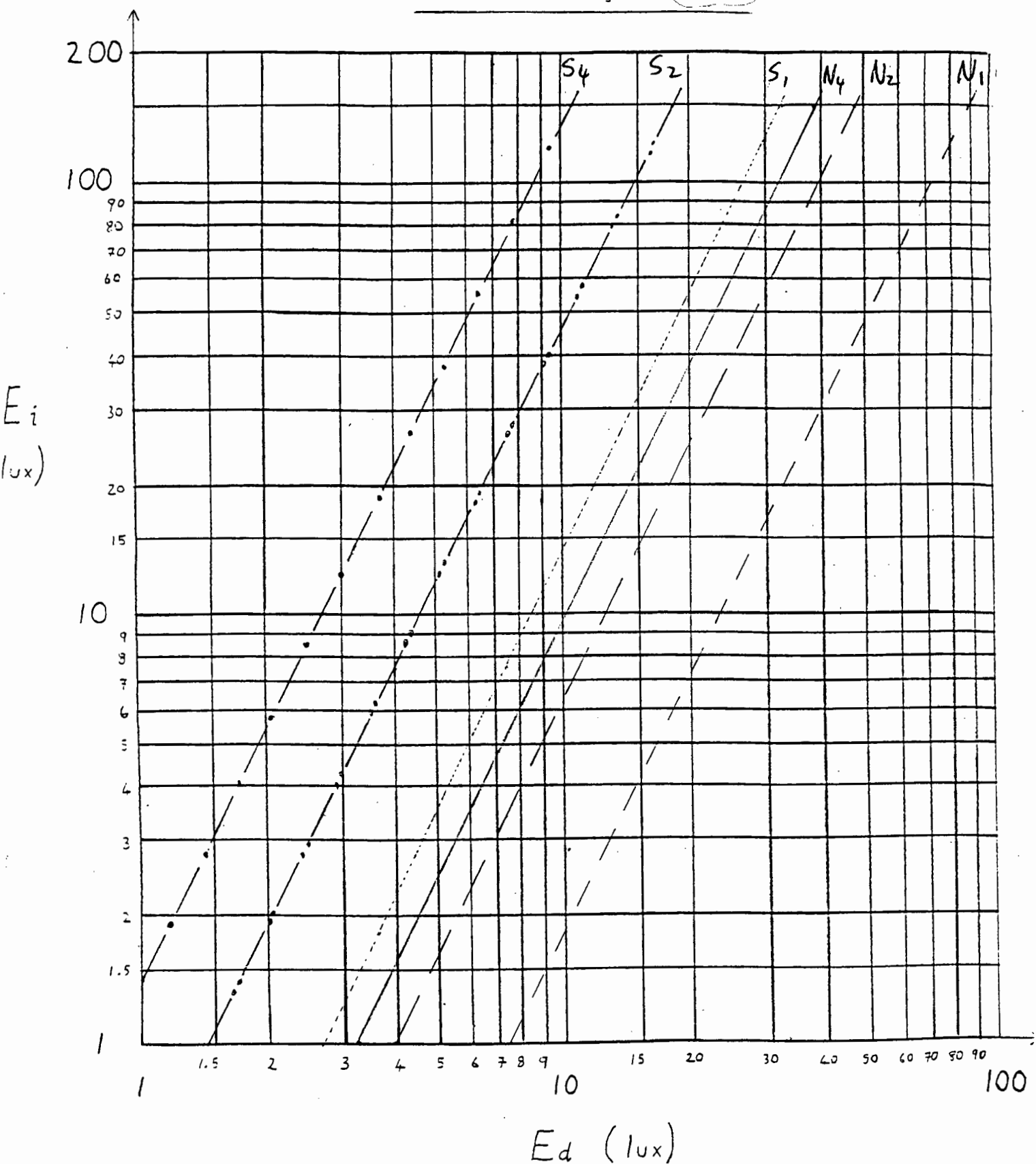
E_d vs E_i for [] 'just uncomfortable'



<u>Small</u>		<u>Normal</u>	
.....	1.37m	— — —	1.37m
— . . —	2.3 m	— — —	2.3 m
— . —	3.94 m	— — —	3.94 m

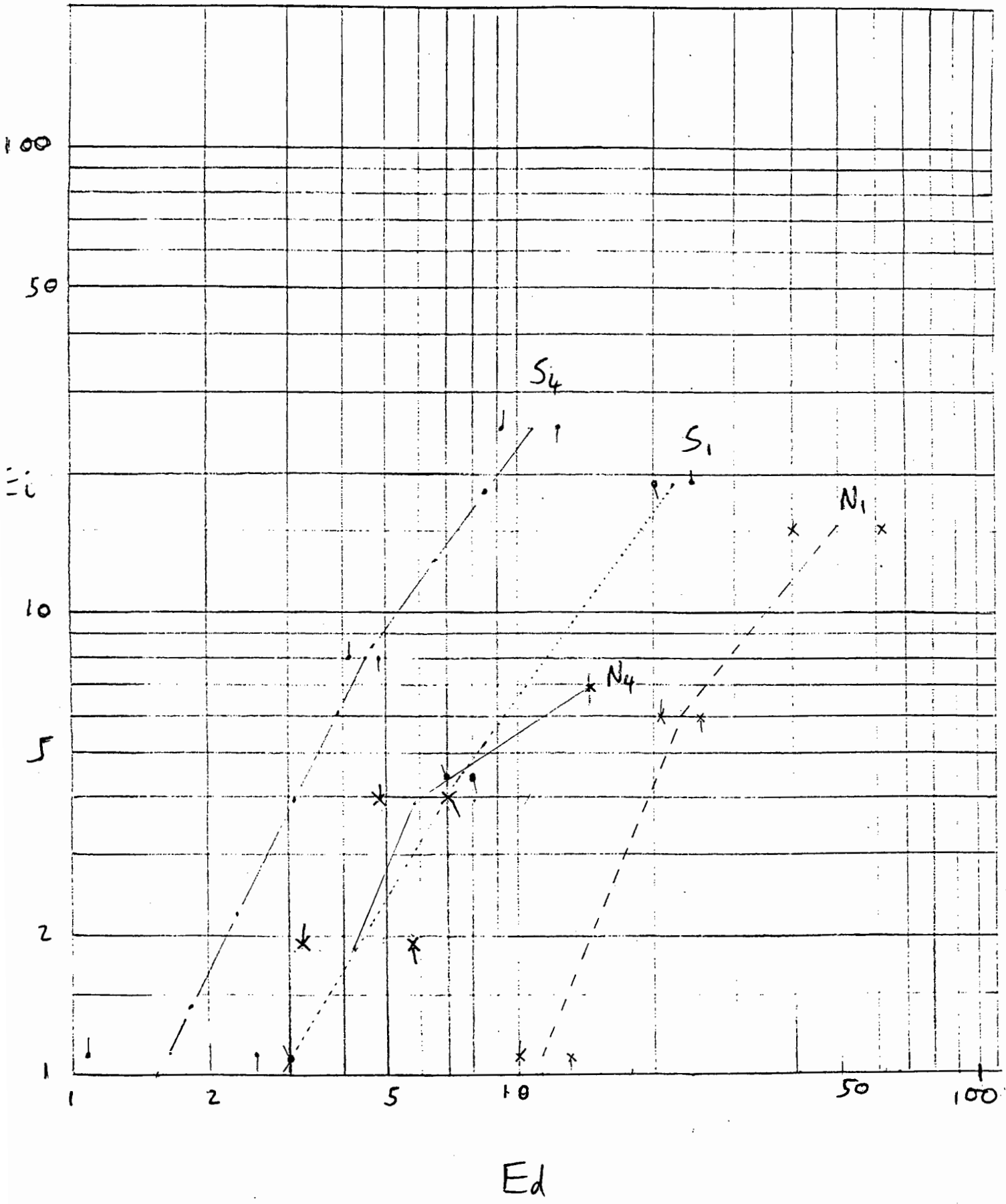
NAME — D. K. JAY
 DATE — 13/02/75

E_d vs E_i for 1.37m 'just uncomfortable'



<u>Small</u>		<u>Normal</u>	
.....	1.37m	- - - -	1.37m
- . . -	2.3 m	- - - -	2.3 m
- . -	3.94 m	- - - -	3.94 m

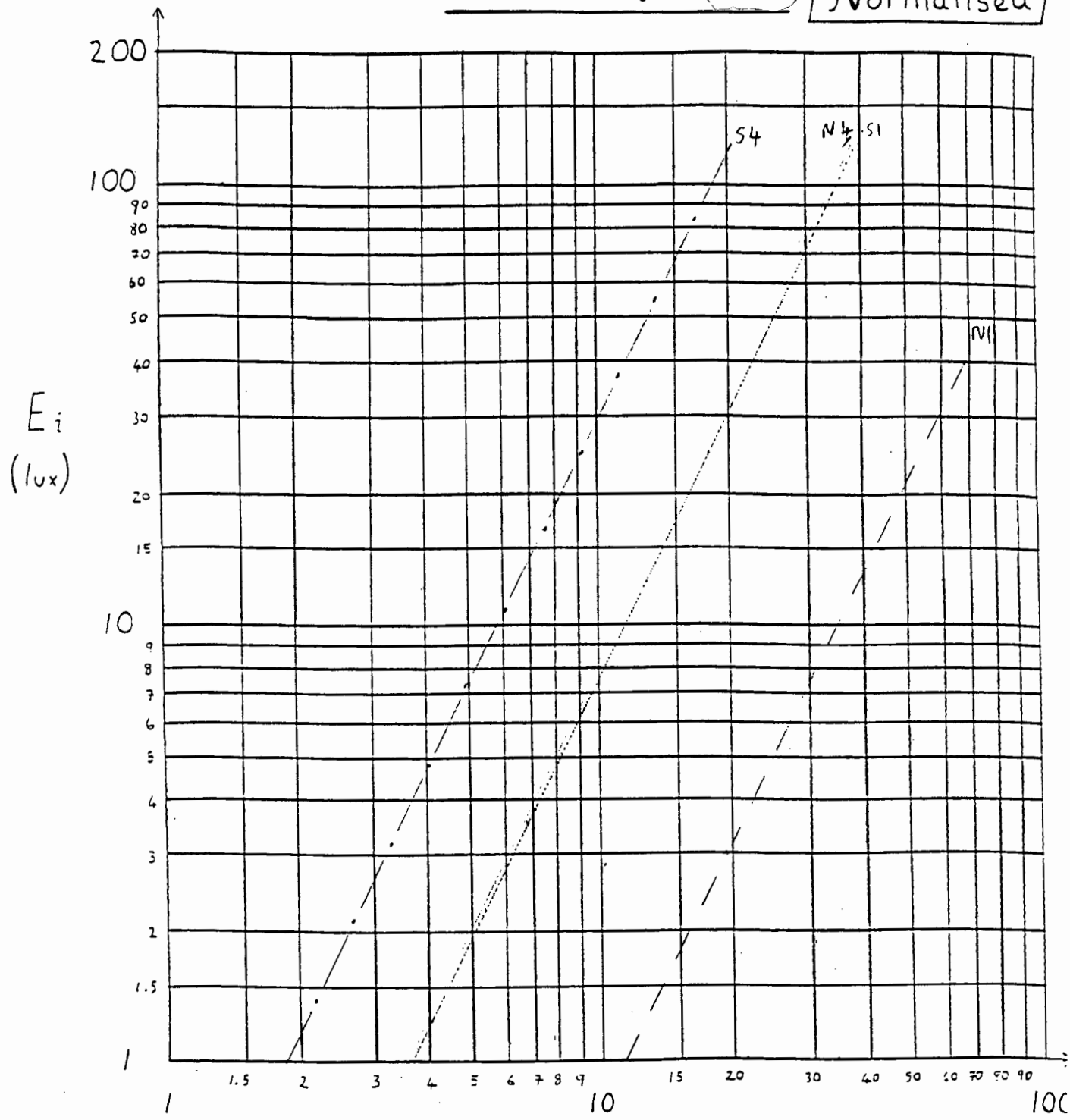
B. PAUL 29/10/95



DATE 29/10/95

just uncomparable

E_d vs E_i for Normalised



<u>Small</u>		<u>Normal</u>	
.....	1.37m	-----	1.37m
— . . —	2.3 m	—— —	2.3 m
—— . ——	4 m	—————	4 m
⊖	Buffer Up	⊗	Buffer Up
⊙	Buffer Down	⊘	Buffer Down
⊖	Direct Up	×	Direct Up
⊙	Direct Down	×	Direct Down

The Supervisor's Results

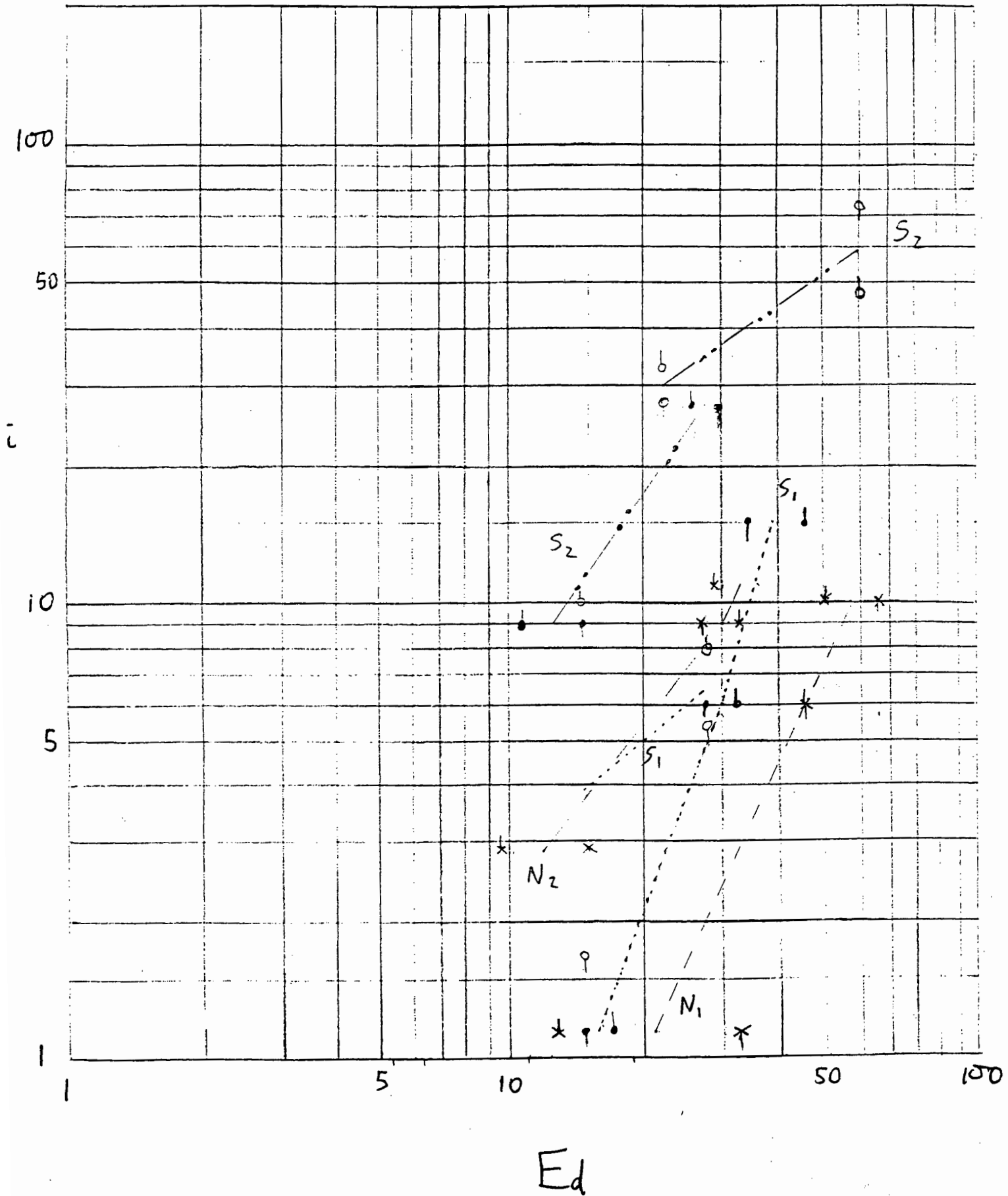
Name: H.D. Einhorn

Date: 26/10/94

Time: 12:25

Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i	Source	Buf/dir	V _b	E _i	V _s	E _d	E _d ² /E _i	
N ₁	D ↗	70	1,2	158	12,5	112	N ₂	D ↗	80	3,9	185	9,8	33,1	
		95	6	218	46	353			100	9	255	32,2	115	
		105	10	223	50	250			105	11	248	29,4	79	
		105	10	240	67	449			105	11	265	36,4	120	
		95	6	218	46	353			100	9	242	27	81	
		70	1,2	200	33	778			80	3,9	207	15	78	
		Geometric Average = 327							Geometric Average = 78					
S ₁	D ↗	70	1,2	158	17	241	S ₁	B ↗	104	10	150	14	19,6	
		95	6	190 (175)	37 (27)	167			101	8	175	27	91	
		115	15	190 (214)	37 (58)	143			94	5,5	175	27	133	
		115	15	180 (190)	30 (37)	74			95	1,7	150	14	115	
		95	6	175	27	122			Geometric Average = 72					
		70	1,2	155	16	213			Geometric Average = 104					
Geometric Average = 149														
S ₂	D ↗	100	9	175	10,6	12,5	S ₂	B ↗	135	33	210	21,8	14,4	
		130	28	221	26,6	25,3			152	53	265	60	68	
		130	28	227	29,4	30,9			172	74	265	60	48,6	
		150	9	189	14,3	22,7			130	28	210	21,8	17	
Geometric Average = 22						Geometric Average = 30								
						Geometric Average = 26								

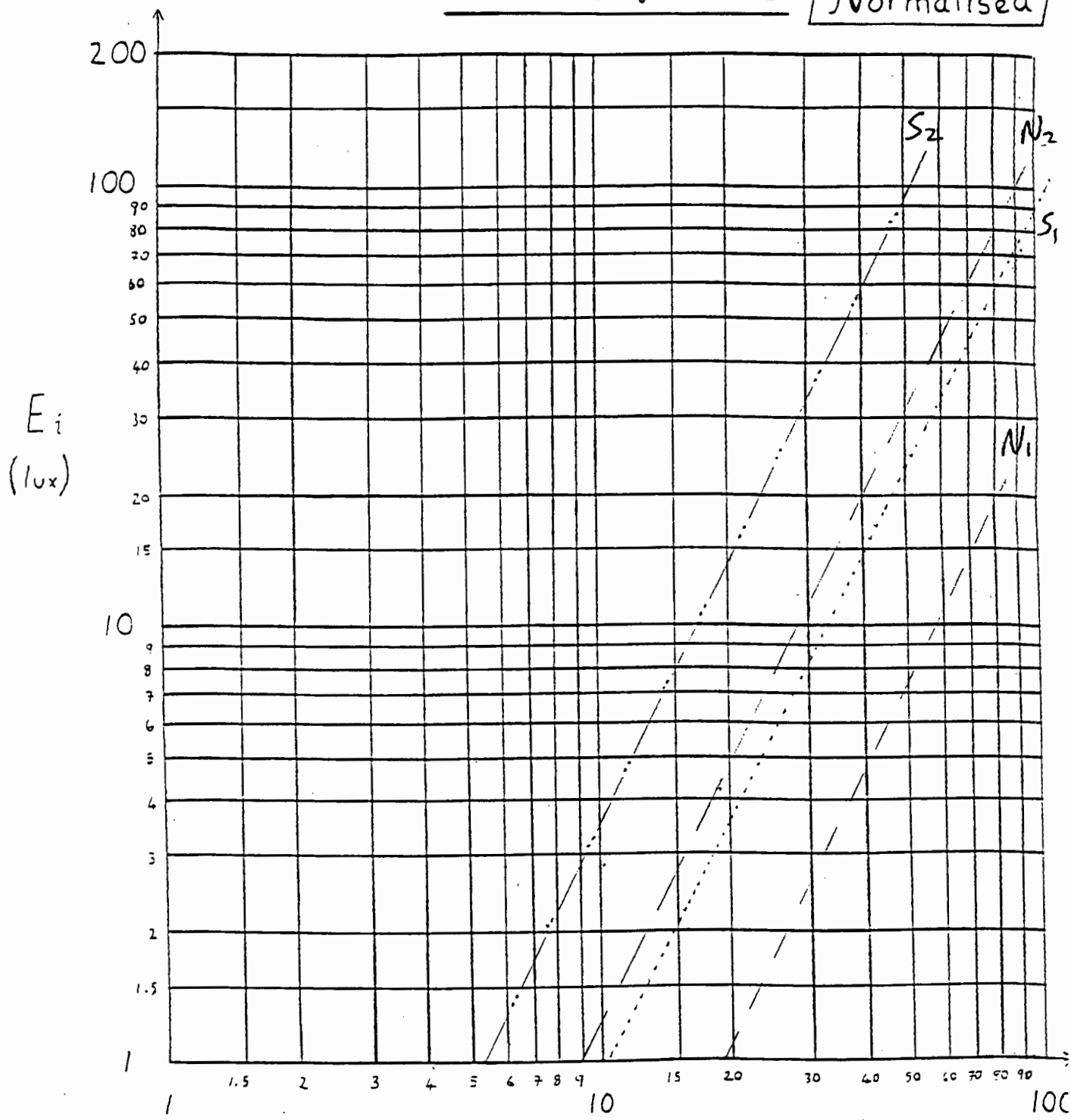
H.-D. Einhorn 26/10/94



DATE — 26/10/94

E_d vs E_i for BCD

Normalised



<u>Small</u>		<u>Normal</u>	
.....	1.3 m	— — —	1.3 m
— .. —	2.3 m	— — —	2.3 m
— . —	4 m	— — —	4 m
∩	Buffer Up	⊗	Buffer Up
∩	Buffer Down	⊗	Buffer Down
∩	Direct Up	x	Direct Up
∩	Direct Down	x	Direct Down

Name: H. D. Zinkhorn

Date: 14/03/95

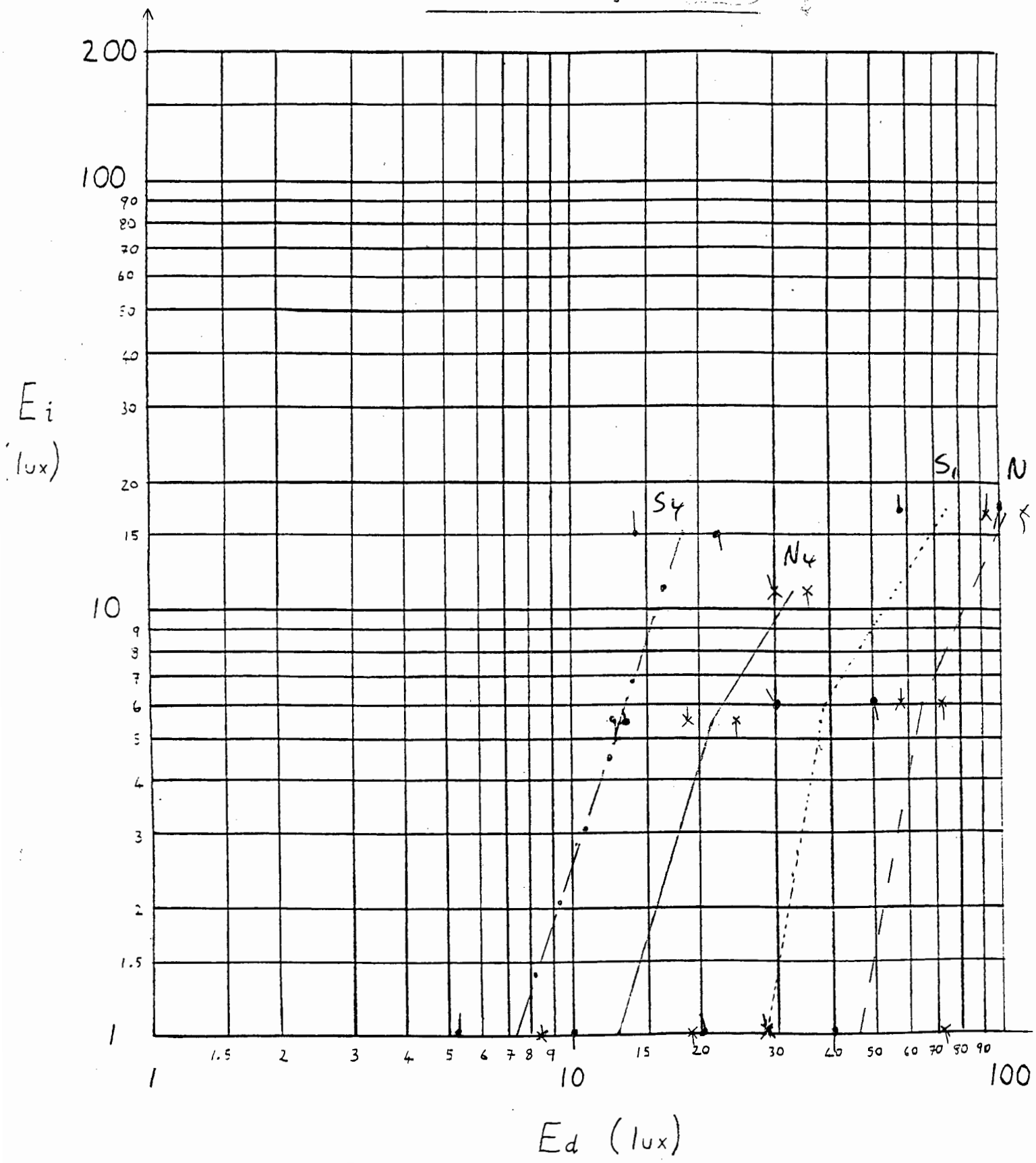
Time: 11:00

Source	Buf/dir	V_b	E_i	V_s	E_d	E_d^2/E_i	Source	Buf/dir	V_b	E_i	V_s	E_d	E_d^2/E_i
S ₄	D ↗	80	1	194	5,2	27	N ₁	D ↗	80	1	145	28	784
	↗	110	5,5	248	13,9	30.3		↗	110	6	175	58	561
	↗	140	15	256	14,3	13.6		↗	140	17	200	92	498
	↘	140	15	265 [†]	21 [†]	29.4		↘	140	17	211	112	738
	↘	110	5,5	245	12,5	28.4		↘	110	6	185	71	840
	↘	80	1	230	10	100		↘	80	1	185	71	5041
	Geometric Average = 31.2							Geometric Average = 939					
N ₄	D ↗	80	1	176	8,3	69	S ₁	D ↗	80	1	164	20	400
	↗	110	5,5	220	18,6	63		↗	110	6	186	30	150
	↗	130	11	255	30	82		↗	140	17	216	58	198
	↘	130	11	265	35	111		↘	140	17	250	100	588
	↘	110	5,5	235	23	96		↘	110	6	208	50	417
	↘	80	1	220	18,6	346		↘	80	1	195	40	1600
Geometric Average = 105						Geometric Average = 409							

NAME — H. D. ZIMMERN

DATE — 14/03/95

E_d vs E_i for  'just uncomfortable'



	<u>Small</u>		<u>Normal</u>
.....	1.37m	-----	1.37m
— .. —	2.3 m	—— —	2.3 m
— . —	3.94 m	————	3.94 m

Name: H. V. Zuhra

Date: 24/06/94 Time: 11 am.

Source	Buf/Dir	V _b	E _i	V _s	E _d	E _d ² /E _i	Source	Buf/Dir	V _b	E _i	V _s	E _d	E _d ² /E	
S ₂	B ↗	170	10.5	170	8	6.1	D ↗	170	24	169	7.8	2.5		
	↗	165	21.5	200	15.4	11.0		↗	210	53	184	11	2.3	
	↘	182	34	200	15.4	7.0		↘	210	53	225	13.8	3.6	
	↘	134	9	170	8	7.1		↘	170	24	170	8	2.7	
	Geometric Average = 7.6							Geometric Average = 4.55	Geometric Average = 2.7					
S ₁	B ↗	155	24	170	24	24	D ↗	170	34	152	15	7		
	↗	180	43	200	38.5	34.5		↗	210	75	176	27.5	1.1	
	↘	250?	140	200	38.5	10.6		↘	210	75	206	48	3.1	
	↘	144?	17	170	24	33.9		↘	170	34	166	21.5	4	
	Geometric Average = 23.3							Geometric Average = 17.7	Geometric Average = 13.5					
where? means observer doubtful														
N ₂	B						D							
	↗	131	7.4	200	14.3	27.6		↗	130	7.7	205	15.8	32.4	
	↗	130	11	240	27.2	67.3		↗	170	18	238	26.6	39.3	
	↘	205?	31.1	240	27.2	23.8		↘	170	18	238	26.6	39.3	
	↘	120?	0.3	200	14.3	32.5		↘	130	9.5	226	22.4	52.8	
Geometric Average = 34.6						Geometric Average = 37.4	Geometric Average = 40.3							
? means doubtful														

. D. Senhora

24/06/94⁵₄

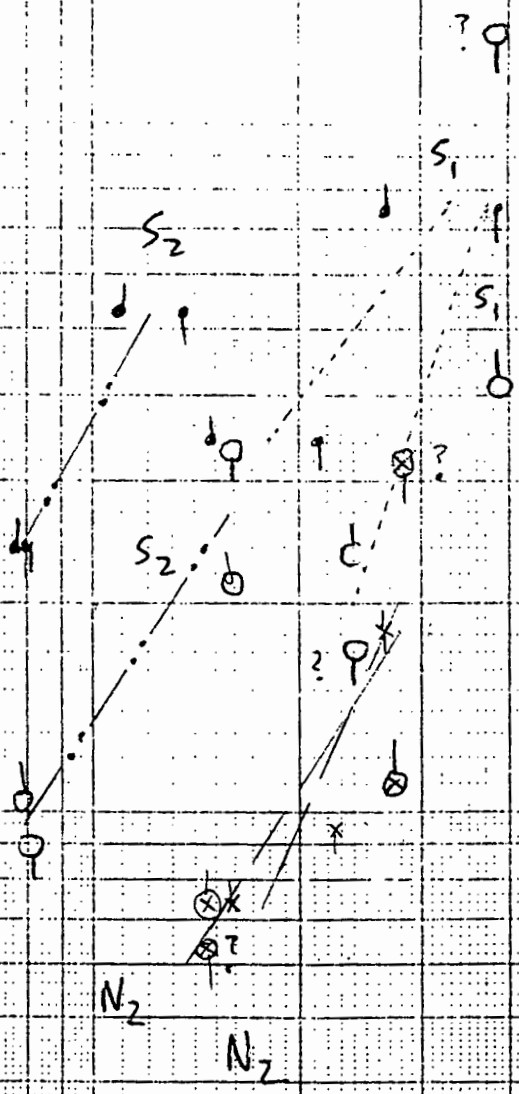
100

111

10

3
2
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1

1 2 3 4 5 6 7 8 9 10 10 100



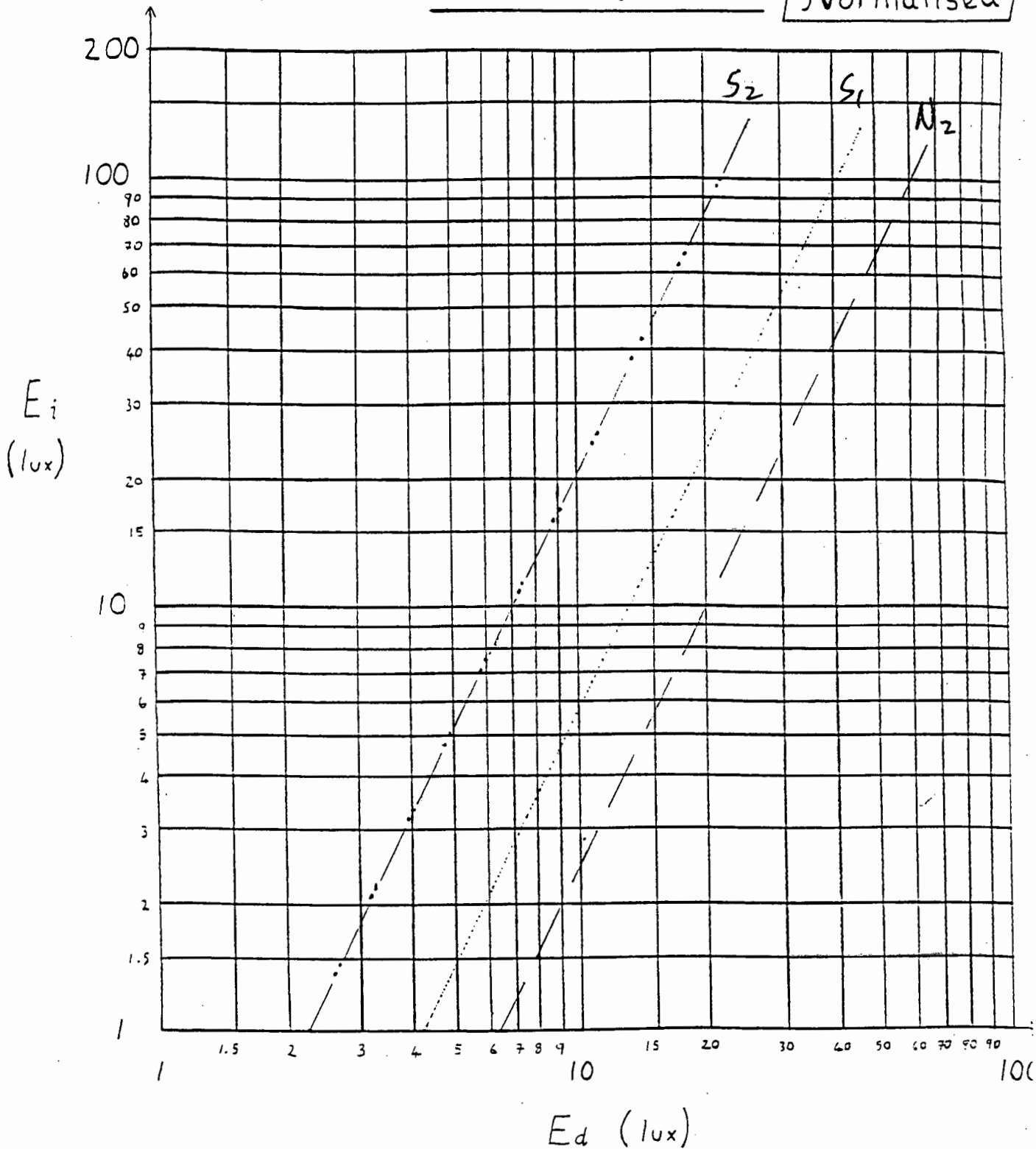
E_d

DATE —

24/06/14

E_d vs E_i for BCD

Normalised



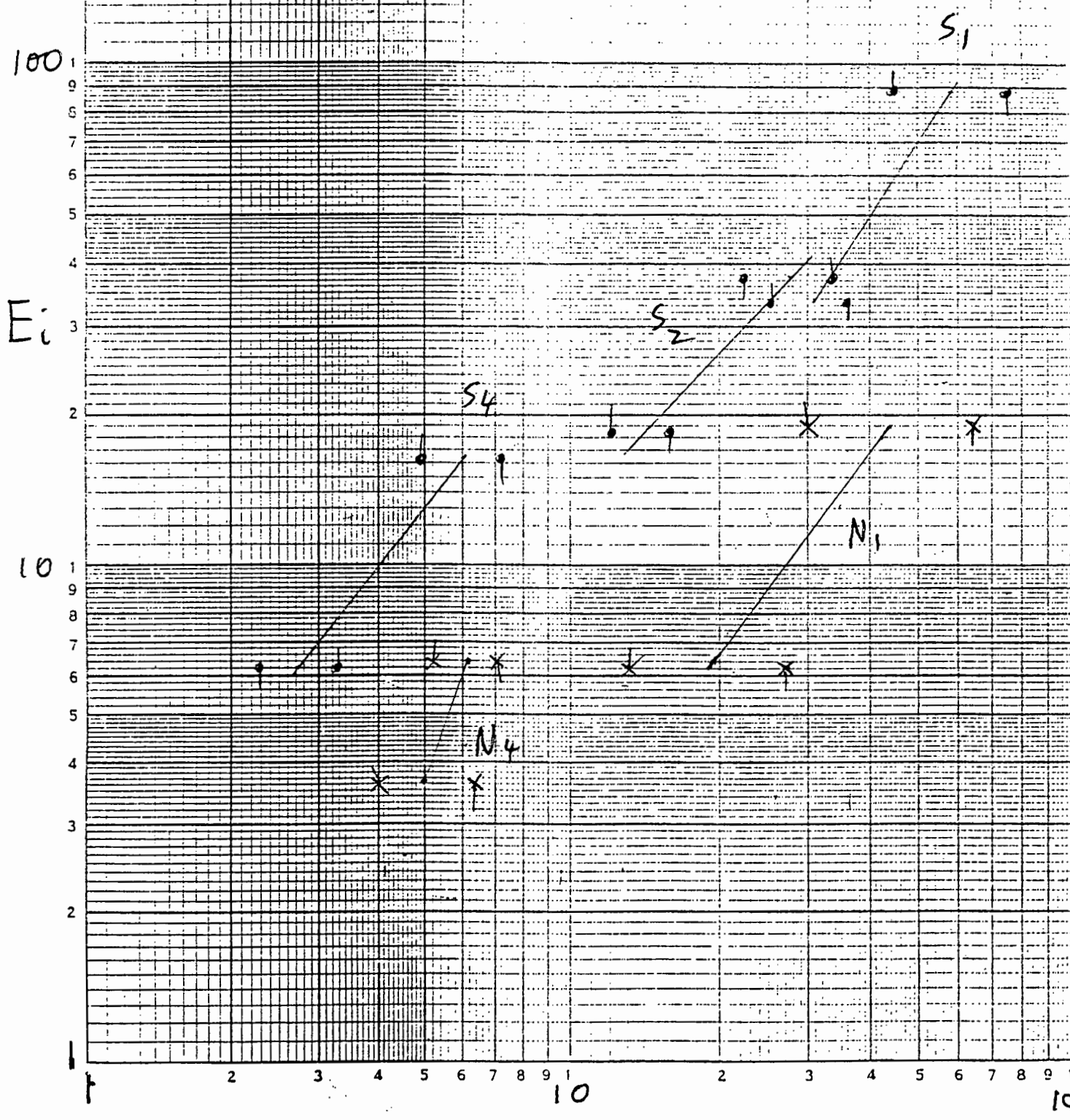
E_d (lux)

	<u>Small</u>		<u>Normal</u>
.....	1.3 m	---	1.3 m
- . - . -	2.3 m	---	2.3 m
— . —	4 m	---	4 m
⊖	Buffer Up	⊗	Buffer Up
⊙	Buffer Down	⊘	Buffer Down
⊙	Direct Up	×	Direct Up
⊙	Direct Down	×	Direct Down

H.D. *Handwritten*

22/08/95

Log 4 Cycles x 3 Cycles



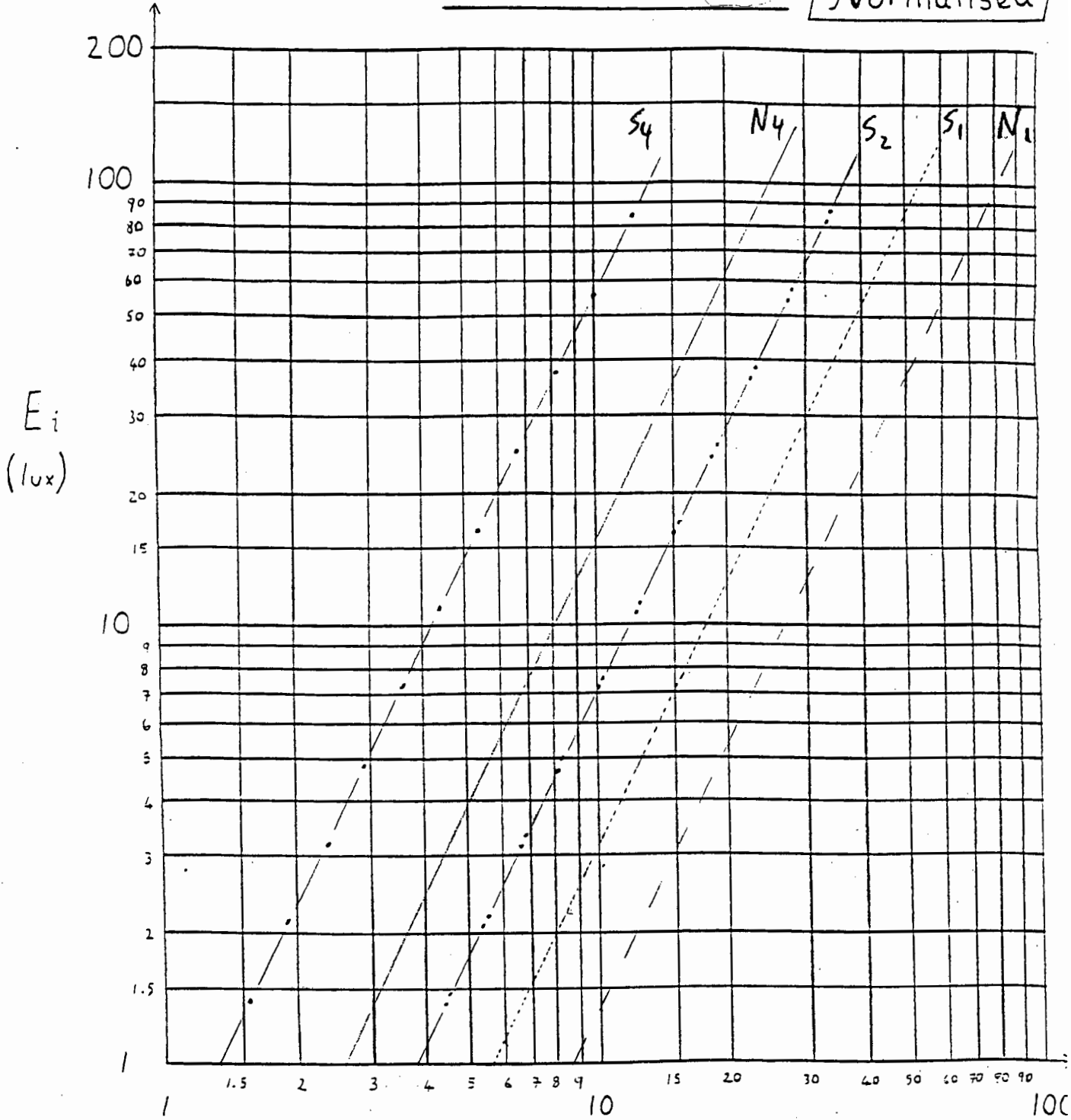
E_d

DATE — 22/08/95

Just uncomfortable

E_d vs E_i for

Normalised



E_d (lux)

<u>Small</u>		<u>Normal</u>	
.....	1.37m	-----	1.37m
- . - . - .	2.3 m	-----	2.3 m
-----	3.94 m	-----	3.94 m
o	Buffer Up	o	Buffer Up
q	Buffer Down	q	Buffer Down
•	Direct Up	x	Direct Up
•	Direct Down	x	Direct Down

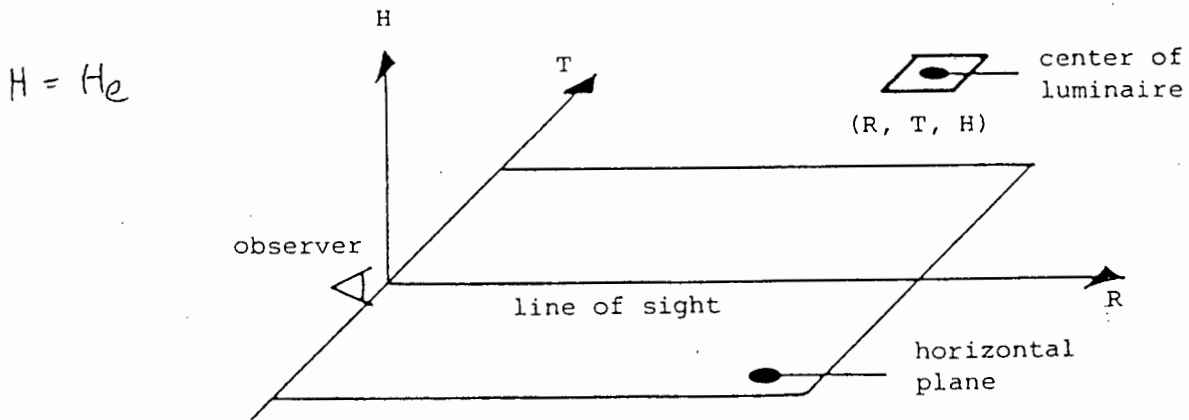
APPENDIX 3

[Miscellaneous]

- Guth Position Index (p)
- Target Height calculations
- Unchanged Projected Area of normal source
- Calibration Curves
- Statistical Formulae and Tables
- Least Square Fit $m=2$ 'normalisation' Pascal Program

A3.1 The Guth Position Index, p

Diagram showing the dimensions contributing to the Position Index



- a. coordinate system (R, T, H) with the origin in the observer position. For the center of a luminaire, the ratios H/R and T/R are formed

The Position Index Formula

$$1/p = [d^2 / (0.97d^2 + 2.3d + 4) - 0.1] \times \exp(-0.17s^2/d + 0.013s^3/d) + 0.09 + (0.075 - 0.035/d) / (1 + 3(s - 0.5)^2)$$

where $d =$ forward distance of source/height $= R/H_e$

$s =$ sideways distance of source/height $= T/H_e$

forward means in the direction of the line of sight

sideways means perpendicular to it

height means height above eye level, H_e

The calculation of p for this experiment

$s = 0$ (since no sideways displacement)

$d = W / H = \tan (90 - 16) = 3.4874$

$\therefore 1 / p = 0.54074$

$\therefore p = 1.8493$

$\therefore p^2 = 3.42$

The Position Index Table

$1/d = H/w$

Table A1.3

T/R	H/R	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	
0.00	1.00	1.26	1.53	1.80	2.07	2.35	2.62	2.89	3.16	3.43	3.70	3.97	4.24	4.51	4.78	5.05	5.32	5.59	5.86	6.13	6.40	6.67
0.10	1.05	1.22	1.46	1.80	2.20	2.75	3.40	4.10	4.80	5.50	6.20	6.90	7.60	8.30	9.00	9.70	10.40	11.10	11.80	12.50	13.20	13.90
0.20	1.12	1.30	1.50	1.80	2.20	2.66	3.18	3.88	4.60	5.50	6.50	7.60	8.75	9.85	11.20	12.70	14.00	15.70	-	-	-	-
0.30	1.22	1.38	1.60	1.87	2.25	2.70	3.25	3.90	4.60	5.45	6.45	7.40	8.40	9.50	10.85	12.10	13.70	15.00	-	-	-	-
0.40	1.32	1.47	1.70	1.96	2.35	2.80	3.30	3.90	4.60	5.40	6.40	7.30	8.30	9.40	10.60	11.90	13.20	14.60	16.00	-	-	-
0.50	1.43	1.60	1.82	2.10	2.48	2.91	3.40	3.98	4.70	5.50	6.40	7.30	8.30	9.40	10.50	11.75	13.00	14.40	15.70	-	-	-
0.60	1.55	1.72	1.98	2.30	2.65	3.10	3.60	4.10	4.80	5.50	6.40	7.35	8.40	9.40	10.50	11.70	13.00	14.10	15.40	-	-	-
0.70	1.70	1.88	2.12	2.48	2.87	3.30	3.78	4.30	4.88	5.60	6.50	7.40	8.50	9.50	10.50	11.70	12.85	14.00	15.20	-	-	-
0.80	1.82	2.00	2.32	2.70	3.08	3.50	3.92	4.50	5.10	5.75	6.60	7.50	8.60	9.50	10.60	11.75	12.80	14.00	15.10	-	-	-
0.90	1.95	2.20	2.54	2.90	3.30	3.70	4.20	4.75	5.30	6.00	6.75	7.70	8.70	9.65	10.75	11.80	12.90	14.00	15.00	16.00	-	-
1.00	2.11	2.40	2.75	3.10	3.50	3.91	4.40	5.00	5.60	6.20	7.00	7.90	8.80	9.75	10.80	11.90	12.95	14.00	15.00	16.00	-	-
1.10	2.30	2.55	2.92	3.30	3.72	4.20	4.70	5.25	5.80	6.55	7.20	8.15	9.00	9.90	10.95	12.00	13.00	14.00	15.00	16.00	-	-
1.20	2.40	2.75	3.12	3.50	3.90	4.35	4.85	5.50	6.05	6.70	7.50	8.30	9.20	10.00	11.02	12.10	13.10	14.00	15.00	16.00	-	-
1.30	2.55	2.90	3.30	3.70	4.20	4.65	5.20	5.70	6.30	7.00	7.70	8.55	9.35	10.20	11.20	12.25	13.20	14.00	15.00	16.00	-	-
1.40	2.70	3.10	3.50	3.90	4.35	4.85	5.35	5.85	6.50	7.25	8.00	8.70	9.50	10.40	11.40	12.40	13.25	14.05	15.00	16.00	-	-
1.50	2.85	3.15	3.65	4.10	4.55	5.00	5.50	6.20	6.80	7.50	8.20	8.85	9.70	10.55	11.50	12.50	13.30	14.05	15.02	16.00	-	-
1.60	2.95	3.40	3.80	4.25	4.75	5.20	5.75	6.30	7.00	7.65	8.40	9.00	9.80	10.80	11.75	12.60	13.40	14.20	15.05	16.00	-	-
1.70	3.10	3.55	4.00	4.50	4.90	5.40	5.95	6.50	7.20	7.80	8.50	9.20	10.00	10.85	11.85	12.75	13.45	14.20	15.10	16.00	-	-
1.80	3.25	3.70	4.20	4.65	5.10	5.60	6.10	6.75	7.40	8.00	8.65	9.35	10.10	11.00	11.90	12.80	13.50	14.20	15.10	16.00	-	-
1.90	3.43	3.86	4.30	4.75	5.20	5.70	6.30	6.90	7.50	8.17	8.80	9.50	10.20	11.00	12.00	12.82	13.55	14.20	15.10	16.00	-	-
2.00	3.50	4.00	4.50	4.90	5.35	5.80	6.40	7.10	7.70	8.30	8.90	9.60	10.40	11.10	12.00	12.85	13.60	14.30	15.10	16.00	-	-
2.10	3.60	4.17	4.65	5.05	5.50	6.00	6.60	7.20	7.82	8.45	9.00	9.75	10.50	11.20	12.10	12.90	13.70	14.35	15.10	16.00	-	-
2.20	3.75	4.25	4.72	5.20	5.60	6.10	6.70	7.35	8.00	8.55	9.15	9.85	10.60	11.30	12.10	12.90	13.70	14.40	15.15	16.00	-	-
2.30	3.85	4.35	4.80	5.25	5.70	6.22	6.80	7.40	8.10	8.65	9.30	9.90	10.70	11.40	12.20	12.95	13.70	14.40	15.20	16.00	-	-
2.40	3.95	4.40	4.90	5.35	5.80	6.30	6.90	7.50	8.20	8.80	9.40	10.00	10.80	11.50	12.25	13.00	13.75	14.45	15.20	16.00	-	-
2.50	4.00	4.50	4.95	5.40	5.85	6.40	6.95	7.55	8.25	8.85	9.50	10.05	10.85	11.55	12.30	13.00	13.80	14.50	15.25	16.00	-	-
2.60	4.07	4.55	5.05	5.47	5.95	6.45	7.00	7.65	8.35	8.95	9.55	10.10	10.90	11.60	12.32	13.00	13.80	14.50	15.25	16.00	-	-
2.70	4.10	4.60	5.10	5.53	6.00	6.50	7.05	7.70	8.40	9.00	9.60	10.16	10.92	11.63	12.35	13.00	13.80	14.50	15.25	16.00	-	-
2.80	4.15	4.62	5.15	5.56	6.06	6.55	7.08	7.73	8.45	9.05	9.65	10.20	10.95	11.65	12.35	13.00	13.80	14.50	15.25	16.00	-	-
2.90	4.20	4.65	5.17	5.60	6.07	6.57	7.12	7.75	8.50	9.10	9.70	10.23	10.95	11.65	12.35	13.00	13.80	14.50	15.25	16.00	-	-
3.00	4.22	4.67	5.20	5.65	6.12	6.60	7.15	7.80	8.55	9.12	9.70	10.23	10.95	11.65	12.35	13.00	13.80	14.50	15.25	16.00	-	-

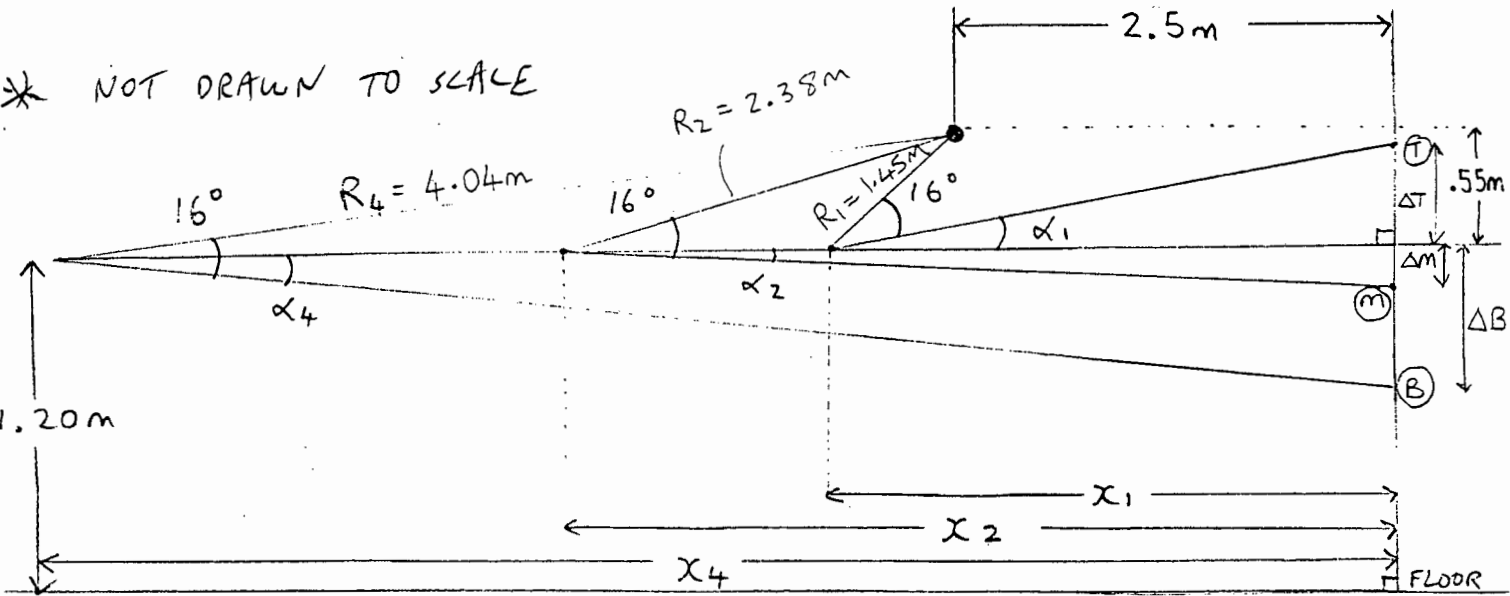
b. table of position index data

Fig. A1.3 The position index as obtained by means of the table of position index data.

A3.2 Target heights Calculation

Calculation for Initial Lay-out

* NOT DRAWN TO SCALE



$$\alpha_1 = \sin^{-1} (0.55 / R_1) - 16 = \sin^{-1} (0.55 / 1.45) - 16 = 6.3^\circ$$

$$x_1 = 2.5 + R_1 \cos (16 + \alpha_1) = 3.84\text{m}$$

$$\Delta T = x_1 \tan \alpha_1 = 0.42\text{m}$$

$$\therefore \textcircled{T} = 1.20 + 0.42 = 1.62\text{m (above floor)}$$

$$\alpha_2 = 16 - \sin^{-1} (0.55 / R_2) = 16 - \sin^{-1} (0.55 / 2.38) = 2.6^\circ$$

$$x_2 = 2.5 + R_2 \cos (16 + \alpha_2) = 4.82\text{m}$$

$$\Delta M = x_2 \tan \alpha_2 = 0.22\text{m}$$

$$\therefore \textcircled{M} = 1.20 - 0.22 = 0.98\text{m (above floor)}$$

$$\alpha_4 = 16 - \sin^{-1} (0.55 / R_4) = 16 - \sin^{-1} (0.55 / 4.04) = 6.3^\circ$$

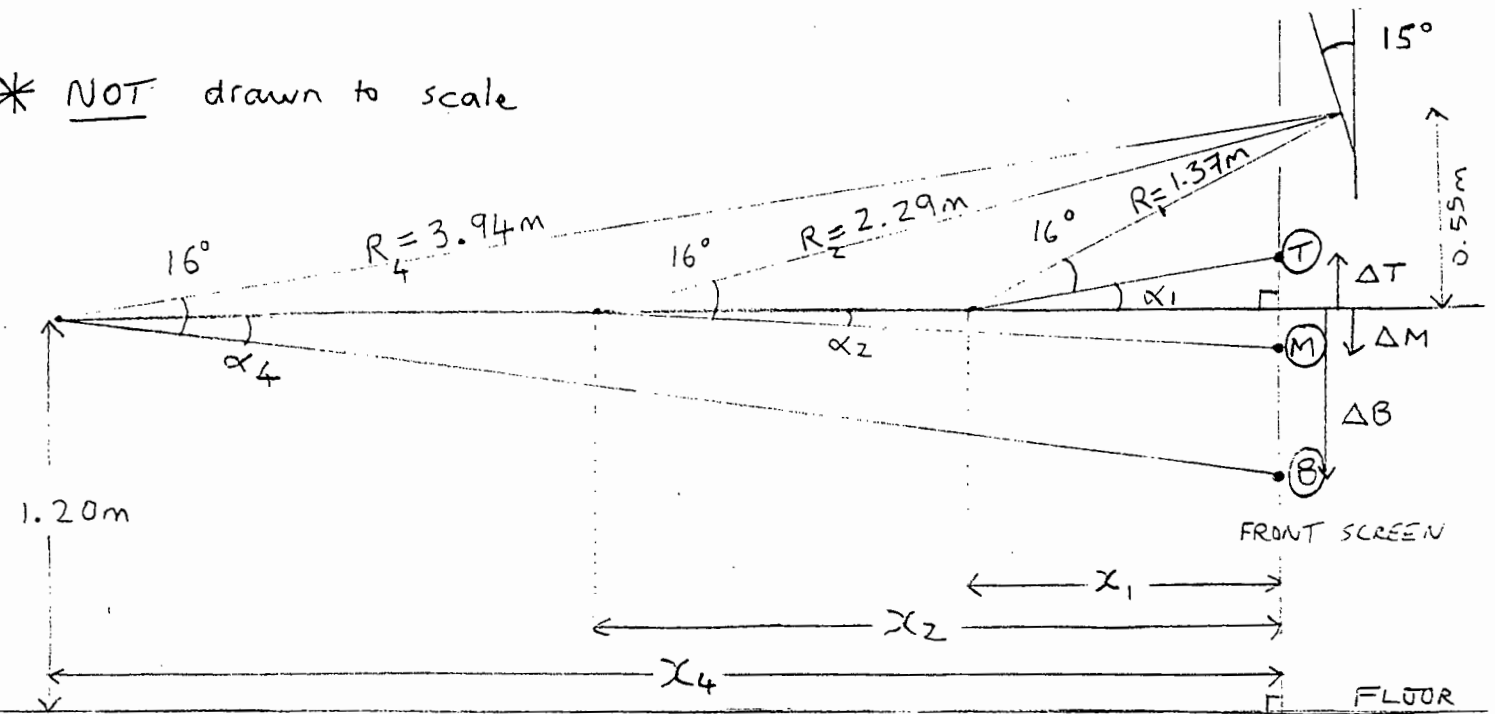
$$x_4 = 2.5 + R_4 \cos (16 + \alpha_4) = 6.5\text{m}$$

$$\Delta B = x_4 \tan \alpha_4 = 0.93\text{m}$$

$$\therefore \textcircled{B} = 1.20 - 0.93 = 0.27\text{m (above floor)}$$

Calculation for Improved Lay-out

* NOT drawn to scale



$$\alpha_1 = \sin^{-1} (0.55 / R_1) - 16 = \sin^{-1} (0.55 / 1.37) - 16 = 7.7^\circ$$

$$x_1 = R_1 \cos (16 + \alpha_1) = 1.37 \cos (23.7) = 1.26\text{m}$$

$$\Delta T = x_1 \tan \alpha_1 = 0.17\text{m}$$

$$\therefore \textcircled{T} = 1.20 + 0.17 = 1.37\text{m (above floor)}$$

$$\alpha_2 = 16 - \sin^{-1} (0.55 / R_2) = 16 - \sin^{-1} (0.55 / 2.29) = 2.1^\circ$$

$$x_2 = R_2 \cos (16 - \alpha_2) = 2.29 \cos (13.9) = 2.22\text{m}$$

$$\Delta M = x_2 \tan \alpha_2 = 0.08\text{m}$$

$$\therefore \textcircled{M} = 1.20 - 0.08 = 1.12\text{m (above floor)}$$

$$\alpha_4 = 16 - \sin^{-1} (0.55 / R_4) = 16 - \sin^{-1} (0.55 / 3.94) = 8.0^\circ$$

$$x_4 = R_4 \cos (16 - \alpha_4) = 3.94 \cos (8.0) = 3.90\text{m}$$

$$\Delta B = x_4 \tan \alpha_4 = 0.55\text{m}$$

$$\therefore \textcircled{B} = 1.20 - 0.55 = 0.65\text{m (above floor)}$$

A3.3 Proof that the Projected Area of the Normal source $\approx 0.04\text{m}^2$ at all distances

Calculation of projected area, A_p of the normal source at varying distances for the improved layout:
[refer to the 'Target Heights' Figure in the previous section]

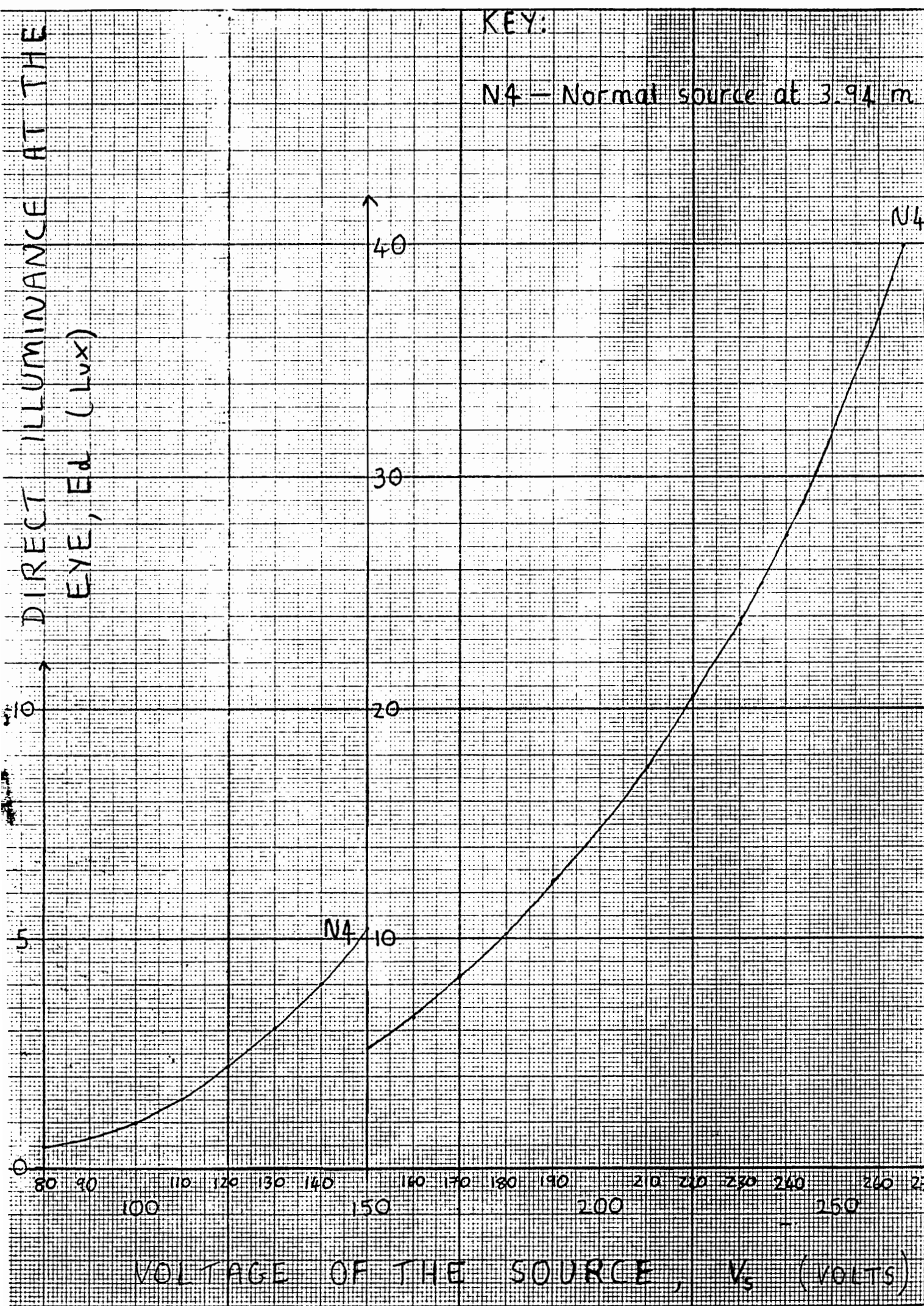
$$\begin{aligned}A_{p(1)} &= A_n \cos (16 + \alpha_1 - 15) \\ &= A_n \cos (8.7) \\ &= 0.988 A_n \\ &\approx A_n\end{aligned}$$

$$\begin{aligned}A_{p(2)} &= A_n \cos (16 - \alpha_2 - 15) \\ &= A_n \cos (-1.1) \\ &= 0.999 A_n \\ &\approx A_n\end{aligned}$$

$$\begin{aligned}A_{p(4)} &= A_n \cos (16 - \alpha_4 - 15) \\ &= A_n \cos (8.7) \\ &= 0.993 A_n \\ &\approx A_n\end{aligned}$$

Key: $A_n = \text{Area of the Normal source} = 0.04\text{m}^2$
 $A_{p(1)} = \text{Projected Area of the Normal source at } R = 1.37\text{m}$
 $A_{p(2)} = \text{Projected Area of the Normal source at } R = 2.29\text{m}$
 $A_{p(4)} = \text{Projected Area of the Normal source at } R = 3.94\text{m}$

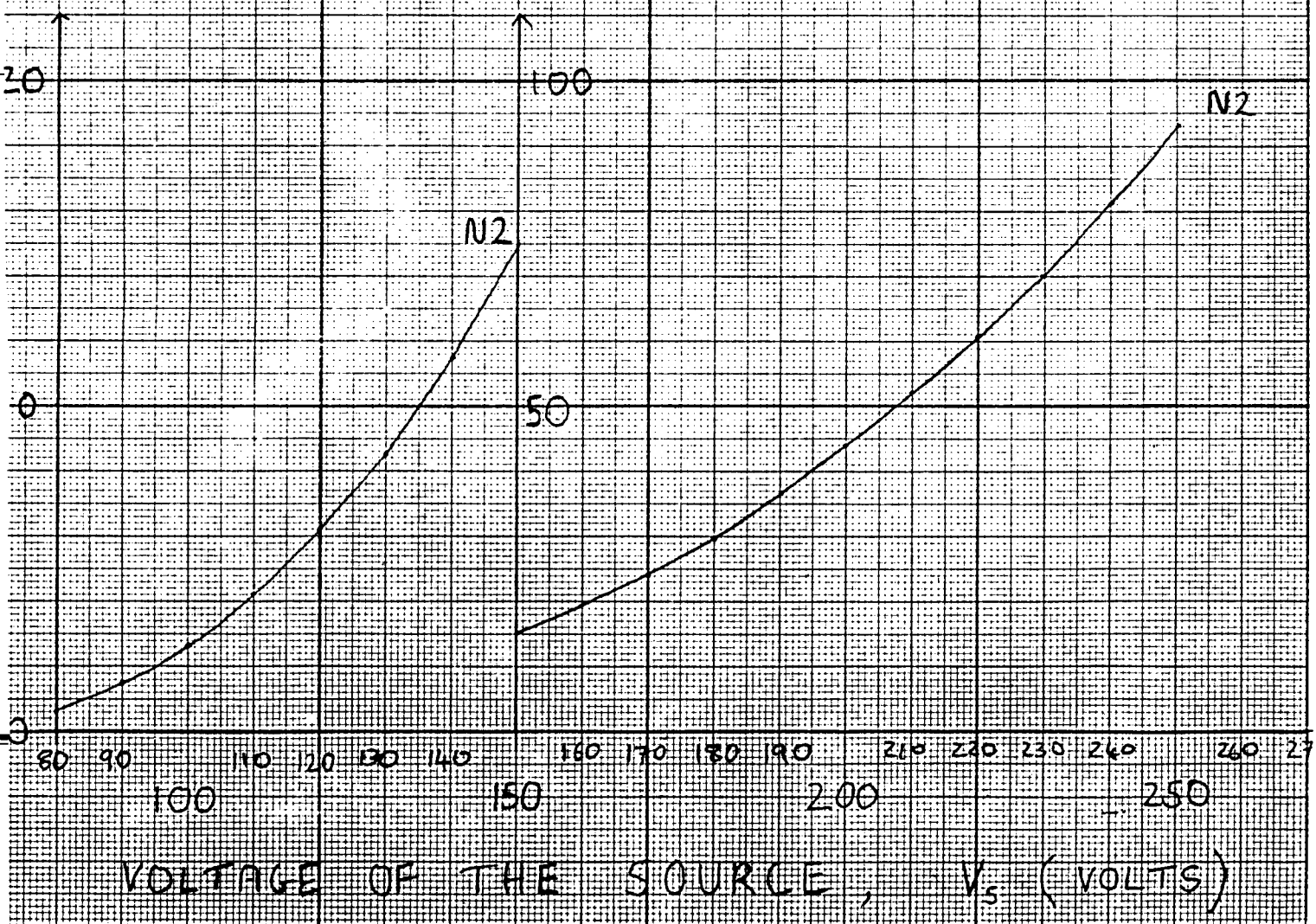
A3.4 Illuminance versus Voltage Calibration



DIRECT ILLUMINANCE AT THE EYE, E_d (LUX)

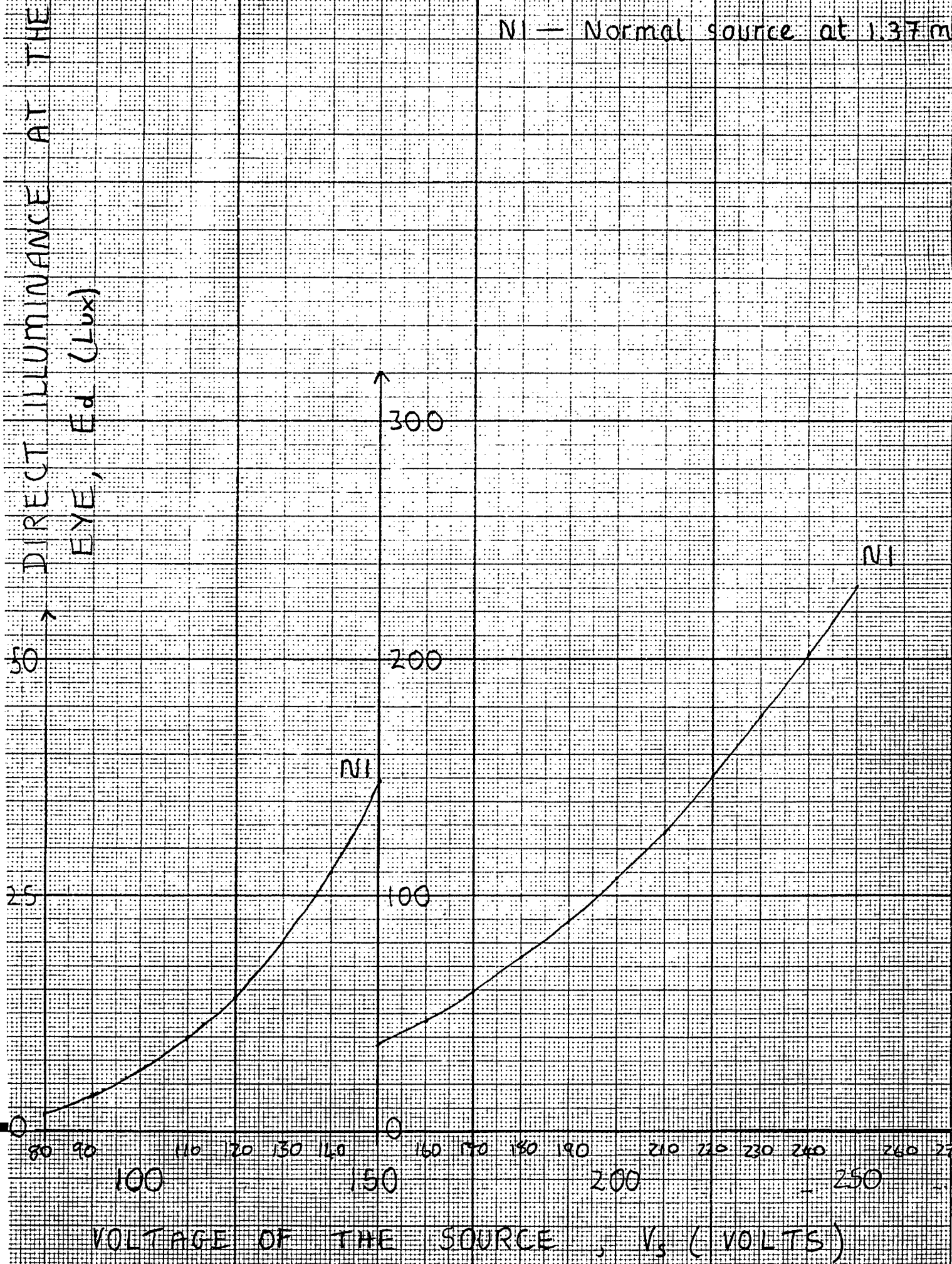
KEY:

N2 - Normal source at 2.29 m



KEY:

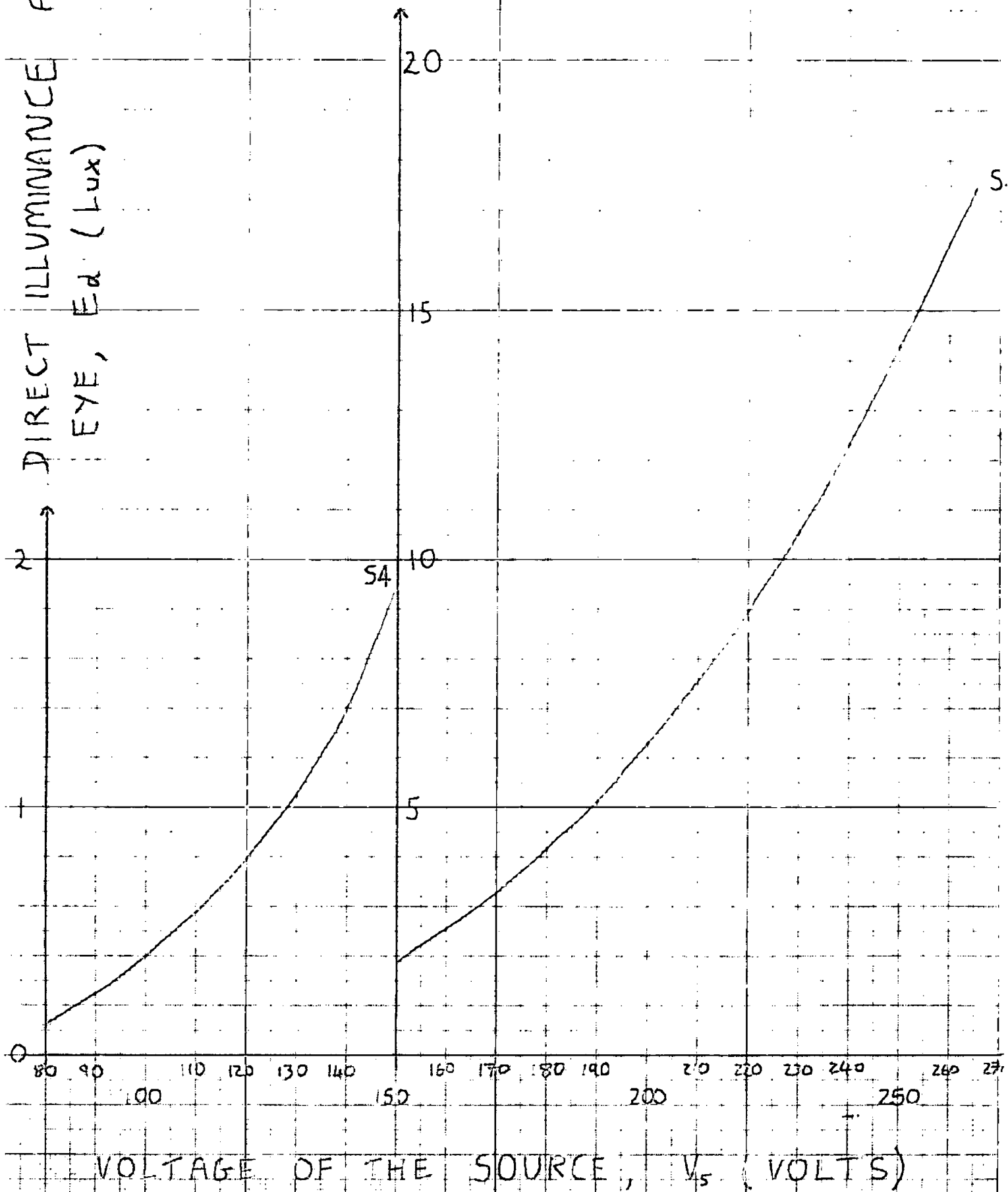
NI — Normal source at 1.37 m



KEY:

S4 - Small source at 3.94 m

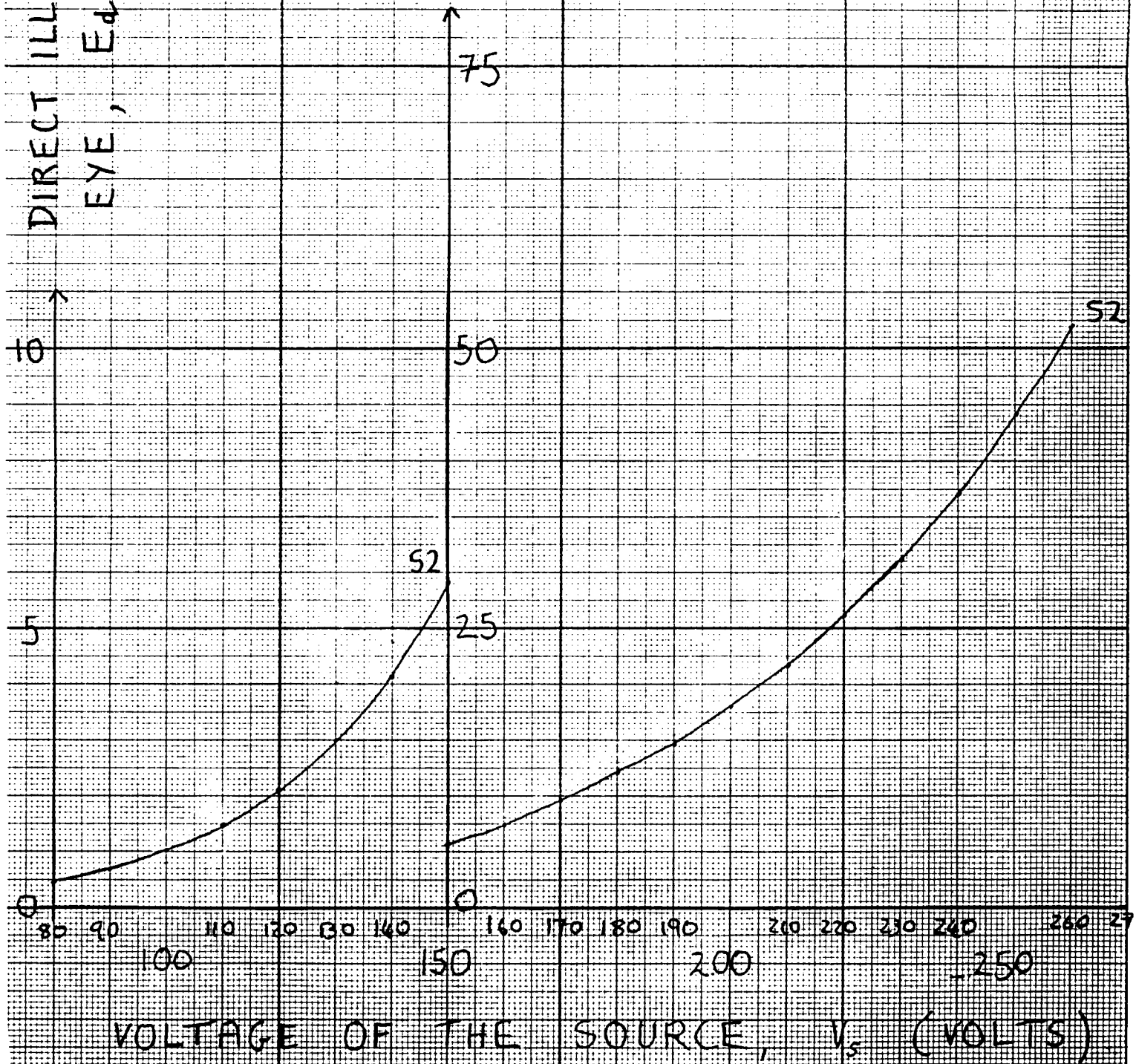
DIRECT ILLUMINANCE AT THE EYE, E_d (Lux)



KEY:

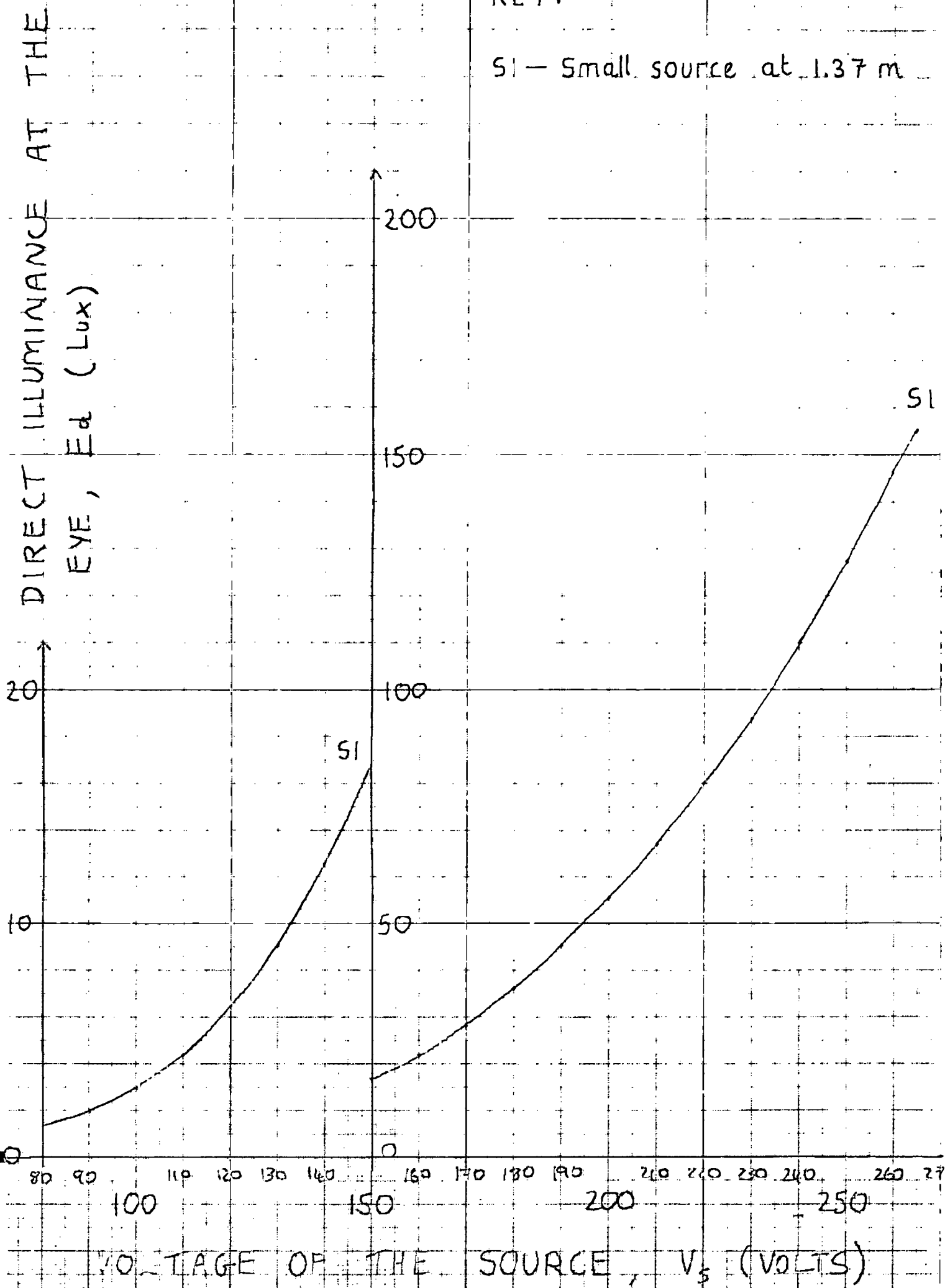
S2 - Small source at 2.29m

DIRECT ILLUMINANCE AT THE EYE, E_d (Lux)



KEY:

SI - Small source at 1.37 m



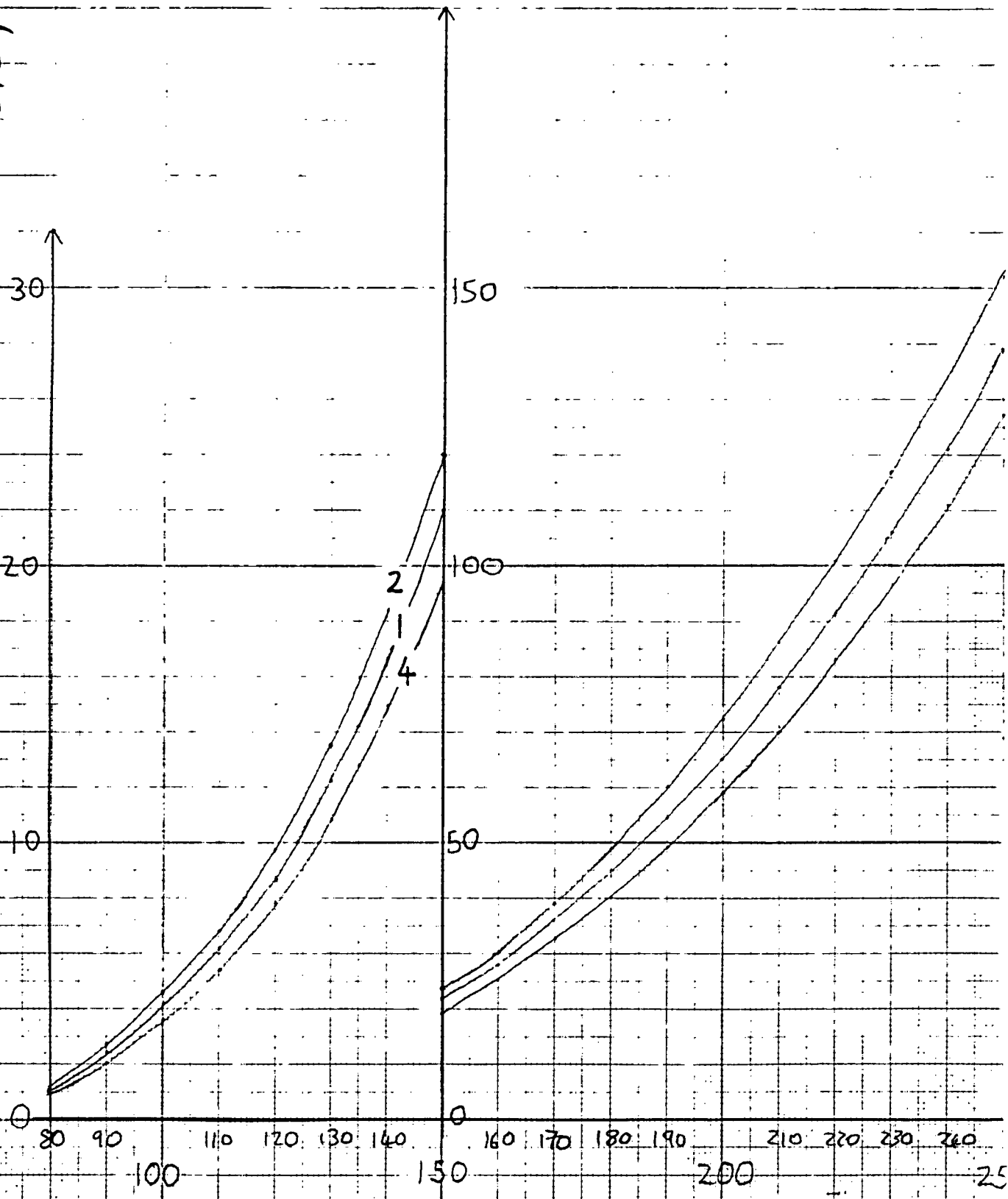
INDIRECT ILLUMINANCE AT THE EYE, E_i (Lux)

KEY:

2 - At 2.29 m

1 - At 1.37 m

4 - At 3.94 m



VOLTAGE OF THE BACKGROUND LAMP, V_b (VOLTS)

A3.5 Statistics Section

1. Geometric Mean (GM)

$$GM = (x_1 \cdot x_2 \cdot \dots \cdot x_i \cdot \dots \cdot x_n)^{1/n}$$

where x_i = a numerical value

n = the sample number

2. Arithmetic Mean (\bar{x})

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

3. Standard Deviation, Std Dev (s)

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$$

4. 95% Confidence Interval (C.I₉₅)

The 95% Confidence Interval of a sample is centred around the mean, \bar{x} and has a 95% probability of encapsulating the true mean, μ . (The true mean is the average if an infinite sample was used.)

$$C.I \text{ for } \mu = \bar{x} \pm \frac{t_{\alpha/2} s}{\sqrt{v}}$$

where v = degrees of freedom = $(n-1)$

The $t_{\alpha/2}$ values for different degrees of freedom are given in the t-distribution table over the page.

t-distribution table

95% Confidence

Table 4 ↓ Values of t_{α} *

v	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.025$	$\alpha = 0.01$	$\alpha = 0.005$	v
1	3.078	6.314	12.706	31.821	63.657	1
2	1.886	2.920	4.303	6.965	9.925	2
3	1.638	2.353	3.182	4.541	5.841	3
4	1.533	2.132	2.776	3.747	4.604	4
5	1.476	2.015	2.571	3.365	4.032	5
6	1.440	1.943	2.447	3.143	3.707	6
7	1.415	1.895	2.365	2.998	3.499	7
8	1.397	1.860	2.306	2.896	3.355	8
9	1.383	1.833	2.262	2.821	3.250	9
10	1.372	1.812	2.228	2.764	3.169	10
11	1.363	1.796	2.201	2.718	3.106	11
12	1.356	1.782	2.179	2.681	3.055	12
13	1.350	1.771	2.160	2.650	3.012	13
14	1.345	1.761	2.145	2.624	2.977	14
15	1.341	1.753	2.131	2.602	2.947	15
16	1.337	1.746	2.120	2.583	2.921	16
17	1.333	1.740	2.110	2.567	2.898	17
18	1.330	1.734	2.101	2.552	2.878	18
19	1.328	1.729	2.093	2.539	2.861	19
20	1.325	1.725	2.086	2.528	2.845	20
21	1.323	1.721	2.080	2.518	2.831	21
22	1.321	1.717	2.074	2.508	2.819	22
23	1.319	1.714	2.069	2.500	2.807	23
24	1.318	1.711	2.064	2.492	2.797	24
25	1.316	1.708	2.060	2.485	2.787	25
26	1.315	1.706	2.056	2.479	2.779	26
27	1.314	1.703	2.052	2.473	2.771	27
28	1.313	1.701	2.048	2.467	2.763	28
29	1.311	1.699	2.045	2.462	2.756	29
inf.	1.282	1.645	1.960	2.326	2.576	inf.

* Abridged by permission of Macmillan Publishing Co., Inc., from *Statistical Methods for Research Workers*, 14th ed., by R. A. Fisher. Copyright © 1970 University of Adelaide.

5. Determining the Standard Deviation and 95% C.I of a sample where a GM is appropriate

The GM of a number of values is equivalent to $10^{\text{(the arithmetic mean of the log of the values)}}$

$$\text{i.e. GM} = 10^{\left(\frac{\sum_{i=1}^n \log x_i}{n} \right)}$$

Because the Std Dev and C.I use the *arithmetic* mean in their evaluation, the arithmetic mean and Std Dev of the log values must be determined first and then converted back.

$$\log(s) = \sqrt{\frac{\sum_{i=1}^n (\log x_i - \log \bar{x})^2}{n-1}}$$

$$s = 10^{(\log(s))}$$

$$\log(\mu) = \frac{\sum_{i=1}^n \log x_i}{n} \pm t_{\alpha/2} \frac{\log s}{\sqrt{n}}$$

$$\text{C.I} = 10^{(\log(\mu))}$$

A3.6 Least Square Fit Pascal Program for $m = 2$ 'normalisation'

The Program shown below is useful when plotting the 'normalised' / theoretical E_d versus E_i lines because it gives out the E_d and E_i intercept points.

```
program least_fit(input,output);
var
    n          :integer;
    lx,ly,xc,yc,a,b,x,y : real;
    out        : text;

Procedure enter(var lx,ly,x,y : real;var n :integer);
var m : integer;
begin

    writeln('enter number of co-ordinates');
    readln(n);

    lx := 0;
    ly := 0;

For m := 1 to n do
begin
    writeln('enter x,y co-ordinate');

    readln(x,y);
    lx:= lx + ln(x);
    ly:= ly + ln(y);
end;
end;
begin
; assign(out,'con');
assign(out,'out.prn');
rewrite(out);
enter(lx,ly,x,y,n);

a:= (ly - (2*lx)) / n;
b:= -a/2;
yc:= exp(a);
xc:= exp(b);
writeln('value of y-axis intercept is':25,yc:30);
writeln('value of x-axis intercept is':25,xc:30);
close(out);
end.
```

**PART II THE COMPUTERISATION OF GONIO
PHOTOMETRIC MEASUREMENTS FOR
LUMINAIRE OUTPUT, DISTRIBUTION
AND GLARE CLASSIFICATION**

ACKNOWLEDGEMENTS

I would like to acknowledge Rob Clarence for his computer interfacing electronics and programming which allows the analogue photocell readings to be fed into the computer as digital values.

I would also like to acknowledge Matee Mohapi for his participation in introducing optical switches (infra red direction and position sensors) between the small photometer and computer.

I would also like to thank Dr. Einhorn for sharing some of his expert knowledge with me which allowed me to achieve my goal.

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GLOSSARY

uLOR...upward Light Output Ratio

dLOR...downward Light Output Ratio

LOR...Light Output Ratio

FFR...Flux Fraction Ratio

RI...Room Index

BZ...British Zonal (class)

DR...Direct Ratio

p...Guth Position Index [refer to diagram in Appendix 3]

$$1/p = [d^2 / (0.97d^2 + 2.3d + 4) - 0.1] \times \exp (-0.17s^2 / d + 0.013s^3 / d) + 0.09 \\ + (0.075 - 0.035 / d) / (1 + 3(s - 0.5)^2)$$

{ d ... forward distance of source/height = R/He

s ... sideways distance of source/height = T/He

(forward means in the direction of the line of sight; sideways means perpendicular to it; and height, He means height above eye level) }

TERMS OF REFERENCE

Dr H. D. Einhorn requested that the existing small photometer in the illumination lab at UCT be interfaced with a personal computer (PC) in a similar way to that of the mirror photometer. He requested the assignment as *partial* fulfilment of the requirements for the degree of M.Sc. in Engineering.

Dr Einhorn's specific instructions were:

1. To get the existing PC controlled mirror photometer, commissioned in 1992, working again.
2. To reconfigure and reprogram the mirror photometer for gamma, $\gamma = 2.5^\circ$ interval.
measurements from the existing $\gamma = 1^\circ$ interval measurements, at any chosen C-Plane.
3. To program and configure the small photometer for $\gamma = 5^\circ$ interval measurements.
4. To use the PC data obtained from the small photometer measurements to:
 - a) obtain intensity distribution plots for the lamp and/or luminaire, at any chosen C-Plane.
 - b) determine the uLOR, dLOR, LOR and FFR of the tested luminaire (see Glossary).
 - c) determine the Direct Ratio (D.R.) and BZ class of the tested luminaire, for different Room Indices (R.I.)
 - d) determine the Glare Class (Crosswise and Endwise) for the tested luminaire.
 - e) explain and demonstrate the use of the program in conjunction with the manual handling of the small photometer.

SYNOPSIS

The main body of this thesis involves the creation of software (in the form of Turbo Pascal programming) for the computerisation of a manually operated small photometer.

A 'graduated transparent disk' was made and fixed centrally in the small photometer to operate with existing optical switches. Turning the photometer activated the switches in accordance with their relation to the graduations on the disk. These signals fed an existing 'electronic box' which connected the photocell and computer: This way, the 'electronic box' would accept a photocell reading every 5°, convert it to a voltage, filter it, put it through an Analogue to Digital Converter(ADC) and make it available at a computer input port.

[See Appendix 3 for circuit diagrams ⁽¹⁾]

The Pascal programming then used those 'intensity' values to determine the photometrics of the luminaire being tested, computing lamp and luminaire flux, LORs, FFRs, the DR and BZ Class for different RIs, and the Glare Classification (crosswise and endwise).

The user had the flexibility of choosing: which photometer to use; the number of azimuth (C) planes to be used; whether or not the lamp and luminaire needed testing; and whether or not a Glare Class evaluation was needed. In the latter, the user could define the luminaire being tested as having either a 'Constant Luminance, L-const' or 'Area cosine, A-cos' characteristic.

The luminaires that were tested as samples included bare Fluorescent Channel, Winged Fluorescent and a down-lighter.

The program was also capable of evaluating luminaires on a nearby, large, mirror gonio-photometer at 2.5° gamma angle intervals. A street luminaire was used for this test.

1 INTRODUCTION

The requirement of computerising a *manually* operated small photometer was to dramatically speed up the process of photometry measurements. The existing mirror photometer driven by a 1.1KW 3 Phase Motor takes approximately 12 minutes for one revolution. To turn the small photometer through one revolution is a matter of seconds.

The small photometer is intended for *interior* lighting testing where intensities measured at $\gamma = 5^\circ$ intervals are adequate. The small photometer was therefore configured and programmed for $\gamma = 5^\circ$ interval measurements.

The mirror photometer is intended mainly for street light testing where intensities measured at $\gamma = 2.5^\circ$ intervals are adequate. The mirror photometer was therefore reconfigured and reprogrammed from the existing $\gamma = 1^\circ$ interval measurements to $\gamma = 2.5^\circ$ interval measurements.

The objectives of the assignment were:

1. to modify the existing $\gamma = 1^\circ$ interval operation of the mirror photometer to 2.5° intervals, and obtain intensity distribution plots at any number of chosen azimuth (C) plane lobes for tested luminaires.
2. to computerise the existing small photometer in a similar way to that of the mirror photometer, though without any motor involvement, with $\gamma = 5^\circ$ as opposed to $\gamma = 2.5^\circ$ interval operation.
3. to modify the existing PC photometry Pascal program *{gonio.pas}* to:
 - a) give the user the option of testing with the small *or* mirror photometer.
 - b) obtain / determine the following for luminaires tested on the small photometer:
 - i) the γ , c intensity distribution at any number of chosen c-plane lobes, with corresponding plots.
 - ii) the dLOR, uLOR, LOR and FFR.
 - iii) the D.R. and BZ class for different R.I.
 - iv) the Glare Class, Crosswise and Endwise.

The photometric specifications of a lamp and/or luminaire are vital to the user in deciding on what luminaire to use for a particular installation. The LOR, uLOR and dLOR of a luminaire are needed to establish the efficiency of the lamp, the amount of luminaire flux going up and the amount going down. The intensity distribution of a luminaire is needed to calculate the D.R. for different R.I. and establish the BZ class.

The report begins by outlining the *hardware* steps taken by the *Author* to computerise the small photometer and is very brief. Details of the *software* side of the computerisation are then given with explanations of how the objectives are to be fulfilled in the programming. The results are then presented followed by Conclusions and Recommendations. Operating instructions for the computer, Electronics Box and the small photometer are outlined in Appendix 1

2. THE HARDWARE INVOLVEMENT IN THE COMPUTERISATION OF THE SMALL PHOTOMETER

This involved the constructing and erecting of a graduated transparent disk. A donut shaped planar disk graduated at 5° intervals was created using the AutoCad computer package, and laser printed. This print was then photocopied onto a transparency to produce the graduated transparency like the one shown in Appendix 3, only smaller.

The parts of the transparency around the graduation, i.e. inside and outside, were then cut away with the remainder glued and bolted onto a transparent piece of perspex, identical in shape. This was now to be referred to as a 'graduated transparent disk', and was fixed centrally in the small photometer.

3. THE SOFTWARE INVOLVEMENT IN THE COMPUTERISATION OF THE SMALL PHOTOMETER

3.1 Details of the program which existed for the mirror photometer

In 1992 Rob Clarence wrote a Pascal program *{gonio.pas}* (see Appendix 2) for the PC interfaced mirror photometer which would record photocell measurements of tested luminaires at angular gamma steps of one degree. No facility in the program existed to specify at what C-Plane the luminaires were tested.

3.2 Details of the modified program

The modified program *{photometry.pas}* (see Appendix 2) uses the recording techniques of Clarence's program (the highlighted code in *photometry.pas*) with the option of testing a luminaire on the small or mirror photometer, and specifying the number of C-Plane lobes to be tested at.

A second, separate program, *{glareclass.pas}*, was written (see Appendix 2) to determine the Glare Class of a luminaire which was tested in the *photometry.pas* program.

The program displays the measured gamma intensities for each azimuth (C) angle on the screen and stores it on disk for import to a spread sheet where printouts and plots can be made.

3.2.1 Part of the program pertaining to the mirror photometer

This part of the code essentially does the same as Clarence's program (i.e. obtaining intensity values at particular gamma intervals) with some modifications and improvements. Instead of recording photocell measurements every $\gamma = 1^\circ$, they are now recorded every 2.5° , at a chosen number of C-Plane lobes.

3.2.2 Part of the program pertaining to the small photometer

The user has the option of measuring ‘just the lamp’, ‘just the luminaire’ or ‘both’.

If ‘just the lamp’ is chosen, then the program only calculates the lamp flux (once the ‘black test’ has been carried out)

If ‘just the luminaire’ is chosen it calculates the upward and downward flux of the luminaire, Φ_{up} and Φ_{dn} respectively, and the FFR. It also determines the DRs and BZ class of the luminaire for different RIs. The user also has the option of having the Glare Class of the luminaire determined by running the glareclass.pas program directly after

If ‘both’ is chosen then the program works out all of the above as well as the uLOR, dLOR and LOR.

3.2.2.a Determining the lamp flux

The lamp flux is determined by the K_a factor method whereby the lamp is measured from $\gamma = -90^\circ$ to $+90^\circ$ in the axial plane ($C = 90^\circ$)

A black cloth of negligible reflectance is placed between the lamp and the luminaire during the test to ensure that only the lamp is measured.

The lamp flux, Φ_L (in divisions) can be calculated from the following formula :

$$\Phi_L = 2\pi K_a L M_0 L$$

where: $M_0 L$ = the measured intensity value of the lamp at $\gamma = 0^\circ$ (in divisions)

$K_a L$ = the K_a factor of the lamp

$$= \pi \sum_{\gamma=-85}^{+85} \text{zonal flux} / 18 M_0 L$$

$$\text{i.e. } \Phi_L = \pi^2 / 9 \sum_{-85}^{+85} \text{zonal flux}$$

The zonal flux at a particular gamma angle is equivalent to the flux at that angle multiplied by the cosine of that angle. Zonal fluxes are calculated at 10° intervals from $\gamma = -85^\circ$ to $+85^\circ$.

To determine the lamp flux in meaningful units of lumens, a calibration of measured intensity (in divisions) and Actual intensity (in candelas) would have to be done with the use of a lux meter.

3.2.2.b Determination of the luminaire flux

The luminaire flux, Φ is determined by the zone factor method whereby the luminaire is measured from $\gamma = 0^\circ$ to 180° in a number of C Planes. Average intensity values (in divisions) are determined at $\gamma = 10^\circ$ intervals for $\gamma = 5^\circ$ to 175° , and multiplied by their corresponding zone factors to give the zonal fluxes, $\Delta\Phi$ at 10° intervals, for $\gamma = 5^\circ$ to 175° . The greater the number of C-Planes the greater the accuracy. The overall flux, Φ is the sum of all the zonal fluxes:

$$\Delta\Phi = I(\gamma) \times ZF(\gamma) \quad \text{where } ZF(\gamma) = 1.097 \sin(\gamma)$$

$$\Phi = \sum_{\gamma=5}^{175} \Delta\Phi = \sum_{\gamma=5}^{175} [I(\gamma) \times ZF(\gamma)]$$

The downward luminaire flux, Φ_{dn} is determined by the following equation:

$$\Phi_{dn} = \sum_{\gamma=5}^{85} [I(\gamma) \times ZF(\gamma)]$$

The upward luminaire flux, Φ_{up} is determined by the following equation:

$$\Phi_{up} = \sum_{\gamma=85}^{175} [I(\gamma) \times ZF(\gamma)]$$

The overall luminaire flux is the sum of the downward and upward luminaire flux.

i.e. $\Phi = \Phi_{dn} + \Phi_{up}$

Note that intensity distributions for particular C Planes can be measured separately

i.e. A Normal ($C = 0$) and an Axial ($C = 90$) intensity distribution plot for the luminaire is often of interest.

3.2.2.c Determining the uLOR, dLOR, LOR and FFR

The LOR of a luminaire is an expression of its efficiency and is given by the quotient of the luminaire and lamp flux. It can be considered the sum of the uLOR and dLOR

$$\text{i.e. } \text{LOR} = \text{uLOR} + \text{dLOR} = \Phi / \Phi_L$$

$$\text{where } \text{uLOR} = \text{luminaire flux up} / \text{lamp flux} = \Phi_{\text{up}} / \Phi_L$$

$$\text{dLOR} = \text{luminaire flux down} / \text{lamp flux} = \Phi_{\text{dn}} / \Phi_L$$

The FFR is the fraction of upward and downward luminaire flux:

$$\text{FFR} = \Phi_{\text{up}} / \Phi_{\text{dn}}$$

3.2.2.d Determining the Direct Ratios, (D.R.) and BZ class of the luminaire for different Room Indices (R.I.)

The D.R. is given by the proportion of the downward flux which directly strikes the working plane. The Room Index is given by the expression

$$\text{R.I.} = l.w / (l+w)h$$

where: l = length of room

w = width of room

h = height of luminaires above the working plane

i.e. a low R.I. corresponds to a high narrow room and
a high R.I. corresponds to a low large room.

A luminaire in a room with a low R.I. is obviously going to have a lower D.R. than the same luminaire in a room with a high R.I.

The D.R. for a different specified Room Indices is obtained by the zonal multiplier method whereby the 9 downward zonal fluxes are multiplied by the elements of a [9 x 9] zonal multiplier array, to give a [9 x 9] array of the products. The products in each column (corresponding to a particular R.I.) are totalled to give a [1 x 9] array of the total of the products. The Direct Ratios for each of these R.I.s is then given by the fractions of the product total and the downward luminaire flux, Φ_{dn} . (see Appendix 3)

The BZ classification of a luminaire is related to the intensity distribution of the luminaire but is determined by the D.R. of the luminaire. (see BZ, D.R., R.I. graph and table in Appendix 3).

A luminaire's BZ Class can change over to another BZ class with change in the R.I.

The tested luminaire's BZ Class for different R.I.'s is determined by comparing the luminaire's calculated [D.R, R.I.] array with 9 (one for each BZ class) predetermined [D.R, R.I.] arrays. The square of the differences for each BZ Class array is computed, and the least of these determines the BZ class for that particular R.I.

3.2.2.e Determining the Glare Class of luminaire, (Crosswise and Endwise)

The terms *crosswise* and *endwise* refer to the direction of viewing of an observer placed centrally at one end of a room, relative to the layout of the luminaires. If the luminaires are placed parallel to the line of sight (LoS) of the observer, i.e. lengthways, then the viewing is endwise. If the luminaires are placed perpendicular to the LoS of the observer, i.e. transverse, then the viewing is crosswise. (See Appendix 3)

The glare class of a luminaire is determined by the Initial Glare Index (IGI) for different sized rooms, each hosting the same type of luminaire equally spaced. The smaller the spacing, the higher the accuracy, but the longer the computation time. A spacing of 1m between luminaire centres was considered adequate, and was used in the program *glareclass.pas*. A spacing of 0.5m between perimeter luminaire centres and walls was assumed.

(i) Linear interpolation of experimentally measured gamma, C array.

For each room size (36 types considered in all; see Appendix 3), the gamma and azimuth (C) angles for each luminaire, Crosswise and Endwise, are calculated with respect to a seated observer centrally placed at one end of the room. The equations are :

$$C = \arctan (T/R) \text{ for crosswise mounting/viewing}$$

$$C = 90^\circ - \arctan (T/R) \text{ for endwise mounting/viewing}$$

$$\gamma = \arctan [(R^2 + T^2)^{1/2} / H]$$

where: R, T and H are the dimensions of length, width and height respectively between the observer's eyes and the luminaire centre. (see Appendix 3 for graphical illustration)

In the case of rotationally symmetric luminaires there is no distinction between Crosswise and Endwise. In this case the measured intensities at each gamma angle are averaged over all the measured C-Planes and only one Glare Class calculation is made.

The intensities of each luminaire towards the seated observer's eyes is obtained by interpolating the experimentally measured $[\gamma, c]$ array for the luminaire. In this program a *linear* interpolation was used in the gamma and azimuth directions.

(ii) Calculating the IGI (Crosswise and Endwise)

'The IGI is based on a reference downward flux (1000 luminaire lumens), reference luminaire size (0.1m^2) and flux fraction ratio (FFR = 0) and reference room reflectances ($\rho_c = 0.7$; $\rho_w = 0.5$; $\rho_f = 0.2$)', (Einhorn, *Discomfort Glare assessment in the New SA Code for interior lighting*, SANCI Congress 1994).

The IGI is given by the following:

$$IGI = 8 \log [0.785/E_i \sum (L^2 \omega / p^2)]$$

where: $L = I / A_p$ = the luminance of the source in the direction of the seated observer.

I = the intensity (in divisions), M towards the observer's eyes scaled for $\Phi_{dn} = 1000$ lumens
 $= f_1 M$ where $f_1 = 1000 / \Phi_{dn}$

I_0 = the intensity (in divisions) in the $\gamma = 0$ direction scaled for $\Phi_{dn} = 1000$ lumens

A_p = the projected area of the source (m^2)
 $= 0.1 \cos(\gamma)$ (for 'constant area' sources)
 $= 0.1 I/I_0$ (for 'constant luminance' sources)

ω = the solid angle of the source as seen by the seated observer = A_p/r^2 (st.r)

$$r^2 = R^2 + T^2 + H^2$$

p = the Guth position index (see Glossary)

E_i = the indirect illuminance at the eye (lux), and for IGI conditions can be approximated by the expression: $E_i = [0.21 - 0.07(x + y)/xy] \Phi_{dn1}$

Φ_{dn1} = the downward flux per $m^2 = f_1 \times \Phi_{dn} = 1000$

x = the room width in terms of $H_e = W/H_e$

y = the room length in terms of $H_e = L/H_e$

H_e = the height of the luminaires above eye level (m)

W = the width of the room (m)

L = the length of the room (m)

$$IGI = 8 \log [0.785/E_i \sum (I^2/A_p^2)(A_p/r^2)(1/p^2)] \quad \text{since } L = I/A_p \quad \text{and } \omega = A_p/r^2$$

$$= 8 \log [0.785/E_i \sum (I^2/(A_p r^2 p^2))]$$

$$\text{i.e. } IGI = 8 \log [0.785/E_i \sum (f_1^2 M^2 / (A_p r^2 p^2))] = 8 \log [\text{glare factor}]$$

Intensity interpolations and 'glare factor' summations are only done for each half of the rooms which are symmetrical. The resultant 'glare factors' for each room after all iterations are complete are then doubled to get the 'glare factors' for the full rooms. These factors are then used in the UGR formula above to obtain the IGIs for the full rooms.

(iii) Comparing experimental IGI tables with Standard IGI Tables for different Glare Classes.

The IGIs obtained experimentally for Crosswise and Endwise mounting for the 36 room sizes are then tabulated in a [6 x 6] array and compared with the 16 Standard IGI Tables (corresponding to the 16 different Glare Classes). The square of the difference is taken for each room size and totalled, and the Table which gives the lowest total is considered the best fit. This Table determines the Glare Class for that luminaire, either Crosswise or Endwise, depending on which experimental IGI table was used in the comparison

4. RESULTS

Four different interior-lighting luminaires were tested on the small photometer and one street light on the mirror photometer. Three of the interior luminaires were single tube 1.2m fluorescents and the other a 150W Pearl Incandescent Down Lighter. The one fluorescent luminaire was a Bare Channel and the other two had the addition of two different types of Wings.

In all the fluorescent lamp calculations an average K_a factor for the lamp of about 1.47 was calculated which is what is expected.

Intensity distribution graphs plotted in Cartesian co-ordinates were made for all the tested luminaires by importing the measured values into the spreadsheet EXCEL. For all Fluorescent luminaires, an axial normal and averaged intensity graph was plotted. No lamp calculation was done for the Down Lighter due to difficulties in doing a 'black test', but a BZ and Glare Class evaluation was done.

[Refer to Appendix 4 for all results]

4.1 Output for the Bare Fluorescent Channel (BFC)

Two separate tests were done on this luminaire: one with 8 C-Planes and one with 12 C-Planes Both tests resulted in identical BZ and Glare Class classifications, proving that for this intensity distribution 8 C -Planes were adequate.

The LOR was high (0.87) which is understandable for bare fluorescents since the surface area of the channel exposed to the lamp is relatively small compared with Winged Fluorescents. (The greater the area the more energy is absorbed) With a FFR of nearly 33% , a significant proportion of the light is going upward.

The BZ Class changed over from 7 to 6 between RIs of 1 and 2 which is quite acceptable. The reason for the *fluctuation* of the BZ numbers over the change-over region (i.e. from 7-6-7-6) is probably due to variances of readings from true values, and less likely to be a true representation of the luminaire.

The choice of an L_const description for this luminaire was appropriate. The Glare Class of GFC Endwise was expected but a Glare class of G10 Crosswise was a bit surprising as this is usually associated with long hanging unshielded luminaires. It happened however to be the closest fit under the not quite accurate assumption of 'constant luminance'

4.2 Output for the Winged Fluorescent Channel with cut-off at 90 degrees

For this luminaire the Glare Class program was run twice: once with the luminaire described as having an A_cos characteristic and once with an L_const characteristic

As expected the uLOR is almost negligible since the luminaire had cut-off at 90 degrees. The only upward flux came through slots in the back. A LOR of 0.73 seems reasonable for this type of luminaire, and as expected is significantly lower than that for the BFC

A BZ number of around 5 was expected for this luminaire, and a BZ of mostly 5 was what was obtained except for a BZ of 6 for the smallest room.

With a specified A_cos distribution the resultant Glare Classes were G5 Crosswise and G5 Endwise which is expected for a BZ number of 5. With a specified L_const distribution the resultant Glare Classes were G5 Crosswise and G45 Endwise. For a true BZ 5 luminaire, like a plane perfect diffuser, the Glare Class should be unchanged by using either the A_cos or L_const equations.

4.3 Output for the Winged Fluorescent Channel with cut-off at 95 degrees

For this luminaire the Glare Class program was run twice: once with the luminaire described as having an A_cos characteristic and once with an L_const characteristic

The BZ numbers were fairly evenly divided between numbers 6 and 5 which is also expected. A similar but slightly higher LOR of 0.77 was obtained for this luminaire (cf 4.2) because of the additional upward light.

With an A_{\cos} specification, Glare Classes of G10 and G5 were obtained for Crosswise and Endwise evaluation, respectively. This luminaire should not be specified as having an A_{\cos} distribution because there is still a fair intensity at $\gamma = 90$ degrees (The intensity should theoretically be zero at $\gamma = 90$ for true A_{\cos} distribution)

With an L_{const} definition, more expected Glare Classes of G5 Crosswise and G45 Endwise were obtained

4.4 Output for the 150W Pearl Incandescent Down Lighter

A BZ number of 1 was obtained for this luminaire which describes a $\cos^4\theta$ distribution. This is confirmed by observing that the intensity at 45 degrees is close to 25% of the I_0 value.

By observing the measured $[\gamma, C]$ array it can be seen that the luminaire does not have true rotational symmetry as expected. This was clarified when the Glare Class for Crosswise and Endwise evaluation were different: namely G12 Crosswise and G2 Endwise. A modification to the program then made which allows the user to specify whether or not the luminaire should have rotational symmetry. If it should, then the program computes an average intensity at each γ angle, and the glare evaluation program uses this array in determining just *one* Glare Class number. When this was done an overall Glare Class of G12 was obtained for this downlighter (see Appendix 4)

The results were obtained by using an A_{\cos} distribution. When an L_{const} definition was used there was a 'division by zero' in the program because some of the averaged intensities beyond 75 degrees were zero. In theory, all intensities before 90 degrees should be greater than zero, so a zero adjustment (see Appendix 1, A1.2) should be made before the next test.

4.5 Output for the Street Light luminaire

The luminaire was tested in the $C = 180$ degree plane for γ angles = 0 to 100 degrees. Note the sharp peak intensities around $\gamma = 70$ to 75 degrees which is typical of street lights. Note too that intensities are measured every 2.5 degrees

CONCLUSIONS AND RECOMMENDATIONS

On the whole the computerisation of the small photometer was a success, with all objectives being fulfilled.

The programming could have been improved by

1. Using a *quadratic* as opposed to *linear* interpolation of the measured intensities for the Glare Class determination program
2. Making full use of the every-5-degree measurements in the luminaire zone factor method by calculating over 18 zones as opposed to 9.

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APPENDIX 1

Operating Instructions for the computer, Electronics Box and the Small Photometer

A1. OPERATING INSTRUCTIONS FOR THE COMPUTER, ELECTRONICS BOX AND THE SMALL PHOTOMETER

A1.1 Getting the Program *photometry.pas* up and running

- 1.) Switch on the Computer
- 2.) At the A> type 'C:' and ENTER.
- 3.) At the C> type 'CD TURBOPAS' and ENTER
- 4.) At the C:\TURBOPAS> type 'TURBO' and ENTER

The Turbo Pascal editor will appear and **FILE** will be highlighted in the MENU

- 5.) Press ENTER twice and select LOAD on the pullout menu that appears and then press ENTER.
- 6.) From the *.PAS files choose PHOTOMETRY.PAS (abbreviated to PHOTOMET.PAS) and press ENTER. The program listing will appear on the screen.
- 7.) To run the program either
 - a) Press CTRL F9, or
 - b) (i) Press F10 to retrieve MENU
(ii) Select RUN and press ENTER
(iii) Select RUN from pull down MENU and press ENTER

A1.2 Making the necessary adjustments on the PhC.Pos Electronics Box

- 1.) Make sure all the plugs are inserted into their respective positions on the electronics box.
- 2.) Turn the LINEAR SETTING knob on the electronics box anti-clockwise until it stops. Then turn it clockwise until the red LED labelled NON LINEAR INDICATOR comes on. A slight tweak anti-clockwise will turn it OFF and ensure operation is in the linear region. (The voltage at the two green banana plug sockets on the front of the electronics box should be approximately 1.3V. This could be checked with a digital voltmeter.)
- 3.) After carrying out step 7 in section 4.1 the user is required to respond to a number of prompts before the photometry process can begin. This whole section will be explained in section 4.3 but for the mean time lets assume that we are ready to take measurements.
- 4.) By turning the small photometer in the prescribed direction, (or allowing the mirror photometer to turn automatically) the computer will record photocell measurements every 5 degrees (in the case of

- the small photometer) and every 2.5 degrees (in the case of the mirror photometer)
- 5.) Locate SPAN ADJUST on the electronics Box and adjust it so that measurements of around 200 appear on the screen.
 - 6.) Cover the box containing the photocell and repeat the above procedure for zero adjust using the knob labelled ZERO ADJUST on the electronics box.
 - 6.1) Note that negative values do not appear so be careful when making the zero setting. To check the setting repeat the above process with the photocell box open with a small amount of light falling onto the photocell. A low reading should appear on the screen. For most accurate results the zero setting can be made by calibration with a lux meter.
 - 7.) Once the zero adjust setting has been made, procedure 5 above should be repeated so that values around 230 appear on the screen at the angles where the intensities are expected to be the highest. Values approaching 255 should be avoided as this is the maximum possible output for the 8 bit ADC.
 - 8.) You are now ready to test the luminaire.

A1.3 Running through the Program

- 1.) After completing step 7 in 4.1 (which is running the program) a prompt to put the CAPSLOCK ON will appear. This is to ensure that all inputs (which are case sensitive with regard to 'strings') are in capital letters.
- 2.) The user is then reminded to place a correctly formatted disk into drive b: for storing the output. The program will not run right through to the end if no such disk is inserted.
- 3.) A prompt to select 'just the lamp', 'just the luminaire' or 'both' then emerges. The user is asked to enter '1' if just one or the other is to be tested and '2' if both lamp and luminaire are to be tested.
 - 3.1) If 'just the lamp' is chosen then only the lamp flux is calculated by means of the Ka factor method.
 - 3.2) If 'just the luminaire' is chosen then the upward, downward and total luminaire flux is calculated by means of the zone factor method together with the flux fraction ratio (FFR). The Direct Ratios (D.Rs) and BZ class for different Room Indices (R.Is) is then determined.
 - 3.3) If both luminaire and lamp are chosen then all the calculations in 3.1 and 3.2 are done as well as determining the upward, downward and overall Light Output Ratio (LOR).

- 4.) A prompt to select between the small and mirror photometer appears next and the user is asked to enter '5' for the small photometer and '2.5' for the mirror photometer. These numbers correspond to the gamma angle step that the intensities are recorded at.
- 4.1) If the choice is '2.5', then the user is prompted to choose the starting gamma angle (Th0); number of c-plane lobes (numcplanes) to be tested at, the starting azimuth angle (c0), the gamma angle through which to rotate (N) and the direction of rotation (d) clockwise or anti-clockwise.
- 4.2) If the choice is '5' then the user is prompted to choose the lamp (LP) or luminaire (LUM).
- 4.2.1) If 'LP' is chosen then the user is prompted in the same way as in 4.1 above.
- 4.2.2) If 'LUM' is chosen then the user is asked whether he/she wants a glare classification for the luminaire
- a) If the answer is 'YES' then the following settings are automatically made:
- Th0 = 0
- N = 180
- c0 = 0
- The user is still asked to choose the 'numcplanes' and the direction of rotation. All inputs and results from this run are stored in a file on hard drive and used in the program *glareclass.pas* at a later stage.
- b) If the answer is 'NO' then the user is prompted in the same way as in 4.1 above.

A1.4 Handling of the small photometer

After all responses to the computer prompts have been made, the user is asked to check that the photometer starting angle is correct and that the screen is orientated correctly. (The user is asked earlier to check that the starting azimuth angle is correct and that the correct infra red position sensor is plugged into the Pos.PhC electronics box).

If the choice in 4.2 above is 'LP' then the user is then invited to turn the photometer (slowly but steadily) through at least 'N' degrees in the prescribed direction. i.e. from gamma = -90 to +90 degrees in the axial plane when doing a 'black test'.

If the choice in 4.2 above is 'LUM' then turning the small photometer through the full 180 degrees from gamma = 0 to 180 degrees would not be ideal because the luminaires orientation with respect to the screen opening will be different for C-planes other than c = 0, 90, 180 and 270. The program is written so

that at $N/2$ degrees it halts and prompts the user to check, and change if need be, the orientation of the screen, so that it is OK thereafter. It is therefore quite acceptable to orient the $N/2$ degree mark and then to swing the photometer back again for the remaining $N/2$ degrees. After aligning the photometer on the $N/2$ mark the user must press ENTER and continue turning until the full N degrees has been completed.

A1.5 Glare Classification Program (*glareclass.pas*)

If the user responded 'YES' when prompted whether or not he/she wanted a glare classification of the luminaire, then at the end of the *photometry.pas* program the following steps are displayed on the screen to aid the user into running the *glareclass.pas* program immediately afterwards.

- 1) After pressing ENTER do the following:
- 2) press F10
- 3) select FILE and press ENTER
- 4) select LOAD and press ENTER
- 5) press ENTER again
- 6) select GLARECLASS.PAS and press ENTER
- 7) to RUN program press CTRL F9

After carrying out the above steps the computer displays the number of C-Planes chosen, the lobe angular spacing, the downward luminaire flux, and the factor f_1 ($= 1000 / \text{downward luminaire flux}$) obtained from the last run in the *photometry.pas* program. The user is then prompted to describe 'in a few words' the tested luminaire. e.g. Bare Fluorescent Channel. The user is then prompted as to whether the luminaire tested had an A_cos or L_const characteristic.

The experimental IGI tables for both crosswise and endwise layouts are then displayed after lengthy interpolation and iterations. After a 'least-square-of-the-differences' comparison of the experimental IGI tables and the standard ones, the Glare Class of both endwise and crosswise layouts is determined for the tested luminaire.

A1.6 Flow Diagram

STEP (Gamma), 2.5 or 5 [2.5 = SMALL PHOTOMETER
5 = BIG PHOTOMETER]

KEY

TH θ = STARTING GAMMA ANGLE

numplanes = NUMBER OF C-PLANE LOBES

C θ = STARTING AZIMUTH ANGLE

N = GAMMA ANGLE TO ROTATE

d = DIRECTION ROTATION

Lamp (Lp) OR Lum (Lum)

2.5

5

Lp

Lum

GLARE CLASSIFICATION (Y/N)?

N

Y

TH θ = ? numplanes = ? C θ = ? N = ? d = ?

TH θ = ? numplanes = ?
C θ = 0, N = 180, d = ?
[OBTAIN GLARE CLASS (glareglass.par)]

MEASURE = 1 OR 2 [1 = LAMP OR LUMINAIRE ; 2 = BOTH]

1

2 BOTH

Lp

Lum

Luminaire Flux [ϕ_{up}, ϕ_{dn}]

Lamp Flux

Luminaire Flux [ϕ_{up}, ϕ_{dn}]

Lamp Flux [Ka Factor Method]

FFR

DRs

B7 CLASS

FFR, LOR [dLOR, uLOR]

DRs B7 class

APPENDIX 2

Pascal Programs

- *photometry.pas*
- *glareclass.pas*

photometry.pas

Program **photometry** (input,output);

uses crt;

```
CONST  BASE = $210;    { addresses of pc-14 interface card }
      PORTA = BASE;    {input port for ADC intensity readings}
      PORTB = BASE + $1; {output port for mirror photometer
                          contactors}
      PORTC = BASE + $2; {input port monitoring the state of the
                          position and direction of rotation of the
                          photometer}
      (CONTROLP = BASE + $3; {control port})

VAR    GCinten :ARRAY[1..40,1..36] of integer; {g,c intensity array}
      gc-info : array[1..3] of real; {contains the chosen number of
                                      cplane lobes, the angular
                                      spacing between the lobes, and
                                      the gamma angle through which
                                      the photometer is rotated}

      zonefac : array[1..10] of real; {stores zone factors}
      Ave-Inten : array[1..20] of real; {stores average
                                          luminaire intensities}
      Lp-Inten : array[1..20] of real; {stores average
                                          lamp intensities}
      bzclassif : array[1..10] of integer; {stores calculated BZ
                                             numbers for different
                                             room indices}
      drzonalflux : array[1..20] of real; {stores Fdn zonal fluxes}
      zonalmult : array[1..10,1..10] of real; {contains zonal
                                                multipliers}
      product : array[1..10,1..10] of real; {store inter-mediate}
      prodtots : array[1..10] of real; {values in the Direct}
                                          {Ratios calculation}
      directratios : array[1..10] of real; {stores calculated D.Rs}
      zonalflux : array[1..20] of real; {stores Fup zonal fluxes and
                                          lamp zonal fluxes for C = 90}
      BZarray : array[1..9,1..9] of real; {stores BZ table}
      LUMdata : array[1..4] of real; {stores lum Fdn in divisions,
                                      factor f1 (where f1 = 1000/lum
                                      Fdn), lum Fup, and the calc
                                      lamp flux in divisions}
      gcdata : file of real; {stores gc-info array data for
                              glareclass.pas program}
      lumgcdata : file of integer; {stores lum GCinten array data
                                     for glareclass.pas program}
      photometm : file of real; {stores LUMdata array data}
      zonemult : text; {text file}
      lumtextdata :text; {buffer for lum GCinten array}
      lptextdata :text; {buffer for lamp G,C=90 inten array}
      out: text; {buffer for output file}
      bzclass :text; {buffer for zonal multiplier array}
```

```

DCCLKH, DCCLKL, DACCLKH, DACCLKL : BYTE; { direction and impulse
                                         sensing }
Yes, pos, answer, crep, response, lp, lum, choice, reply :      STRING;

I, TH0, N, D, CC, CAC, cplanes, cmax, numcplanes, bz, A, W, B, M,
s, t, X, Y, Z, angle, j, k, measure, meas, gamma :             INTEGER;

gsumlamp, val, ka, kaL, lor, ulor, dlor, prod, gsumup, least, sq,
gsumdn, FFR, c0, c, c1, Q, e, step, cspace, lumflux, lumfluxdn,
lumfluxup, lampflux, fl :                                     REAL;

```

BEGIN

```

clrscr; {clear screen}
repeat
  writeln('All entries must be in CAPITAL LETTERS !!!');
  writeln('enter YES when CAPS LOCK light on keyboard is ON');
  writeln;
  readln(reply);
until reply = 'YES';
writeln;
writeln
('MUST have correctly formatted disk in drive B to store output');
writeln('press ENTER when this is done');
readln;
writeln;
writeln('Do you want measurements of both the lamp and the luminaire');
writeln('or just one or the other ?');
writeln;
writeln('Enter 2 for both');
writeln('Enter 1 for one');
writeln;
readln(measure);
meas:=0;
assign(out, 'b:test.txt');
rewrite(out);
repeat
  meas := meas + 1;
  D := 0; {initializing variables}
  N := 0;
  TH0 := 0;
  e := 0;
  step := 0;
  Q := 0;
  W := 0;
  s := 0;
  c := 0;
  t := 0;
  cplanes:= 0;

```

```

cspace := 1;      {avoid divide by zero}
cmax := 0;
response := 'N';
ClrScr;
DCCLKH := $3;
DCCLKL := $2;
DACCLKH := $1;
DACCLKL := $0;   {4 different states of PORT C}
port[portb] := $00; {de-energize contactors}
writeln('enter angular gamma step in degrees :');
writeln;
writeln('choose 5 for small photometer');
writeln('choose 2.5 for mirror photometer');
readln(step);
if step = 5 then
begin
  writeln('Do you want to measure LAMP or LUMINAIRE ?');
  writeln('enter LP for LAMP');
  writeln('enter LUM for LUMINAIRE');
  readln(choice);
  IF choice = 'LUM' then
  begin
    writeln
      ('Do you want a glare class classification for this luminaire ?');
    writeln(' Y or N');
    readln(response);
  end;
end;
if response = 'Y' then
begin
  writeln('do you want to measure anti-clockwise or clockwise ?');
  writeln('ENTER 1 for anticlockwise');
  writeln('ENTER 2 for clockwise');
  readln(d);
  if d = 1 then d := 2
  else d := 1; {to be consistent with mirror photometer}
  TH0 := 0;
  N := 180;
  gc-info[1] := N;
  i := 0;
  writeln('enter number of c-plane lobes');
  readln(numcplanes);
  gc-info[3] := numcplanes;
  cspace := 360/numcplanes;
  gc-info[2] := cspace;
  c := 0;
end
else
begin
  writeln('Starting gamma angle in degrees = ');

```

```

readln(TH0);
repeat
  writeln('enter YES when photometer positioned at ',th0:2,' degrees');
  readln(pos);
until pos = 'YES';
writeln('Enter number of cplane lobes');
readln(numcplanes); {means number of cplane lobes}
writeln('Enter starting Azimuth (c) angle in degrees');
readln(c);
ospace := 360/numcplanes;
writeln('Gamma Angle through which you wish to rotate = ');
writeln('-----'); {emphasizing through as opposed to to}
readln(N);
writeln('Direction of rotation 1 = Anti-Clockwise, 2 = Clockwise ');
writeln('Please enter 1 or 2');
readln(D);
if step = 5 then
begin
  if d = 1 then d := 2
  else d:= 1; {to be consistent with mirror photometer}
end;
end;
repeat
  writeln('-----');
  writeln('Enter YES when you are sure that all that needs to be ');
  writeln('switched ON is ON and that the correct INFRARED, POSITION ');
  writeln('INDICATOR is plugged into the POS./Ph.C box and that there');
  writeln('will be adequate clearance between the two photometers');
  writeln('-----');
  readln(answer);
until answer = 'YES';
ClrScr; {clear screen}
c0 := c;
c1 := c;
cplanes := 0; {initialize counter}
repeat
  repeat
    clrscr;
    writeln('enter YES when luminaire/lamp positioned at c = ',c0:3:1,
      ' degrees');
    writeln('and photometer screen orientated correctly');
    readln(crep);
  until crep = 'YES';
  cplanes := cplanes + 1; {cplane lobes counter}
  writeln;
  PORT[CONTROLP] := $99; { control word to I/O, port A = input,
    C = input, B = output}
  PORT[PORTB] := $00; { clears port B, contactors de-energised }
  If D = 1 then

```

```

begin
  if step = 2.5 then PORT[PORTB] := $01 { activates clockwise
                                         contactor for mirror
                                         photometer}

  else IF choice = 'LP' then
    writeln
    ('turn small photometer SLOWLY through at least ',n:2,' degrees
     clockwise')
    else
    writeln
    ('turn small photometer SLOWLY through at least ',(n/2):2:0,'
     degrees clockwise'); {turn through half the desired angle so that
     the screening can be altered if need be at g = 90 degrees}
    I := 1; { initialise counter for entering values into array }
    Q := th0; { initialize gamma angle counter}
    repeat
      (CC := 0;) { initialise delay counter }
      (if PORT[PORTC] = DCCLKH then) { if the goniometer is }
      begin { turning clockwise and the pulse is }
        { high then read the a/d converter }

        repeat
          (CC := CC + 1;`
          until (CC = 4000; {delay}
          ( GCinten[i,cplanes]:= PORT[PORTA]; { store the value of the a/d }
          ( writeln(q:5:1,GCinten[i,cplanes]:5); {value to screen }
          IF Q = 90 then
            begin
              if choice = 'LUM' then
                begin
                  Writeln('make sure screening correct hereafter 90 degrees');
                  writeln('ensure photometer in 90 degree position');
                  writeln(' then press ENTER');
                  readln;
                  writeln
                    ('continue turning clockwise for atleast another 90 degrees');
                end
              else
                end;
            (i := i + 1; {gamma intensity array counter}
            (q := q + step; {gamma angle counter}
            repeat
              until (PORT[PORTC] = DCCLKL; {wait until the the pulse goes low }
              repeat
                until (PORT[PORTC] = DCCLKH) { wait until the pulse is high again }
            end
            else
            begin
              repeat
                until (PORT[PORTC] = DCCLKH) { if clk is low when first read then

```

```

                                wait }

end;
until(Q > (N + th0)); {stop when full gamma angle been turned through}
PORT[PORTB] := $00; { zero port B to de-energise the contactors }
end
else
begin                                { see clk condition for comments }
  if step = 2.5 then
    PORT[PORTB] := $02 {activates anti-clk contactor }
  else IF choice = 'LP' then
    writeln
    ('turn small photometer SLOWLY through at least ',n:2,' degrees
     clockwise')
  else
    writeln
    ('turn small photometer SLOWLY through at least ',(n/2):2:0,' degrees
     anti-clockwise');
    I := 1;
    Q := th0;
    repeat
      CAC := 0;
      IF PORT[PORTC] = DACCLKH THEN
        begin
          repeat
            CAC := CAC + 1;
          until CAC = 4000;
          GCinten[i,cplanes] := PORT[PORTA];
          writeln( Q:5:1,GCinten[i,cplanes]:5);
          IF Q = 90 THEN
            begin
              if choice = 'lum' then
                begin
                  Writeln('make sure screening correct hereafter 90 degrees');
                  writeln('ensure photometer in 90 DEGREE position');
                  writeln(' then press ENTER');
                  readln;
                  writeln
                  ('continue turning anti-clockwise for atleast another
                   90 degrees');
                end
              else
                end;
            end;
          i := i + 1;
          q := q + step;
          repeat
            until PORT[PORTC] = DACCLKL;
          repeat
            until PORT[PORTC] = DACCLKH;
          end
        end
      end
end

```

```

else
begin
  repeat
    until PORT[PORTC] = DACCLKH
  end;
  until (Q > (N + th0));
  PORT[PORTB] := $00;
end;
PORT[PORTB] := $00;
c0 := c0 + cspace;
until cplanes = numcplanes; {until all cplane lobes been measured at}
if response = 'Y' then
begin
  cplanes := 0;
  assign (lumgcdata, 'C:\TURBOPAS\TEMP\lumgc.dat');
  rewrite(lumgcdata);
  repeat
    cplanes := cplanes + 1;
    i := 1;
    q := th0;
    repeat
      write(lumgcdata, GCinten[i, cplanes]); {sending the intensity
                                              array data to a file HARD
                                              drive for glareclass.pas
                                              program}

      i := i + 1;
      q := q + step;
    until q = (n + step + th0);
    c := c + cspace;
  until cplanes = numcplanes;
  close(lumgcdata);
  begin
    i := 0;
    assign(gcdata, 'C:\TURBOPAS\TEMP\gcinfo.dat');
    rewrite(gcdata);
    for i := 1 to 3 do
      begin
        write(gcdata, gc-info[i]);
      end;
    close(gcdata);
  end;
end;
clrscr;
Writeln('press ENTER to see calculations');
readln;
clrscr;
if step = 5 then
begin
  if choice = 'LUM' then

```

```

begin
  assign(lumtextdata, 'b:lumcalc.TXT');
  rewrite(lumtextdata);
  write(lumtextdata, 'g , c ':8);
  for j:= 1 to numcplanes do
  write(lumtextdata, (j-1)*cspace:8:0);
  writeln(lumtextdata);
  writeln(lumtextdata, '-----
  -----');
  for i:= 1 to trunc(N/step + 1) do
  begin
    write(lumtextdata, step*(i-1)+Th0:8:0);
    for j := 1 to numcplanes do
      begin
        write(lumtextdata, GCinten[i,j]:8); {sending lum Gcinten array
        to file in b: drive}
      end;
    writeln(lumtextdata);
  end;
  close(lumtextdata);
  write(out, 'g':10);
  write('g':10);
  k:=0;
  for k:= 1 to 9 do
  begin
    gamma := (-5 + k*10);
    write(out, gamma:7);
    write(gamma:7);
  end;
  writeln;
  writeln(out);
  i := 0;
  j := 0;
  k := 0;
  if TH0 < 85 then {if starting angle is > 85 then no Fdn}
  begin
    write(out, 'Ave-Inten':10);
    write('Ave-Inten':10);
    repeat
      i:=i+2;
      gsumdn := 0;
      for j:= 1 to numcplanes do
      begin
        gsumdn := gsumdn + GCinten[i,j] ;
      end;
      k:=k+1;
      Ave-inten[k] :=(gsumdn / numcplanes); {calculate average downward
      zonal intensities}
    until k=9;
    write(out, Ave-Inten[k]:7:1);
  end;
end;

```

```

    write(Ave-Inten[k]:7:1);
until k = 9;  {until all 9 zones complete}
readln;
writeln(out);
k:=0;
angle := 5;   {starting angle}
write(out,'zf':10);
write('zf':10);
repeat
    k:=k+1;
    zonefac[k] := 1.097 * sin(angle*3.14159/180);    {calculating zone
                                                    factors for each
                                                    10 degree gamma
                                                    spacing}

    angle := angle + 10;   (next zonal angle)
    write(out,zonefac[k]:7:3);
    write(zonefac[k]:7:3);
until k = 9;
readln;
writeln(out);
k:= 0;
lumfluxdn := 0;
write(out,'Zonal Fdn':10);
write('Zonal Fdn':10);
for k:= 1 to 9 do
begin
    drzonalflux[k] := Ave-Inten[k] * zonefac[k];    {calculate downward
                                                    zonal fluxes}
    lumfluxdn := lumfluxdn + Ave-Inten[k] * zonefac[k]; {determines
                                                    total downward
                                                    flux in
                                                    divisions}

    write(out,drzonalflux[k]:7:1);
    write(drzonalflux[k]:7:1);
end;
readln;
writeln(out);
writeln(out);
writeln;
write(out,'Lum Fdn = ':6);
write('Lum Fdn = ':6);
write(out,lumfluxdn:6:0);
write(lumfluxdn:6:0);
readln;
writeln(out);
writeln(out);
writeln;
f1 := 1000/lumfluxdn;    {factor f1 used in glareclass.pas program
                        since IGI based on a downward lum flux of 1000}
LUMdata[1] := f1;

```



```

    angle := angle + 10;
    write(out,zonefac[10-k]:7:3);
    write(zonefac[10-k]:7:3);
until k = 9;
readln;
writeln(out);
k:= 0;
lumfluxup := 0;
write(out,'Zonal Fup':10);
write('Zonal Fup':10);
for k:= 1 to 9 do
begin
    zonalflux[k] := Ave-Inten[k] * zonefac[10-k];    {calculate upward
                                                    zonal fluxes}
    lumfluxup := lumfluxup + Ave-Inten[k] * zonefac[10-k]; {determines
                                                            total upward
                                                            flux in
                                                            divisions}

    write(out,zonalflux[k]:7:1);
    write(zonalflux[k]:7:1);
end;
readln;
writeln(out);
writeln(out);
writeln;
write(out,'Lum Fup = ':6);
write(out,lumfluxup:6:1);
writeln(out);;
writeln;
write('Lum Fup = ':6);
write(lumfluxup:6:1);
writeln;
writeln;
writeln(out);
writeln(out);
lumflux:= lumfluxup + lumfluxdn;    {total lum flux in divisions}
write(out,'total lum flux = ':10);
write('total lumflux = ':10);
write(out,lumflux:6:0);
write(lumflux:6:0);
writeln;
writeln(out);
writeln(out);
writeln;
LUMdata[3] := lumfluxup;
end;
if (N + TH0) > 95 then    {then both Fup and Fdn measured}
begin
    write(out,'FFR':8);
    writeln(out);

```

```

    FFR := LUMdata[3]/LUMdata[2];    {FFR = Fup / Fdn}
    write(out,FFR:8:4);
    writeln(out);;
    write('FFR':8);
    writeln;
    write(FFR:8:4);
    readln;
end;
end
else    {lamp calculation}
begin
    assign(lptextdata,'b:lpcalc.TXT');
    rewrite(lptextdata);
    write(lptextdata,'g , c ':8);
    for j:= 1 to numcplanes do
    write(lptextdata,(j-1)*cspace:8:0);
    writeln(lptextdata);
    writeln(lptextdata,'-----
                        -----');
    for i:= 1 to trunc(N/step + 1) do
    begin
        write(lptextdata,step*(i-1)+Th0:8:0);
        for j := 1 to numcplanes do
        begin
            write(lptextdata,GCinten[i,j]:8);    {sending lamp G,C=90 intensity
                                                    array to file in b: drive}

        end;
        writeln(lptextdata);
    end;
    close(lptextdata);
    i := 0;
    j := 0;
    k := 0;
    repeat
        i:= i+2;
        k:=k+1;
        Lp-Inten[k] := GCinten[i,1];
    until k = 18;
    i:=0;
    k:=0;
    angle := -85;    {starting angle for axial calculation}
    repeat
        k:=k+1;
        zonefac[k] := cos(abs(angle*3.14159/N));    {calculating ka zone
                                                    factors for each 10
                                                    degree gamma spacing}

        angle := angle + 10;    {next zonal angle}
    until k = 18;    {until all zones complete}
    k:= 0;

```

```

ka := 0;
val := 0;
for k:= 1 to 18 do
begin
  i:=i +2;
  zonalflux[k] :=GCinten[i,1] * zonefac[k];    {calculating lamp zonal
                                               fluxes}
  val := val + GCinten[i,1] * zonefac[k];    {used in calculating KaLp}
end;
write(out, 'g':10);
write(out, 'Lp-Inten':10);
write(out, 'ka zf':10);
write(out, 'zonal Fdn':15);
writeln(out);
write('g':10);
write('Lp-Inten':10);
write('ka zf':10);
write('zonal Fdn':15);
readln;
for k:= 1 to 18 do
begin
  gamma:= -95 + 10*k;
  write(out, gamma:10);
  write(out, GCinten[2*k,1]:10);
  write(out, zonefac[k]:10:3);
  write(out, zonalflux[k]:15:1);
  writeln(out);
  write(gamma:10);
  write(GCinten[2*k,1]:10);
  write(zonefac[k]:10:3);
  write(zonalflux[k]:15:1);
  readln;
end;
readln;
writeln(out);
writeln(out);
writeln;
write(out, 'kaLp factor':6);
writeln(out);
write('kaLp factor':6);
writeln;
ka := (3.14159 * val)/(18 * Gcinten[19,1]);    {Ka factor for the
                                               lamp, KaLp}

write(out, ka:6:3);
writeln(out);
writeln(out);
write(out, 'Lamp Flux = ':10);
write(ka:6:3);
readln;
writeln;

```

```

write('Lamp Flux = ':10);
lampflux := ka * 2 * 3.14159 * Gcinten[19,1];    {calculating lamp
                                                    flux in divisions}

write(out,lampflux:10:0);
write(lampflux:10:0);
writeln;
writeln(out);
LUMdata[4] := lampflux;    {total lamp flux}
end;
if meas = 2 then    {if both lamp and luminaire measured}
begin
  writeln(out);
  write(out,'dLOR':8);
  write(out,'uLOR':8);
  write(out,'LOR':8);
  writeln(out);
  writeln;
  write('dLOR':8);
  write('uLOR':8);
  write('LOR':8);
  writeln;
  dlor := LUMdata[2]/LUMdata[4];    {dLOR = lum Flux dn / lamp flux}
  ulor := LUMdata[3]/LUMdata[4];    {uLOR = lum Flux up / lamp flux}
  lor := dlor + ulor;
  write(out,dlor:8:3);
  write(out,ulor:8:3);
  write(out,lor:8:3);
  writeln(out);
  writeln(out);
  write(dlor:8:3);
  write(ulor:8:3);
  write(lor:8:3);
  writeln;
  readln;
end;
if choice = 'LUM' then
begin
  k:= 0;
  if response = 'Y' then
  begin
    assign(photometm,'C:\TURBOPAS\TEMP\lumflux.dat');
    rewrite(photometm);
    for k:= 1 to 2 do
    begin
      write(photometm,LUMdata[k]);    {factor f1 needed for IGI
                                       calculation so stored in hard drive}

    end;
    close(photometm);
  end;
end;

```

```

end;
readln;
writeln(out);
end;
if step = 2.5 then    {send mirror photometer Gcinten array to file in
                    b: drive}}
begin
  assign(lumtextdata,'b:gcmirror.TXT');
  rewrite(lumtextdata);
  write(lumtextdata,'g , c ':8);
  for j:= 1 to numcplanes do
  write(lumtextdata,(j-1)*cspace:8:0);
  writeln(lumtextdata);
  writeln(lumtextdata,'-----');
  for i:= 1 to trunc(N/step + 1) do
  begin
    write(lumtextdata,step*(i-1):8);
    for j := 1 to numcplanes do
    begin
      write(lumtextdata,GCinten[i,j]:8);
    end;
    writeln(lumtextdata);
  end;
  close(lumtextdata);
end;
{DISPLAYING INTENSITIES IN DIVISIONS IN TABLES NEATLY ON SCREEN AT EACH
AZIM.(C) ANGLE BELOW( All code until the line marked with '*****')}

writeln('press ENTER to see tables');
readln;
clrscr;
cplanes := 0;
repeat
cplanes := cplanes + 1;
writeln(out,' Azimuth Angle, C =',c1:3:1,' degrees');
writeln(' Azimuth Angle, C =',c1:3:1,' degrees');
c1 := c1 + cspace;
q := th0;
i := 1;
if th0 = 0 then
begin
  writeln(out);
  writeln;
  write(out,'Ga':6);
  write('Ga':6);
  write(out,q:6:0);
  write(q:6:0);
  writeln(out);

```

```

writeln;
write(out, 'Io':6);    {displays Io value separately}
write('Io':6);
write(out, GCinten[i, cplanes]:6);
write(GCinten[i, cplanes]:6);
writeln(out);
writeln;
Q := th0 + step;
i := 2;
end;
repeat
  s:=0;
  writeln(out);
  writeln;
  write( out, 'Ga':6);
  write('Ga':6);
  repeat
    if step = 2.5 then
      begin
        write(out, q:6:1);
        write(q:6:1);
      end
    else
      begin
        write(out, q:6:0);
        write(q:6:0);
      end;
    q := q + step;
    s := s + 1;
    if q > (n + th0 ) then
      begin
        t := s;
        s := 9;
      end;
  until s mod 10 = 9;    {9 values on one line}
  writeln(out);
  writeln;
  s := 0;
  if q > (n + th0 ) then s := (9 - t);
  write(out, 'I':6);
  write('I':6);
  repeat
    write(out, GCinten[i, cplanes]:6);
    write(GCinten[i, cplanes]:6);
    i := i + 1;
    s := s + 1;
  until s mod 10 = 9;    {nine values on one line}
  writeln(out);
  writeln;

```

```

until q > (n + th0 );
writeln;
writeln(out);
if cplanes = numcplanes then write('press ENTER to clear the screen')
else write('press ENTER for remaining tables');
readln;
writeln(out);
clrscr;
until cplanes = numcplanes;
until meas = measure;           {*****}
if choice = 'LUM' then
begin
  i:= 0;
  j:= 0;
  writeln('zonalmultipliers from C:');
  writeln;
  assign(zonemult,'C:\TURBOPAS\TEMP\zonemult.dat');
  reset(zonemult);
  for i:= 1 to 9 do
begin
  for j := 1 to 9 do
begin
    read(zonemult,zonalmult[i,j]);   {calling up zonal multiplier array
                                     from hard drive}
    write(zonalmult[i,j]:6:2);
end;
end;
  close(zonemult);
  i:= 0;
  writeln;
  j:= 0;
  for i := 1 to 9 do   {Direct Ratio calculation starts here}
begin
  for j := 1 to 9 do
begin
    product[i,j] := drzonalflux[i] * zonalmult[i,j];
end;
end;
  i:= 0;
  j:= 0;
  for j := 1 to 9 do
begin
  prod := 0;
  for i := 1 to 9 do
begin
    prod := prod + product[i,j];
end;
  prodtots[j] := prod;
end;

```

```

i:= 0;
j:= 0;
for i:= 1 to 9 do
begin
  directratios[i] := prodtots[i]/lumfluxdn;    {determining direct ratios
                                                for each room index}
end;
writeln(out,'Direct Ratios for this luminaire for different R.I');
writeln(out);
write(out,'RI':7);
write(out,'0.8':7);
write(out,'1.0':7);
write(out,'1.25':7);
write(out,'1.5':7);
write(out,'2.0':7);
write(out,'2.5':7);
write(out,'3.0':7);
write(out,'4.0':7);
write(out,'5.0':7);
writeln(out);
writeln(out);
write(out,'D.R':7);
writeln('Direct Ratios for this luminaire for different R.I');
writeln;
write('RI':7);
write('0.8':7);
write('1.0':7);
write('1.25':7);
write('1.5':7);
write('2.0':7);
write('2.5':7);
write('3.0':7);
write('4.0':7);
write('5.0':7);
writeln;
writeln;
write('D.R':7);
i:= 0;
for i:= 1 to 9 do
begin
  write(out,directratios[i]:7:3);
  write(directratios[i]:7:3);    {displays DR for each room index}
end;
writeln;
writeln(out);
writeln(out);
readln;
begin
  i:=0;
  sq:= 0;

```

```

j:= 0;
assign(bzclass,'c:\turbopas\temp\bzclass2.dat');
reset(bzclass);
writeln('BZ DR-RI table from hard drive');
writeln;
for i:= 1 to 9 do
begin
  for j:= 1 to 9 do
  begin
    read(bzclass,BZarray[i,j]);    (calling up BZ classification table
                                   from hard drive)

    write(BZarray[i,j]:5:2);

  end;
  writeln;
  readln;
end;
close(bzclass);
end;
i:= 0;
j:= 0;
for j:= 1 to 9 do    {9 different room indices}
begin
  least := 1000000;    {initialize least value and make impossibly high}
  for i := 1 to 9 do    {9 BZ direct ratios for each room index}
  begin
    sq:=  sqr(directratios[j] - bzarray[i,j]);    {square of the difference
                                                    totals between calculated
                                                    and standard tables}

    if sq < least then
    begin
      bzclassif[j] := i;    {BZ classification array:  9 BZ numbers
                        determined for 9 room indices}

      least:= sq;    {update least value}
    end;
  end;
end;
writeln;
writeln(out);
writeln
(out,'The BZ classification of this luminaire for different RI:');
writeln(out);
write(out,'RI':6);
write(out,'0.8':6);
write(out,'1.0':6);
write(out,'1.25':6);
write(out,'1.5':6);
write(out,'2.0':6);
write(out,'2.5':6);
write(out,'3.0':6);

```

```

write(out, '4.0':6);
write(out, '5.0':6);
writeln(out);
writeln(out);
write(out, 'BZ no.':6);
writeln('The BZ classification of this luminaire for different RI:');
writeln;
write('RI':6);
write('0.8':6);
write('1.0':6);
write('1.25':6);
write('1.5':6);
write('2.0':6);
write('2.5':6);
write('3.0':6);
write('4.0':6);
write('5.0':6);
writeln;
writeln;
write('BZ no.':6);
i:= 0;
for i:= 1 to 9 do
begin
  write
    (out,bzclassif[i]:6);    {displaying determined BZ classification array}
  write(bzclassif[i]:6);
end;
writeln;
writeln(out);
readln;
writeln(out);
clrscr;
end;
if response = 'Y' then
begin
  writeln('write down the following instructions before pressing ENTER');
  writeln('After pressing ENTER do the following:');
  writeln('press F10');
  writeln('select FILE and press ENTER');
  writeln('select LOAD and press ENTER');
  writeln('press ENTER again');
  writeln('select GLARECLASS.PAS and press ENTER');
  writeln('to RUN program press CTRL F9');
  readln;
end;
close(out);
END.□

```

glareclass.pas

```

program glareclass(input,output);    {determines the glare class of a
                                         tested luminaire, endwise and
                                         crosswise}

uses crt;
CONST gstep = 5;    {angular gamma step}
    He = 2;    {height of luminaires above eye level}
VAR GCinten :ARRAY[1..40,1..36] of integer;    {g,c intensity array
                                                from photometry.pas
                                                program}

    gc-info : array[1..3] of real;    {contains the chosen number of
                                         cplane lobes, the angular
                                         spacing between the lobes, and
                                         the gamma angle through which
                                         the photometer was rotated}

    expIGitablex :array[1..6,1..6] of real;    {experimental
                                                crosswise IGI table}
    expIGitablee :array[1..6,1..6] of real;    {experimental
                                                endwise IGI table}
    IGItables : array[1..6,1..6] of real;    {standard IGI tables
                                                buffer}

    LUMdata : array[1..3] of real;    {contains lum Fdn in divisions
                                         and factor f1
                                         where f1 = 1000/lum Fdn}

    photometm : file of real;    {contains LUMdata array data}
    lumgcdata : file of integer;    {containing GCinten array data}
    gcdata : file of real;    {containing gc-info array data}
    igidata : text;    {contains standard IGI tabes}
    glare : text;    {text file for output}

source,classx,classe,reply,YES,N,LC,AC,G1,G1S,G2,G2S,G3,G3S,G4,G4S,
G5,G6B,G8,G9B,G10,GDI,GFL,GFC,description :    STRING;

p,q,firstx,secx,thirdx,fourthx,length,width,firste,sece,thirde,
fourthe,pointerx,pointere,tab,display,i,j,x,y,l,w,k,angle,gtrunc,
ctruncx,ctrunce,totMo :    INTEGER;

Lx,Rx,Mx,Le,Re,Me,grem,cremx,creme,cansx,canse,Apee,Mo,Apxx,cmax,SS,
DD,lumfluxdn,gans,leastx,leaste,sqdifsx,sqdifse,NN,d,s,g,cx,ce,
cstep,rr,recipp,gix,gie,ei,f1,numclanes :    REAL;

```

BEGIN

```

    clrscr;
    y := 0;
    x := 0;
    Lx := 0;
    Rx := 0;
    Mx := 0;
    Le := 0;
    Re := 0;
    Me := 0;

```

```

p := 0;
q := 0;
firstx := 0;
secx := 0;
thirdx := 0;
fourthx := 0;
firste := 0;
sece := 0;
thirde := 0;
fourthe := 0;
gtrunc := 0;
ctruncx := 0;
ctrunce := 0;
g := 0;
cx := 0;
ce := 0;           {initializing}
begin
  assign(gcdata, 'C:\TURBOPAS\TEMP\gcdata.dat');
  reset(gcdata);
  i:= 0;
  for i:= 1 to 3 do
    begin
      read(gcdata,gc-info[i]);
    end;
  close(gcdata);
end;
reply := 'N';
repeat
  writeln('All entries MUST be in CAPITAL letters');
  writeln
  ('enter YES when when the CAPSLOCK light on keyboard is ON');
  readln(reply);
until reply = 'YES';
clrscr;
writeln('in a few words describe the tested fitting, e.g. Bare
Flourescent Channel');
readln(description);
writeln('Could the luminaire you tested last be described');
writeln('as having an L_const or A_cos characteristic?');
writeln;
writeln('enter LC for L_const');
writeln('enter AC for A_cos');
readln(source);
If source = LC then
assign(glare, 'b:\LCigis.PRN');
else if source = AC then
assign(glare, 'b:\ACigis.PRN');
else writeln('You chose neither.  press CTRL F9 to re-run');
rewrite(glare);
writeln(glare, 'The luminaire description was: ',description);

```

```

writeln(glare,'The luminaire was described as having an '
writeln(source,' characteristic);
numcplanes := gc-info[3];    {no. of cplane lobes}
cstep := gc-info[2];    {angular spacing between lobes}
NN := gc-info[1];    {gamma range = 180 degrees}
write('number of cplane lobes = ');
writeln(numcplanes:6:0);
write('lobe angular spacing = ');
writeln(cstep:6:0);
write(glare,'number of cplane lobes = ');
writeln(glare,numcplanes:6:0);
write(glare,'lobe angular spacing = ');
writeln(glare,cstep:6:0);
readln;
writeln(glare);
begin
  assign(lumgcdata,'C:\TURBOPAS\TEMP\lumgc.dat');
  reset(lumgcdata);
  for j := 1 to trunc(numcplanes) do
    begin
      for i := 1 to trunc(NN/gstep + 1) do
        begin
          read(lumgcdata,GCinten[i,j]);
        end;
      end;
      close(lumgcdata);
    end;
  totMo := 0;    {initializing Mo total value}
  For j:= 1 to trunc(numcplanes) do
    begin
      totMo := totMo + Gcinten[1,j];    {summed Mo values}
    end;
  Mo := totMo / trunc(numcplanes);    {average Mo value}
  i := 0;
  j := 0;
  write(' g , c ':5);
  write(glare,' g , c ':5);
  for j := 1 to trunc(numcplanes) do
    begin
      write((j-1)*cstep:5:0);
      write(glare,(j-1)*cstep:5:0);
    end;
  writeln;
  writeln(glare);
  writeln('
-----
-----');
  writeln(glare,'
-----
-----');
  for i := 1 to 19 do

```

```

begin
write(5*(i-1):5);
write(glare,5*(i-1):5);
for j := 1 to trunc(numcplanes) do
begin
write(GCinten[i,j]:5);    {displaying g,c array for downward
                           intensities}
write(glare,GCinten[i,j]:5);
end;
readln;
writeln(glare);
writeln(glare);
end;
begin
i:= 0;
assign(photometm,'C:\TURBOPAS\TEMP\lumflux.dat');
reset(photometm);
for i:= 1 to 2 do
begin
read(photometm,LORdata[i]);
end;
close(photometm);
end;
writeln(glare);
writeln;
lumfluxdn := LORdata[2];
write(glare,'Lum Flux Down':20);
write(glare,lumfluxdn:8:2);
write('Lumfluxdn':20);
write(lumfluxdn:8:2);
writeln;
writeln;
writeln(glare);
writeln(glare);
f1 := LORdata[1];
write('f1 = 1000/Lumfluxdn = ':20);
write(f1:8:3);
write(glare,'Factor f1 = 1000/Lumfluxdn = ':20);
write(glare,f1:8:3);
readln;
writeln(glare);
writeln(glare);
i := 0;
j := 0;
k := 0;
for p:= 1 to 6 do    {6 different room size lengths}
begin
if p = 1 then length := 4;
if p = 2 then length := 6;

```

```

if p = 3 then length := 8;
if p = 4 then length := 12;
if p = 5 then length := 16;
if p = 6 then length := 24;

for q:= 1 to 6 do    {6 different room size widths}
  begin
    if q = 1 then width := 4;
    if q = 2 then width := 6;
    if q = 3 then width := 8;
    if q = 4 then width := 12;
    if q = 5 then width := 16;
    if q = 6 then width := 24;

    DD := 0.5;    {nearest luminaire is 0.5m forward}
    d := DD/He;   {forward distance in terms of He}
    gix := 0;    {initializing xwise and endwise glare summation
    gie := 0;    terms}
    writeln;
    writeln
    ('room dimensions : x = ',(width/2):3:0,' and y = ',
    (length/2):3:0);
    writeln;

    for L := 1 to trunc(length) do
      begin
        SS := 0.5;    {nearest luminaire is 0.5m sideways}
        s := SS/He;   {sideways distance in terms of He}

        for W := 1 to trunc(width/2) do    {calc for only half the
                                                room}
          begin
            g := (180 / 3.14159) * arctan(sqrt(d*d + s*s));
              {calculated gamma value for particular luminaire}
            cx := (180 / 3.14159) * arctan(s/d);
              {calculated xwise C value for particular luminaire}
            ce := 90 - cx;
              {calculated endwise C value for particular luminaire}
            gans := g/gstep;    {c, gamma linear interpolation begins
              here}
            gtrunc := trunc(gans);
            grem := g/gstep - gtrunc;
            cansx := cx/cstep;    {xwise interpolation}
            ctruncx := trunc(cansx);
            cremx := cx/cstep - ctruncx;
            firstx := GCinten[(gtrunc + 1),(ctruncx + 1)];
            secx := GCinten[(gtrunc + 2),(ctruncx + 1)];
            thirdx := GCinten[(gtrunc + 1),(ctruncx + 2)];
            fourthx := GCinten[(gtrunc + 2),(ctruncx + 2)];
            Lx := (firstx + (grem * (secx - firstx)));
          end
        end
      end
    end
  end

```

```

Rx := (thirdx + (grem * (fourthx - thirdx)));
Mx := (Lx + (cremx * (Rx - Lx))); {interpolated
                                   Intensity value in
                                   divisions for each
                                   xwise luminaire }

canse := ce/cstep;   (endwise interpolation)
ctrunc := trunc(canse);
creme := ce/cstep - ctrunc;
firste := GCinten[(gtrunc + 1), (ctrunc + 1)];
sece := GCinten[(gtrunc + 2), (ctrunc + 1)];
thirde := GCinten[(gtrunc + 1), (ctrunc + 2)];
fourthe := GCinten[(gtrunc + 2), (ctrunc + 2)];
Le := (firste + (grem * (sece - firste)));
Re := (thirde + (grem * (fourthe - thirde)));
Me := (Le + (creme * (Re - Le))); {interpolated
                                   Intensity value
                                   in divisions for
                                   each endwise
                                   luminaire }

recipp:= (d*d/(0.97*d*d+2.3*d+4)-0.1)*
          exp(-0.17*s*s/d+0.013*s*s*s/d)+0.09+
          (0.075-0.035/d)/(1+3*(s-0.5)*(s-0.5));
          {recipp = 1/p where p = Guth Position Index}
RR := (SS * SS) + (DD * DD) + (He * He);

if source = 'LC' then
begin
  Apxx := (Mx / Mo) * 0.1;   {projected area xwise}
  Apee := (Me / Mo) * 0.1;   {projected area endwise}
end;
if source = 'AC' then
begin
  Apxx := 0.1 * cos(g*3.14159/180);   {projected area
                                       xwise}
  Apee := 0.1 * cos(g*3.14159/180);   {projected area
                                       endwise}
end;
  readln;
end;

gix := gix + (Mx*Mx * recipp*recipp / (Apxx * RR)) *f1*f1;
{multiply each Mx value by f1 for IGI conditions of Fdn = 1000}
gie := gie + (Me*Me * recipp*recipp / (Apee * RR)) *f1*f1;
{multiply each Me value by f1 for IGI conditions of Fdn = 1000}

SS := SS + 1;   {luminaires spaced 1m apart transversely}
s := SS/He;
{igi glare summation procedure above}
end;

```

```

    DD := DD + 1; {luminaires spaced 1m apart longitudinally}
    d := DD/He;
end;

Ei := (0.21 - 0.07 * (length/2 + width/2) / {indirect}
      (length * width/4)) * lumfluxdn * f1 ; {illuminance
                                             approximation}
{multiply lumfluxdn by f1 for IGI conditions of
 Fdn = 1000 lumens per m^2}

expIGItablex[p,q] := (8/2.3) * ln(0.785 * 2 * gix / Ei);
                    {calculation for IGI xwise}
                    {*2 for full room}
expIGItablee[p,q] := (8/2.3) * ln(0.785 * 2 * gie / Ei);
                    {calculation for IGI xwise}
                    {*2 for full room}

write('IGIX':10);
write('IGIE':10);
writeln;
write(expIGItablex[p,q]:10:1);    {displaying experimental
                                  IGI's for each room for
                                  xwise layout}
write(expIGItablee[p,q]:10:1);    {displaying experimental
                                  IGI's for each room for
                                  endwise layout}

writeln;
end;
end;
writeln;
writeln
(glare,'IGI table (experimental) for CROSSWISE layout');
writeln
('IGI table (experimental) for CROSSWISE layout');
writeln;
For p:= 1 to 6 do
begin
  For q:= 1 to 6 do
    begin
      write(glare,expIGItablex[p,q]:6:1);
      write(expIGItablex[p,q]:6:1);    {displaying experimental
                                       xwise IGI table}

    end;
    readln;
    writeln(glare);
  end;
  writeln(glare);
  writeln;
  writeln(glare,'IGI table (experimental) for ENDWISE layout');
  writeln('IGI table (experimental) for ENDWISE layout');

```

```

writeln(glare);
writeln;
For p := 1 to 6 do
  begin
    for q := 1 to 6 do
      begin
        write(glare,expIGItablee[p,q]:6:1);
        write(expIGItablee[p,q]:6:1);    {displaying experimental
                                         endwise IGI table}

      end;
    readln;
    writeln(glare);
  end;
begin
  assign(igidata,'c:\turbopas\temp\bp.dat');
    {file containing standard IGI tables}
  reset(igidata);
  i := 0;
  j := 0;
  leastx := 10000000;    {start with rediculously high least}
  leaste := 10000000;    {square of the difference values}
  pointerx := 0;
  pointere := 0;
  tab := 0;    {initialization}

  repeat
    for i := 1 to 6 do
      begin
        for j := 1 to 6 do
          begin
            read(igidata,IGItables[i,j]);
          end;
        end;
        i := 0;
        j := 0;
        sqdifsx := 0;
        sqdifse := 0;    {initialization}
        for i := 1 to 6 do
          begin
            for j := 1 to 6 do
              begin
                sqdifsx := sqdifsx + sqr(IGItables[i,j]-
                                         expIGItablex[i,j]);
                sqdifse := sqdifse + sqr(IGItables[i,j]-
                                         expIGItablee[i,j]);
              end;
            {summing the square of the differences between the
             experimental and standard IGI tables for both
             xwise and endwise layouts}
          end;
        end;
      end;
end;

```

```

tab := tab + 1;    {IGI table counter}
if sqdifsx < leastx then
begin
  leastx := sqdifsx;    {update the lowest least square of
                        the differences value xwise}
  pointerx := tab;    {points to the table giving lowest
                      least square of the differences xwise
                      value}

end;
if sqdifse < leaste then
begin
  leaste := sqdifse;    {update the lowest least square of
                        the differences value endwise}
  pointere := tab;    {points to the table giving lowest
                      least square of the differences
                      endwise value}

end;
i := 0;
j := 0;
until tab = 16;    {all 16 tables been compared with
                  experimental tables}

if pointerx = 1 then classx := 'G1';
if pointerx = 2 then classx := 'G12';
if pointerx = 3 then classx := 'G2';
if pointerx = 4 then classx := 'G23';
if pointerx = 5 then classx := 'G3';
if pointerx = 6 then classx := 'G34';
if pointerx = 7 then classx := 'G4';
if pointerx = 8 then classx := 'G45';
if pointerx = 9 then classx := 'G5';
if pointerx = 10 then classx := 'G6B';
if pointerx = 11 then classx := 'G8B';
if pointerx = 12 then classx := 'G9B';
if pointerx = 13 then classx := 'G10';
if pointerx = 14 then classx := 'GDI';
if pointerx = 15 then classx := 'GFL';
if pointerx = 16 then classx := 'GFC';

if pointere = 1 then classe := 'G1';
if pointere = 2 then classe := 'G12';
if pointere = 3 then classe := 'G2';
if pointere = 4 then classe := 'G23';
if pointere = 5 then classe := 'G3';
if pointere = 6 then classe := 'G34';
if pointere = 7 then classe := 'G4';
if pointere = 8 then classe := 'G45';
if pointere = 9 then classe := 'G5';
if pointere = 10 then classe := 'G6B';

```

```
if pointere = 11 then classe := 'G8B';
if pointere = 12 then classe := 'G9B';
if pointere = 13 then classe := 'G10';
if pointere = 14 then classe := 'GDI';
if pointere = 15 then classe := 'GFL';
if pointere = 16 then classe := 'GFC';
```

```
writeln;
writeln(glare);
writeln(glare);
writeln(glare,'GLARE CLASS IS : ',CLASSx:3,' CROSSWISE');
writeln(glare,'GLARE CLASS IS : ',CLASSE:3,' ENDWISE');
writeln('GLARE CLASS IS : ',CLASSx:3,' CROSSWISE');
writeln('GLARE CLASS IS : ',CLASSE:3,' ENDWISE');
readln;
close(igidata);
```

end;

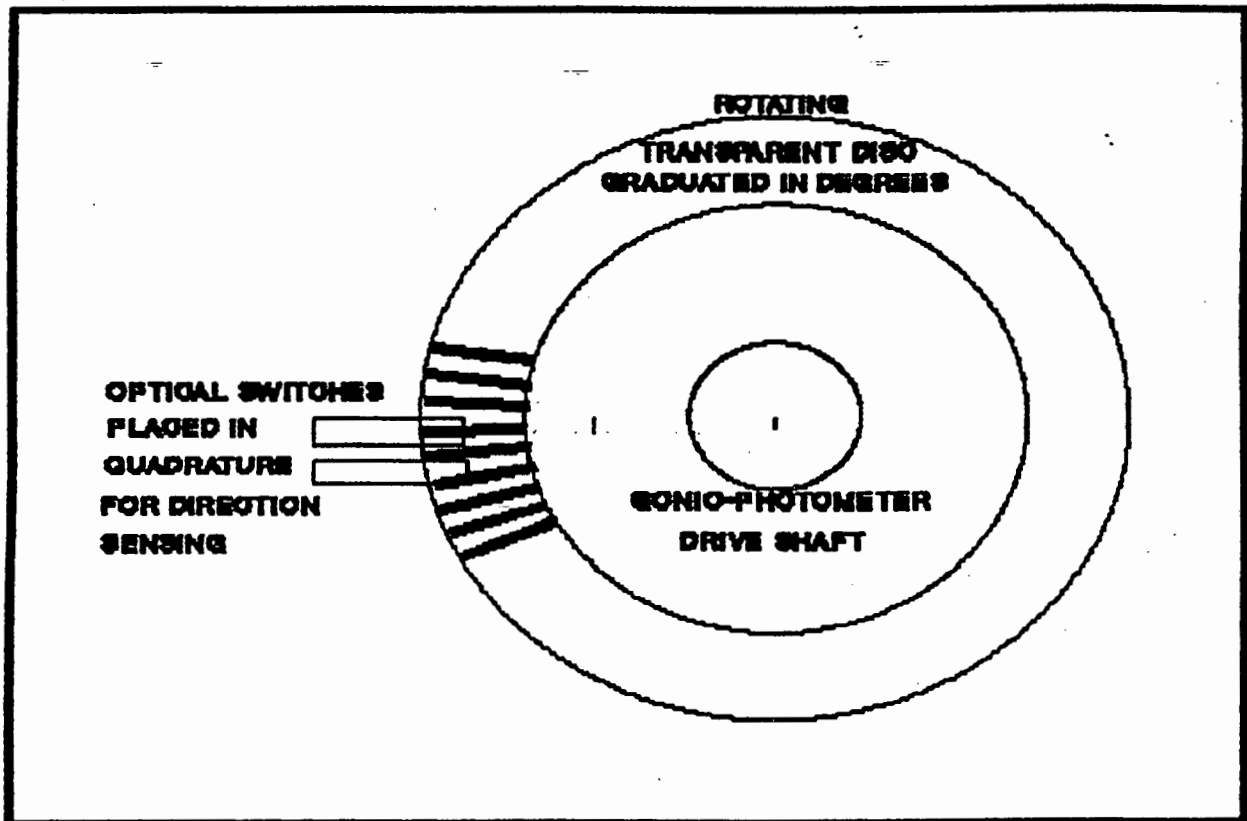
```
close(glare);
writeln;
writeln('press ENTER to return to program');
readln;
```

END.□

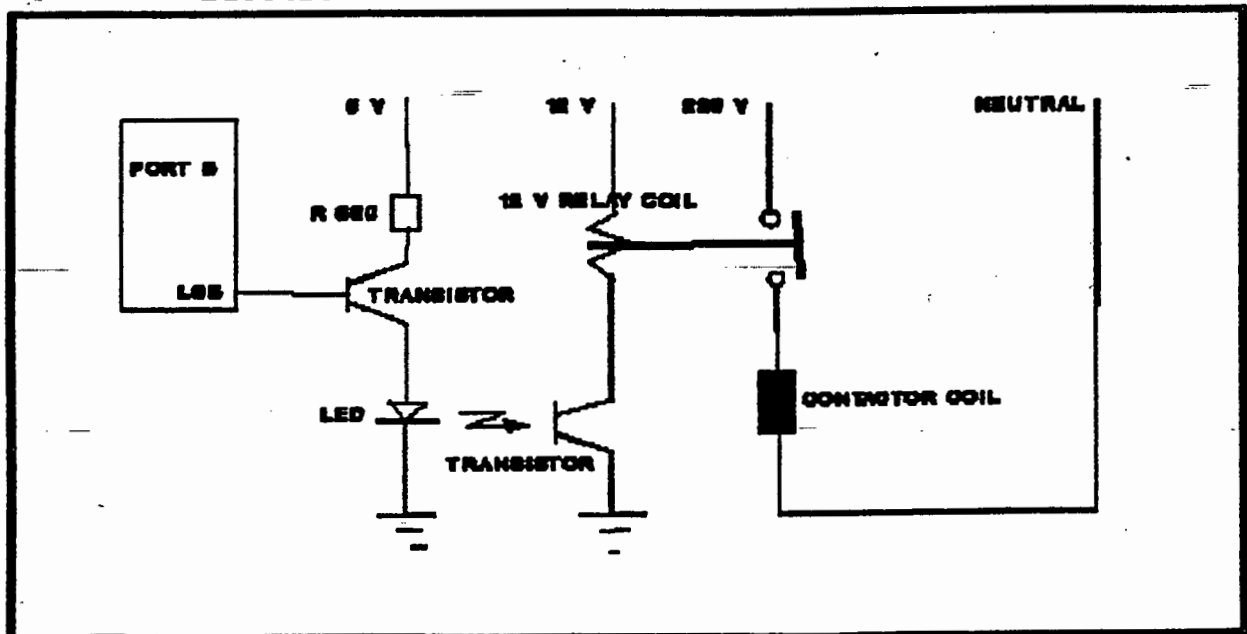
APPENDIX 3

Miscellaneous

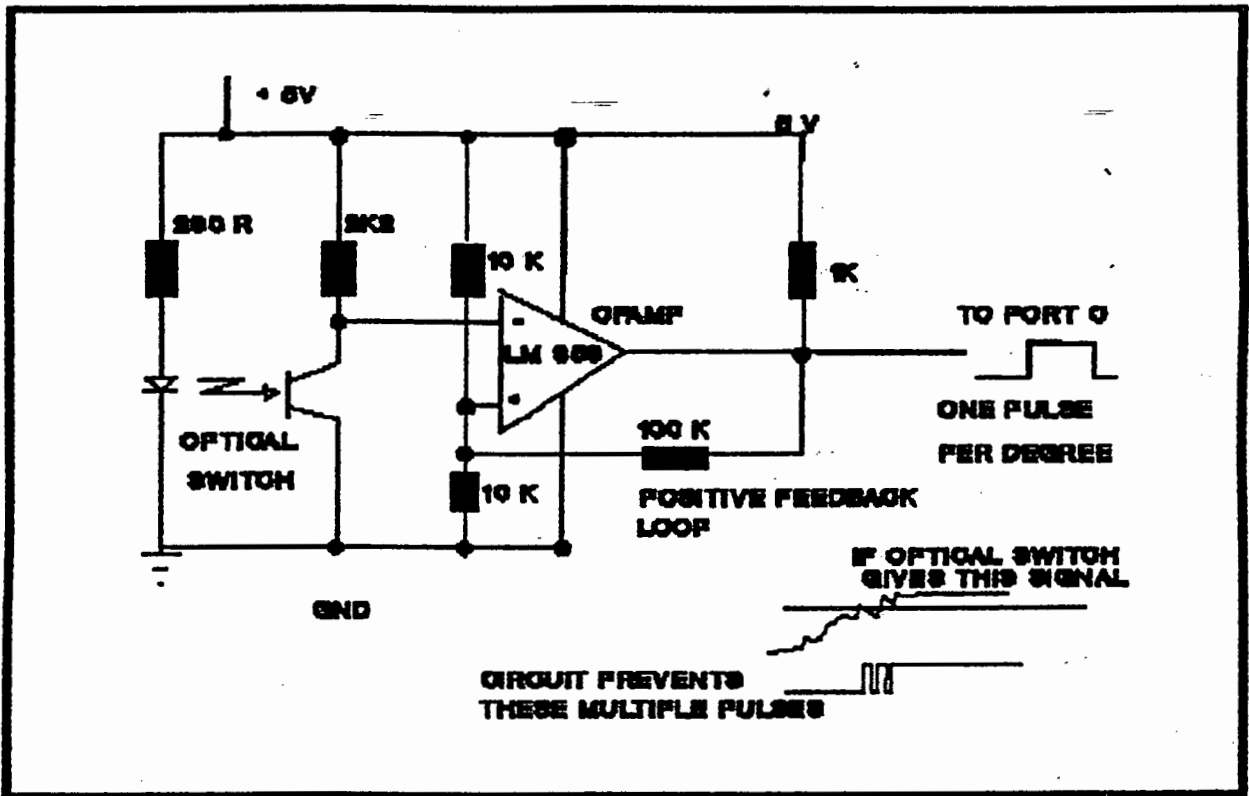
Position Sensor.



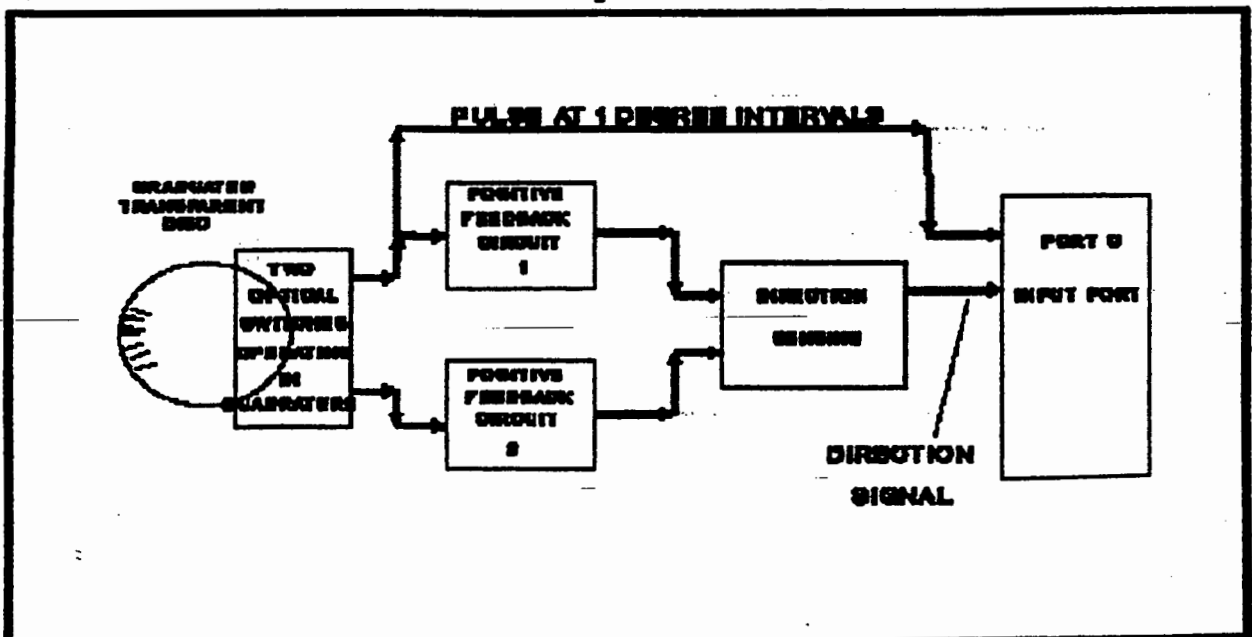
Electronic Circuit for Port B.



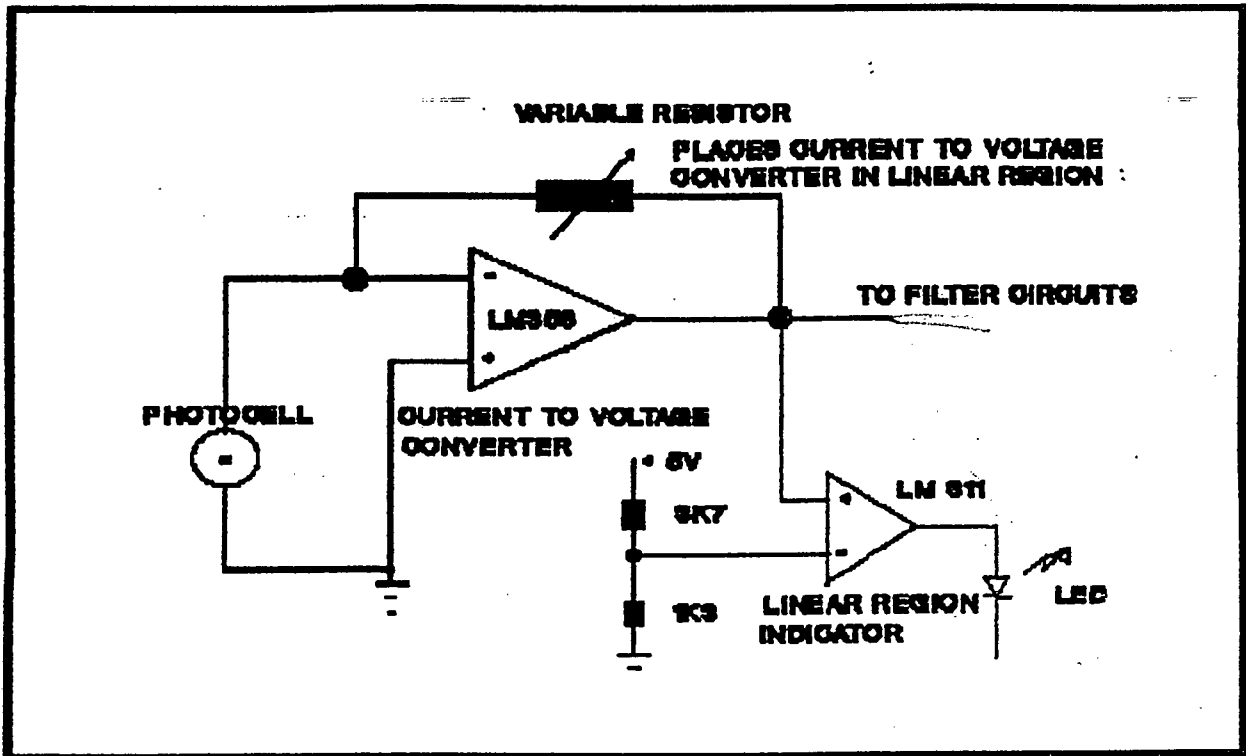
Positive Feedback Circuit.



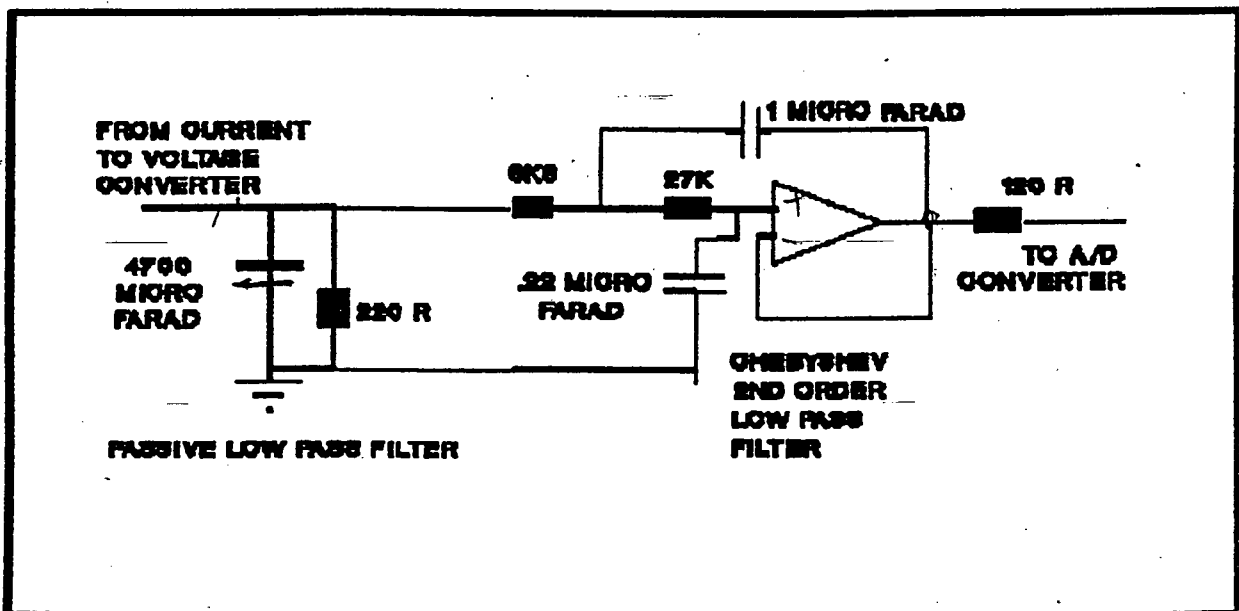
Path of Pulse from Optical Switch to Port C



Current to Voltage Converter.



Low Pass Filters.



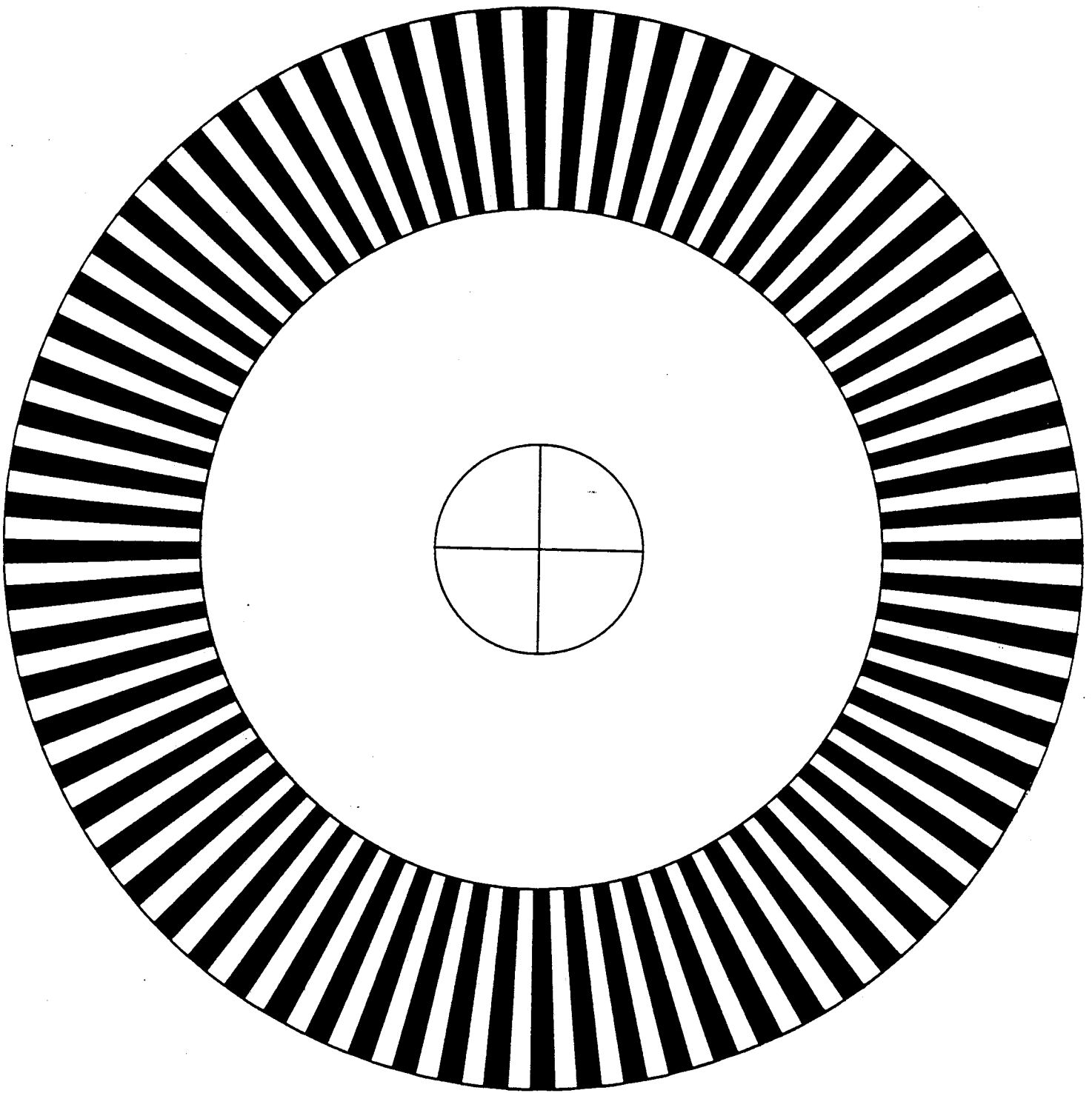


Table 1a Zonal multipliers for small sources

Room index (k_r)		0.6	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
S/H _m ratio	Zone	Zonal multipliers									
0.5	0-10°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	10-20°	0.79	0.84	0.88	0.90	0.92	0.94	0.95	0.96	0.97	0.98
	20-30°	0.51	0.62	0.70	0.76	0.79	0.84	0.88	0.90	0.92	0.94
	30-40°	0.39	0.53	0.62	0.69	0.74	0.80	0.84	0.87	0.90	0.92
	40-50°	0.15	0.32	0.44	0.54	0.61	0.70	0.76	0.80	0.85	0.88
	50-60°	—	0.12	0.26	0.38	0.47	0.59	0.66	0.72	0.78	0.82
	60-70°	—	—	0.30 0.23	0.13	0.25	0.40	0.51	0.58	0.68	0.74
	70-80°	—	—	—	—	0.01	0.10	0.21	0.31	0.46	0.56
	80-90°	—	—	—	—	—	—	—	—	0.04	0.10
0.75	0-10°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	10-20°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	20-30°	0.53	0.65	0.72	0.78	0.815	0.86	0.89	0.91	0.93	0.94
	30-40°	0.27	0.45	0.55	0.63	0.69	0.77	0.81	0.84	0.88	0.90
	40-50°	0.22	0.37	0.47	0.57	0.64	0.72	0.77	0.81	0.86	0.89
	50-60°	—	0.08	0.22	0.36	0.46	0.58	0.66	0.71	0.78	0.82
	60-70°	—	—	0.01	0.14	0.26	0.41	0.51	0.59	0.68	0.74
	70-80°	—	—	—	—	0.01	0.10	0.21	0.31	0.46	0.55
	80-90°	—	—	—	—	—	—	—	—	0.05	0.10
1.0	0-10°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	10-20°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	20-30°	0.85	0.89	0.91	0.93	0.94	0.96	0.97	0.97	0.98	0.98
	30-40°	0.19	0.38	0.52	0.61	0.68	0.76	0.81	0.84	0.88	0.90
	40-50°	0.09	0.29	0.42	0.52	0.59	0.69	0.75	0.79	0.84	0.87
	50-60°	0.02	0.16	0.29	0.39	0.49	0.61	0.68	0.73	0.80	0.83
	60-70°	—	—	0.02	0.14	0.24	0.40	0.51	0.58	0.68	0.74
	70-80°	—	—	—	—	0.01	0.10	0.21	0.31	0.46	0.56
	80-90°	—	—	—	—	—	—	—	0.01	0.05	0.10
1.25	0-10°	1.00 ⁺	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	10-20°	1.00 ⁺	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	20-30°	1.00 ⁺	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	30-40°	0.47 ⁺	0.58	0.66	0.73	0.77	0.83	0.87	0.89	0.91	0.93
	40-50°	0.01	0.19	0.32	0.47	0.54	0.65	0.73	0.76	0.82	0.86
	50-60°	—	0.10	0.26	0.40	0.50	0.60	0.67	0.72	0.79	0.83
	60-70°	—	—	—	0.13	0.23	0.40	0.51	0.58	0.68	0.74
	70-80°	—	—	—	—	—	0.11	0.22	0.32	0.46	0.56
	80-90°	—	—	—	—	—	—	—	—	0.05	0.10
1.5	0-10°	*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	10-20°	*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	20-30°	*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	30-40°	*	0.87	0.90	0.92	0.93	0.95	0.96	0.97	0.97	0.98
	40-50°	*	0.17	0.34	0.47	0.55	0.67	0.73	0.78	0.83	0.87
	50-60°	*	0.03	0.18	0.31	0.43	0.55	0.63	0.70	0.77	0.81
	60-70°	*	—	0.08	0.18	0.27	0.42	0.53	0.60	0.69	0.75
	70-80°	*	—	—	—	0.01	0.10	0.22	0.32	0.47	0.56
	80-90°	*	—	—	—	—	—	—	0.01	0.05	0.10

+ For Room index = 0.625

* Impossible

566 = I₀
 .998
 .989
 .956
 .926
 .867
 .726
 .477
 .175
 .048

Description of fitting			1 x 80W Fluorescent Direct / Indirect																		S/H _m ratio		1.5	
Zone (deg)	Photometric data			ROOM INDEX																				
	Av int (cd)	Zone factor	Zonal flux (lm)	0.6		0.8		1.0		1.25		1.5		2		2.5		3		4		5		
				ZM	Prod	ZM	Prod	ZM	Prod	ZM	Prod	ZM	Prod	ZM	Prod	ZM	Prod	ZM	Prod	ZM	Prod	ZM	Prod	
0-10	565	.095	54			1		1		1		1		1		1		1		1		1		
10-20	560	.284	159			1	464	1	464	1	464	1	464	1	464	1	464	1	464	1	464	1	464	
20-30	542	.463	251			1		1		1		1		1		1		1		1		1		
30-40	524	.628	329			.97	286	.90	296	.92	303	.93	306	.95	313	.96	316	.97	319	.97	319	.98	322	
40-50	491	.774	380			.17	65	.34	129	.47	179	.55	209	.67	255	.73	277	.78	296	.83	315	.87	331	
50-60	411	.897	369			.03	10	.18	66	.31	114	.43	159	.55	203	.63	232	.70	258	.77	284	.81	299	
60-70	270	.993	268			-	-	.08	21	.18	48	.27	72	.42	113	.53	142	.60	161	.69	185	.75	201	
70-80	99	1.058	105			-	-	-	-	-	-	.01	1	.10	11	.22	23	.32	34	.47	49	.56	59	
80-90	27	1.091	29			-	-	-	-	-	-	-	-	-	-	.01	0	.05	1	.10	3			
Total of products			1944			826		976		1108		1211		1359		1454		1532		1619		1679		
Direct ratios						0.42		0.50		0.57		0.62		0.70		0.75		0.79		0.83		0.86		

ZM = Zonal multiplier Prod = Zonal flux x ZM

Fig. 4. Example of completed work sheet for the polar curve given in Fig. 3.

2F → R/S
 x
 S10.9
 S10.0
 2M1 → R/S
 RCL9
 x
 S10.1
 2M2 → R/S
 RCL9
 x
 S10.2
 R/S
 2M3 → RCL9
 x
 S10.3
 R/S
 A
 FUSE B
 RCL1
 RCL4
 R/S → D
 RCL2
 RCL4
 R/S → D
 RCL3
 RCL4
 R/S → D
 RCL4
 R/S → D

Table 6 Direct ratios for BZ classifications

Classifi- cation	Room index (k_r)									
	0.6	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
BZ1	0.517	0.609	0.673	0.729	0.769	0.823	0.856	0.879	0.908	0.926
BZ2	0.463	0.546	0.611	0.677	0.720	0.781	0.822	0.848	0.883	0.906
BZ3	0.418	0.488	0.550	0.624	0.669	0.737	0.785	0.814	0.855	0.883
BZ4		0.443	0.508	0.577	0.624	0.696	0.746	0.781	0.827	0.858
BZ5		0.384	0.445	0.507	0.556	0.628	0.680	0.718	0.771	0.807
BZ6		0.311	0.367	0.425	0.473	0.546	0.600	0.641	0.700	0.741
BZ7		0.266	0.318	0.374	0.421	0.494	0.550	0.593	0.656	0.700
BZ8		0.225	0.278	0.333	0.379	0.453	0.511	0.551	0.623	0.670
BZ9		0.173	0.228	0.284	0.328	0.406	0.468	0.516	0.589	0.639
BZ10										

See also Fig 8

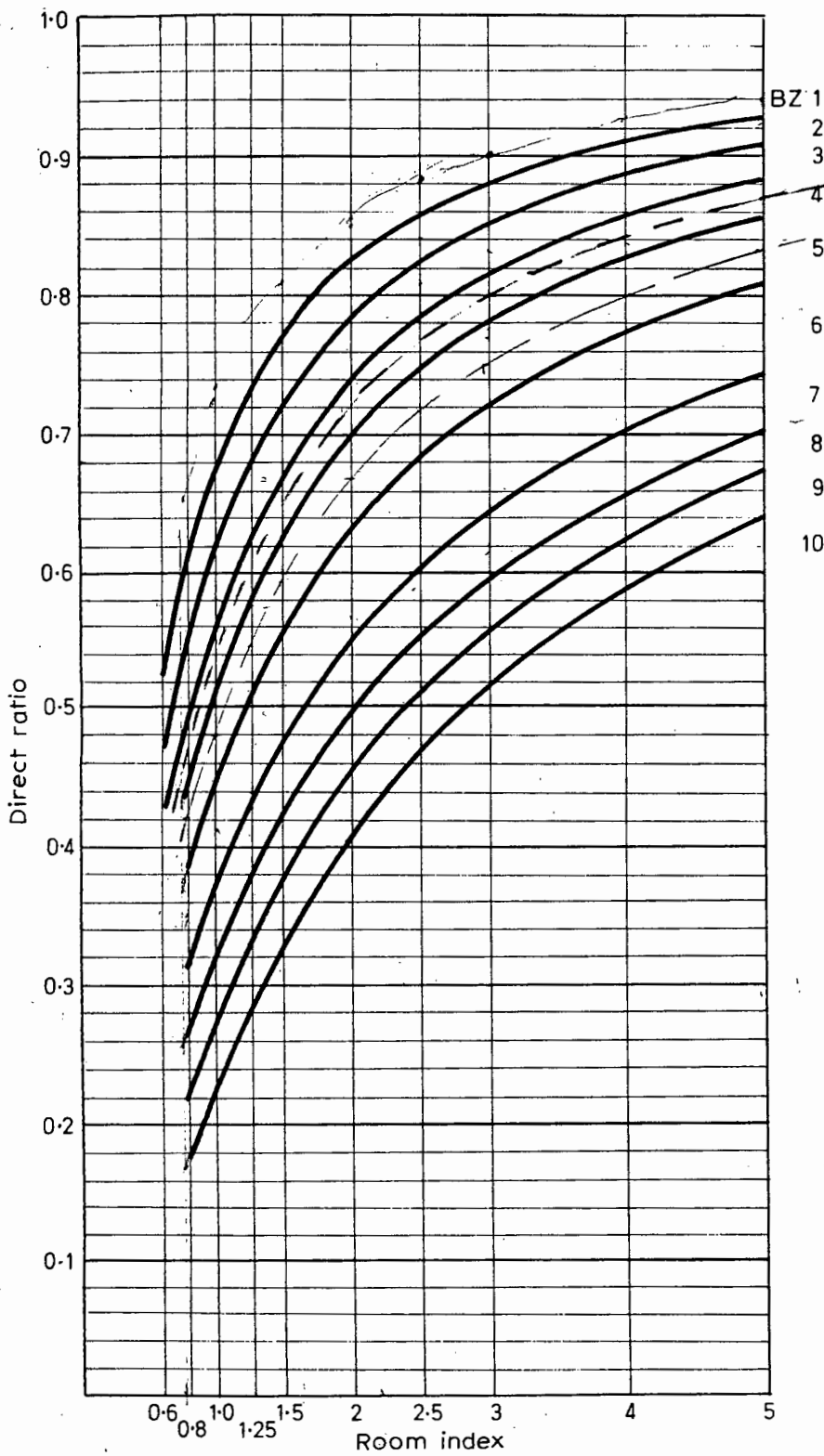


Fig. 8. BZ classification reference curves. (See also Table 6)

CLASS	EQUI-D.R. INTENSITY DISTRIBUTION
BZ1	$\cos^4 \theta$
BZ2	$\cos^3 \theta$
BZ3	$\cos^2 \theta$
BZ4	$\cos^{1.5} \theta$
BZ5	$\cos \theta$
BZ6	$1 + 2 \cos \theta$
BZ7	$2 + \cos \theta$
BZ8	constant
BZ9	$1 + \sin \theta$
BZ10	$\sin \theta$

BZ5: $DR \approx 0,48 + 0,65 \cdot \log RI - 0,2(\log RI)^2$
 (within 1%)



PART 2 CLASSIFICATION OF LIGHT DISTRIBUTIONS

(6) The BZ classification

The objects of the BZ classification are to define the downward light distribution characteristics of lighting fittings, to simplify the calculations of utilization factors for installations of fittings for which the classification is known and to facilitate the initial stages of lighting design by enabling a realistic estimate of the utilization factor to be made before the final selection of fittings.

(6.1) BASIS OF BZ CLASSIFICATION

The method of classification is based on the fact that, in any given interior, the direct ratio of the installation determines the lower flux utilization. The downward light utilization characteristics of lighting fittings can therefore be expressed by the relation between the direct ratio and the geometry of the interior, i.e. the room index, and the installation lay-out, i.e. the spacing/height ratio. Thus, for any particular fitting, a curve can be drawn relating direct ratio (at its particular spacing/height ratio) to room index; this curve is also characteristic of the downward lighting performance. It is then possible to evolve a system of classification by producing a family of curves of direct ratio against room index, for a range of theoretical polar distributions. Such curves have been drawn through points which are, for each value of the room index, midway between the direct ratios calculated for one polar distribution and the next in order. These basic curves mark the limits of zones to which code numbers (BZ numbers) have been allocated. An actual fitting can then be classified by the code number (BZ number) of the direct ratio/room index zone within which its own curve falls.

Fig. 7 shows the ten theoretical polar distributions selected. Each was mathematically derived so as to be simply and accurately reproducible and they cover the range of beam spreads, from narrowest to widest, likely to be met in practice. For the purpose of

classification, each polar distribution was associated with a spacing/height ratio which is related to a uniformity ratio of 0.7 as described in Appendix 2. These theoretical polar curves serve no other purpose than to determine the reference direct ratio curves which are the limits of the zones in the BZ Classification.

Fig. 8 shows the family of reference direct ratio curves corresponding to the limits of each of the zones, calculated from the ten polar curves using the zonal multipliers given in Table 1a. Table 6 gives the figures from which Fig. 8 was drawn.

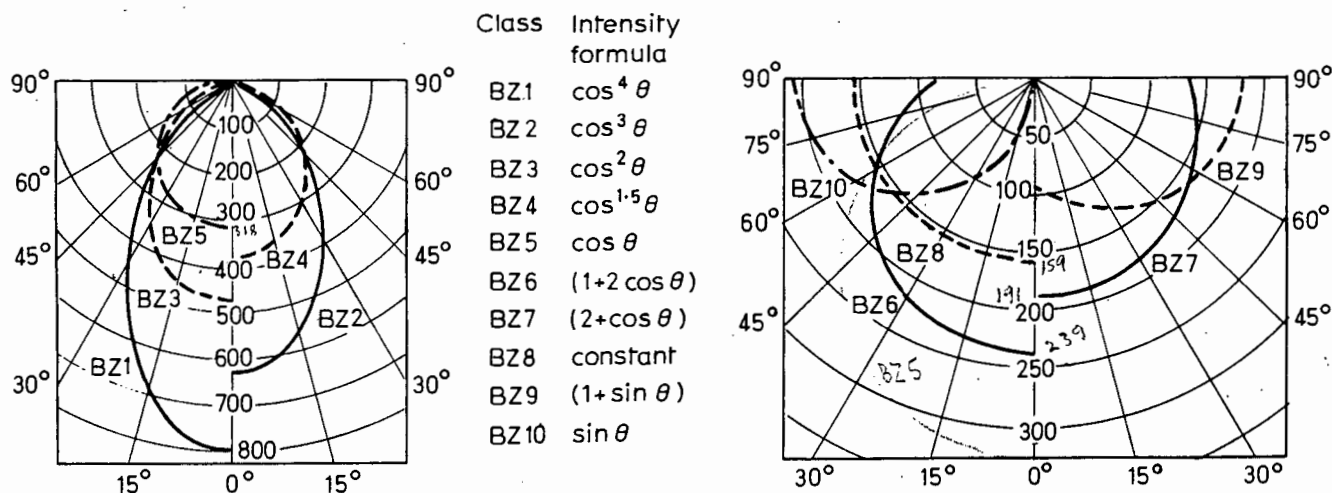
It should be noted that the curves of Fig. 8 cannot be used to determine accurately the direct ratios for a given BZ class.

(6.2) NOTES ON CLASSIFICATION PROCEDURE

In order to classify a fitting, the S/H_m ratio is determined according to the midpoint ratio for the fittings (Appendix 2) and the direct ratios are computed for the full range of room indices as has been described in Section 1.3 and illustrated in Section 4.1. These values are then either compared directly with the reference values given in Table 6 or preferably by plotting the direct ratio curve on the same sheet as the reference curves (Fig. 8). The fitting is then given the BZ number corresponding to the range of values in Table 6 or zone of Fig. 8 within which the calculated values fall. Where the calculated values fall exactly on a line in Fig. 8 or correspond exactly to a row of values in Table 6, the fitting is classified by the next larger BZ number, below the line in Fig. 8 or row in Table 6.

As an example of the latter method, the direct ratio/room index curve for the fitting used in Section 4.1, as illustrated in Fig. 3 and calculated using zonal multipliers for $S/H_m = 1.5$ in Fig. 4, is shown in Fig. 9 plotted with the ten reference curves from Fig. 8. It will be seen that the calculated curve falls in the BZ5 zone for room index 0.6 to 2 and BZ4 for

Fig. 7. Polar curves in the BZ classification. These theoretical polar distributions were used to obtain the basic BZ classification curves shown in Fig. 8. The BZ classification relates only to the shape of the polar curve in the lower hemisphere; these polar curves are scaled to 1000 lumens for purposes of comparison.



LENGTH is parallel to direction of viewing
 WIDTH is perpendicular to direction of viewing

$$X = \frac{\text{WIDTH}}{H}$$

$$Y = \frac{\text{LENGTH}}{H}$$

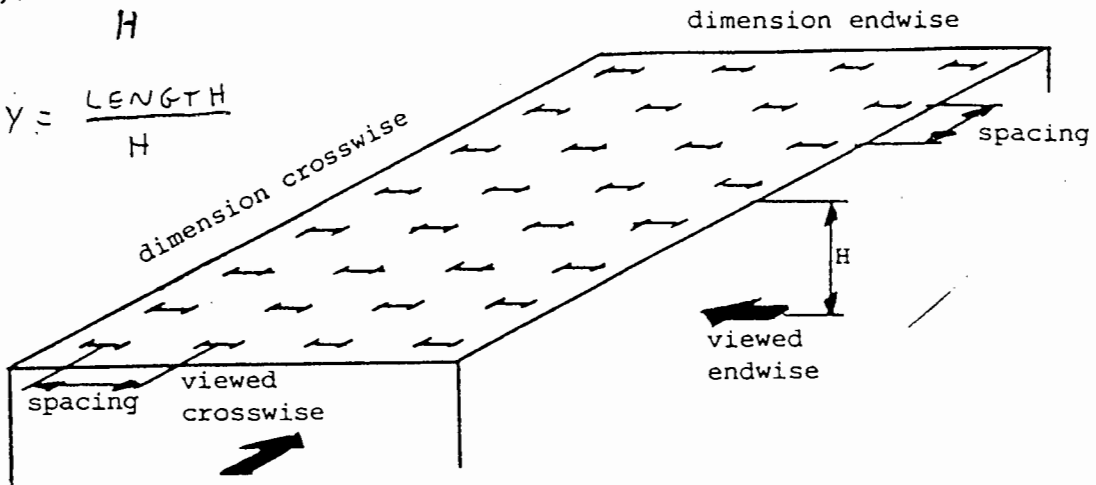


Fig. 3.4 Conventional lighting installation with identical luminaires mounted with uniform spacings in a horizontal mounting plane.

Also indicated are two conventional observer positions, at the middle of respective walls and normally at a height of 1.2 m above the floor.

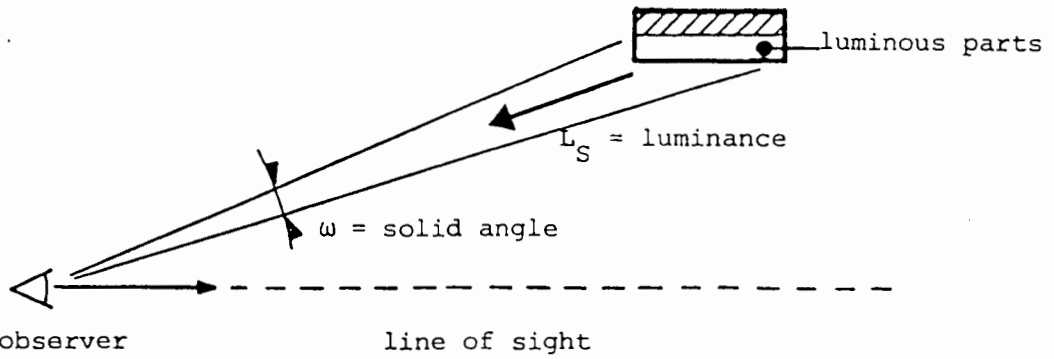
The luminaires are at a height H above the observer position.

The dimensions of the installation, in terms of the height H , are normally related to the line of sight, by x being perpendicular to, and y being parallel to the line of sight. Thus:

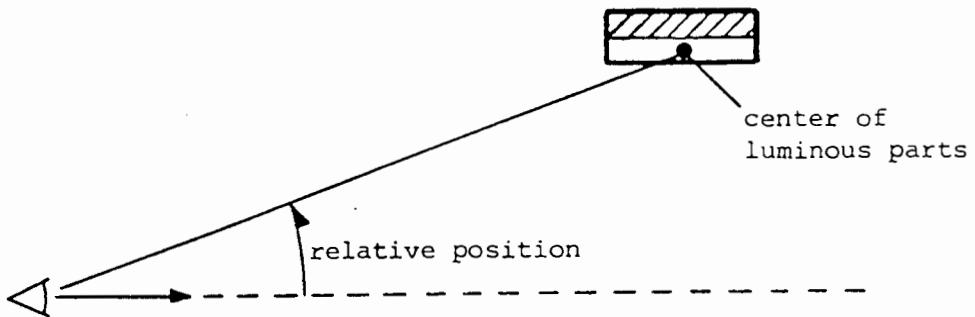
viewed crosswise	{	$x =$ dimension endwise
		$y =$ dimension crosswise
viewed endwise	{	$x =$ dimension crosswise
		$y =$ dimension endwise

For these parameters, a rather small and simple table of uncorrected UGR values can be set up. Normally parameters values of $2H$, $3H$, $4H$, $6H$, $8H$ and $12H$ are considered.

Such tables show that the UGR value depends on x and y in typical ways. First of all, the UGR value increases with increasing values of x and y , as larger installations have more luminaires contributing to glare. For some luminaires, which cause glare from a close range, the UGR reaches its full value already at small x and y and then stays constant. Other luminaires cause glare from a distance, and for these the UGR value increases steadily with x and y .



a. the luminance L and the solid angle ω is as seen by the observer



b. the position index is determined by the position of the center of the luminous parts relative to the line of sight

Fig. A1.1 The data for the luminaire and its position is for the observer and his line of sight.

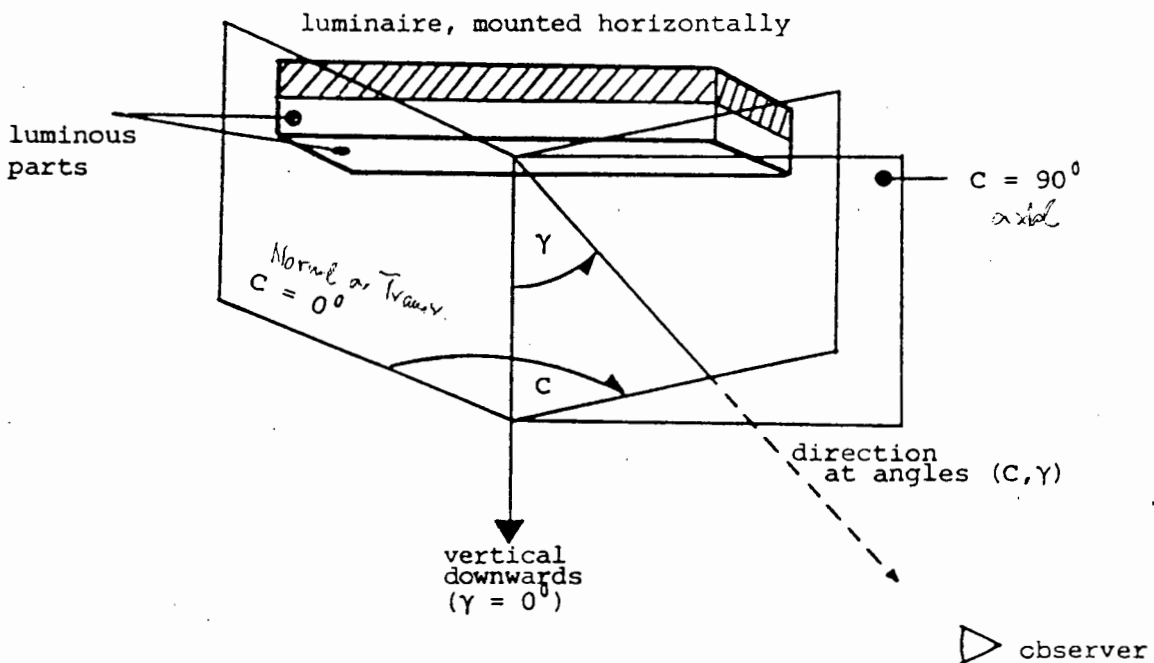
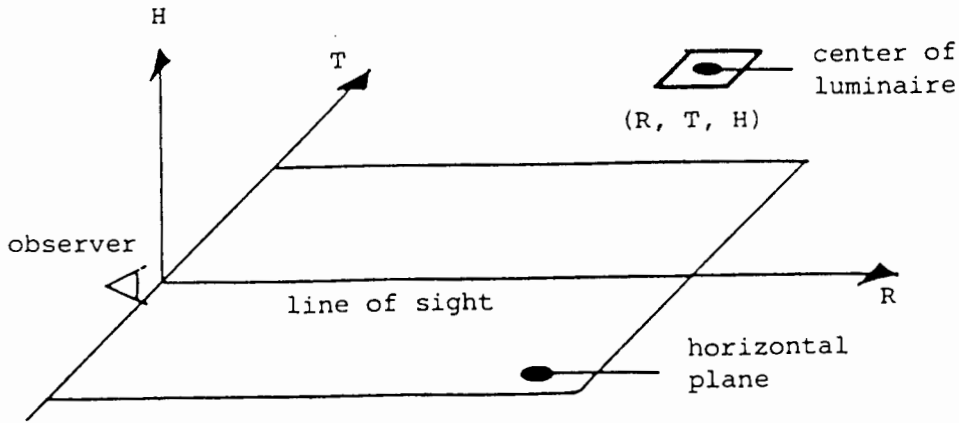


Fig. A1.2 The (C, γ) angular coordinate system.



a. coordinate system (R, T, H) with the origin in the observer position. For the center of a luminaire, the ratios H/R and T/R are formed

$$\frac{1}{d} = \frac{H}{w}$$

T/R	H/R	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90
0.00	1.00	1.26	1.53	1.90	2.35	2.86	3.50	4.20	5.00	6.00	7.00	8.10	9.25	10.35	11.70	13.15	14.70	16.20	-	-
0.10	1.05	1.22	1.46	1.80	2.20	2.75	3.40	4.10	4.80	5.80	6.80	8.00	9.10	10.30	11.60	13.00	14.60	16.10	-	-
0.20	1.12	1.30	1.50	1.80	2.20	2.66	3.18	3.88	4.60	5.50	6.50	7.60	8.75	9.85	11.20	12.70	14.00	15.70	-	-
0.30	1.22	1.38	1.60	1.87	2.25	2.70	3.25	3.90	4.60	5.45	6.45	7.40	8.40	9.50	10.85	12.10	13.70	15.00	-	-
0.40	1.32	1.47	1.70	1.96	2.35	2.80	3.30	3.90	4.60	5.40	6.40	7.30	8.30	9.40	10.60	11.90	13.20	14.60	16.00	-
0.50	1.43	1.60	1.82	2.10	2.48	2.91	3.40	3.98	4.70	5.50	6.40	7.30	8.30	9.40	10.50	11.75	13.00	14.40	15.70	-
0.60	1.55	1.72	1.98	2.30	2.65	3.10	3.60	4.10	4.80	5.60	6.40	7.35	8.40	9.40	10.50	11.70	13.00	14.10	15.40	-
0.70	1.70	1.88	2.12	2.48	2.87	3.30	3.78	4.30	4.88	5.60	6.50	7.40	8.50	9.50	10.50	11.70	12.85	14.00	15.20	-
0.80	1.82	2.00	2.32	2.70	3.08	3.50	3.92	4.50	5.10	5.75	6.60	7.50	8.60	9.50	10.60	11.75	12.80	14.00	15.10	-
0.90	1.95	2.20	2.54	2.90	3.30	3.70	4.20	4.75	5.30	6.00	6.75	7.70	8.70	9.65	10.75	11.80	12.90	14.00	15.00	16.00
1.00	2.11	2.40	2.75	3.10	3.50	3.91	4.40	5.00	5.60	6.20	7.00	7.90	8.80	9.75	10.80	11.90	12.95	14.00	15.00	16.00
1.10	2.30	2.55	2.92	3.30	3.72	4.20	4.70	5.25	5.80	6.55	7.20	8.15	9.00	9.90	10.95	12.00	13.00	14.00	15.00	16.00
1.20	2.40	2.75	3.12	3.50	3.90	4.35	4.85	5.50	6.05	6.70	7.50	8.30	9.20	10.00	11.02	12.10	13.10	14.00	15.00	16.00
1.30	2.55	2.90	3.30	3.70	4.20	4.65	5.20	5.70	6.30	7.00	7.70	8.55	9.35	10.20	11.20	12.25	13.20	14.00	15.00	16.00
1.40	2.70	3.10	3.50	3.90	4.35	4.85	5.35	5.85	6.50	7.25	8.00	8.70	9.50	10.40	11.40	12.40	13.25	14.05	15.00	16.00
1.50	2.85	3.15	3.65	4.10	4.55	5.00	5.50	6.20	6.80	7.50	8.20	8.85	9.70	10.55	11.50	12.50	13.30	14.05	15.02	16.00
1.60	2.95	3.40	3.80	4.25	4.75	5.20	5.75	6.30	7.00	7.65	8.40	9.00	9.80	10.80	11.75	12.60	13.40	14.20	15.05	16.00
1.70	3.10	3.55	4.00	4.50	4.90	5.40	5.95	6.50	7.20	7.80	8.50	9.20	10.00	10.85	11.85	12.75	13.45	14.20	15.10	16.00
1.80	3.25	3.70	4.20	4.65	5.10	5.60	6.10	6.75	7.40	8.00	8.65	9.35	10.10	11.00	11.90	12.80	13.50	14.20	15.10	16.00
1.90	3.43	3.86	4.30	4.75	5.20	5.70	6.30	6.90	7.50	8.17	8.80	9.50	10.20	11.00	12.00	12.82	13.55	14.20	15.10	16.00
2.00	3.50	4.00	4.50	4.90	5.35	5.80	6.40	7.10	7.70	8.30	8.90	9.60	10.40	11.10	12.00	12.85	13.60	14.30	15.10	16.00
2.10	3.60	4.17	4.65	5.05	5.50	6.00	6.60	7.20	7.82	8.45	9.00	9.75	10.50	11.20	12.10	12.90	13.70	14.35	15.10	16.00
2.20	3.75	4.25	4.72	5.20	5.60	6.10	6.70	7.35	8.00	8.55	9.15	9.85	10.60	11.30	12.10	12.90	13.70	14.40	15.15	16.00
2.30	3.85	4.35	4.80	5.25	5.70	6.22	6.80	7.40	8.10	8.65	9.30	9.90	10.70	11.40	12.20	12.95	13.70	14.40	15.20	16.00
2.40	3.95	4.40	4.90	5.35	5.80	6.30	6.90	7.50	8.20	8.80	9.40	10.00	10.80	11.50	12.25	13.00	13.75	14.45	15.20	16.00
2.50	4.00	4.50	4.95	5.40	5.85	6.40	6.95	7.55	8.25	8.85	9.50	10.05	10.85	11.55	12.30	13.00	13.80	14.50	15.25	16.00
2.60	4.07	4.55	5.05	5.47	5.95	6.45	7.00	7.65	8.35	8.95	9.55	10.10	10.90	11.60	12.32	13.00	13.80	14.50	15.25	16.00
2.70	4.10	4.60	5.10	5.53	6.00	6.50	7.05	7.70	8.40	9.00	9.60	10.16	10.92	11.63	12.35	13.00	13.80	14.50	15.25	16.00
2.80	4.15	4.62	5.15	5.56	6.06	6.55	7.08	7.73	8.45	9.05	9.65	10.20	10.95	11.65	12.35	13.00	13.80	14.50	15.25	16.00
2.90	4.20	4.65	5.17	5.60	6.07	6.57	7.12	7.75	8.50	9.10	9.70	10.23	10.95	11.65	12.35	13.00	13.80	14.50	15.25	16.00
3.00	4.22	4.67	5.20	5.65	6.12	6.60	7.15	7.80	8.55	9.12	9.70	10.23	10.95	11.65	12.35	13.00	13.80	14.50	15.25	16.00

b. table of position index data

Fig. A1.3 The position index as obtained by means of the table of position index data.

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Table 2. INITIAL GLARE INDEX

Flux fraction ratio 0. Reflectances: Ceiling 70%; Walls: 50%; Floor: 20%

G1	x=	2	3	4	6	8	12
y=2		13,3	13,3	13,2	13,1	13,1	13,0
	3	13,2	13,2	13,2	13,1	13,0	13,0
	4	13,1	13,1	13,1	13,0	13,0	12,9
	6	13,0	13,1	13,0	12,9	12,9	12,9
	8	13,0	13,0	13,0	12,9	12,9	12,8
	12	13,0	13,0	12,9	12,9	12,8	12,8

G12	x=	2	3	4	6	8	12
y=2		13,9	14,0	14,0	13,9	13,8	13,8
	3	14,0	14,1	14,1	14,0	14,0	13,9
	4	13,9	14,0	14,0	14,0	14,0	13,9
	6	13,9	14,0	14,0	13,9	13,9	13,9
	8	13,8	13,9	13,9	13,9	13,9	13,8
	12	13,8	13,9	13,9	13,8	13,8	13,8

G2	x=	2	3	4	6	8	12
y=2		14,6	14,7	14,7	14,6	14,5	14,5
	3	14,8	14,9	14,9	14,9	14,9	14,8
	4	14,8	14,9	14,9	14,9	14,9	14,8
	6	14,7	14,8	14,9	14,9	14,8	14,8
	8	14,6	14,8	14,8	14,8	14,8	14,8
	12	14,6	14,8	14,8	14,8	14,8	14,7

G23	x=	2	3	4	6	8	12
y=2		15,3	15,5	15,5	15,5	15,4	15,3
	3	15,7	15,9	16,0	16,1	16,0	16,0
	4	15,8	16,0	16,1	16,2	16,2	16,1
	6	15,8	16,1	16,2	16,3	16,3	16,2
	8	15,8	16,1	16,2	16,3	16,3	16,3
	12	15,7	16,0	16,1	16,2	16,2	16,2

G3	x=	2	3	4	6	8	12
y=2		15,9	16,2	16,2	16,3	16,2	16,2
	3	16,6	17,0	17,1	17,2	17,2	17,1
	4	16,8	17,2	17,4	17,5	17,5	17,5
	6	16,9	17,3	17,5	17,6	17,7	17,6
	8	16,9	17,3	17,5	17,7	17,7	17,7
	12	16,9	17,3	17,5	17,7	17,7	17,7

G34	x=	2	3	4	6	8	12
y=2		16,2	16,6	16,6	16,7	16,6	16,6
	3	17,1	17,5	17,7	17,8	17,8	17,8
	4	17,5	17,9	18,2	18,3	18,3	18,3
	6	17,6	18,1	18,3	18,5	18,6	18,6
	8	17,7	18,2	18,4	18,6	18,7	18,7
	12	17,7	18,2	18,4	18,7	18,8	18,8

G4	x=	2	3	4	6	8	12
y=2		16,5	16,9	17,0	17,1	17,1	17,0
	3	17,6	18,1	18,3	18,5	18,5	18,5
	4	18,1	18,6	18,9	19,1	19,1	19,1
	6	18,4	18,9	19,2	19,5	19,6	19,6
	8	18,4	19,0	19,4	19,6	19,8	19,8
	12	18,5	19,1	19,4	19,7	19,9	19,9

G45	x=	2	3	4	6	8	12
y=2		16,7	17,1	17,3	17,4	17,4	17,4
	3	18,1	18,4	18,9	19,1	19,2	19,2
	4	18,8	19,1	19,7	19,9	20,0	20,0
	6	19,2	19,9	20,2	20,6	20,8	20,8
	8	19,4	20,1	20,5	20,9	21,1	21,2
	12	19,6	20,3	20,6	21,1	21,3	21,4

3
17,1
18,6
19,4
19,8
20,1
20,3

G5	x=	2	3	4	6	8	12
y=2		16,9	17,4	17,6	17,7	17,8	17,7
	3	18,6	19,2	19,5	19,7	19,8	19,8
	4	19,4	20,1	20,4	20,7	20,9	20,9
	6	20,1	20,8	21,2	21,7	21,9	22,0
	8	20,3	21,1	21,6	22,1	22,3	22,5
	12	20,6	21,4	21,8	22,4	22,7	22,9

G6B	x=	2	3	4	6	8	12
y=2		15,5	16,1	16,3	16,5	16,6	16,6
	3	17,6	18,2	18,6	18,8	19,0	19,1
	4	18,6	19,3	19,7	20,1	20,3	20,4
	6	19,6	20,4	20,9	21,4	21,7	21,9
	8	20,1	20,9	21,5	22,0	22,3	22,6
	12	20,6	21,4	21,9	22,6	23,0	23,3

G8B	x=	2	3	4	6	8	12
y=2		14,1	14,7	15,0	15,3	15,4	15,4
	3	16,5	17,2	17,6	18,0	18,2	18,3
	4	17,8	18,6	19,0	19,5	19,7	19,9
	6	19,1	20,0	20,5	21,1	21,4	21,7
	8	19,8	20,7	21,3	21,9	22,3	22,7
	12	20,4	21,4	22,0	22,8	23,2	23,7

G9B	x=	2	3	4	6	8	12
y=2		14,6	15,2	15,6	15,9	16,0	16,1
	3	17,1	17,8	18,3	18,7	18,9	19,0
	4	18,4	19,2	19,7	20,2	20,5	20,7
	6	19,8	20,7	21,3	21,9	22,2	22,4
	8	20,5	21,4	22,0	22,7	23,1	23,5
	12	21,1	22,1	22,8	23,6	24,0	24,5

G10	x=	2	3	4	6	8	12
y=2		15,1	15,8	16,1	16,5	16,6	16,7
	3	17,7	18,5	18,9	19,4	19,6	19,7
	4	19,1	19,9	20,4	20,9	21,2	21,4
	6	20,5	21,4	22,0	22,6	23,0	23,2
	8	21,2	22,2	22,8	23,5	23,9	24,2
	12	21,9	22,9	23,5	24,3	24,8	25,3

GDI	x=	2	3	4	6	8	12
y=2		17,8	17,7	17,6	17,6	17,5	17,5
	3	19,1	19,0	18,9	18,9	18,8	18,8
	4	19,6	19,6	19,5	19,4	19,4	19,3
	6	20,1	20,0	19,9	19,9	19,8	19,8
	8	20,0	20,0	19,9	19,8	19,8	19,7
	12	20,0	19,9	19,9	19,8	19,7	19,7

GFL	x=	2	3	4	6	8	12
y=2		13,8	14,6	15,1	15,5	15,7	15,7
	3	15,2	16,2	16,8	17,5	17,7	17,9
	4	15,8	16,9	17,6	18,4	18,8	19,1
	6	16,3	17,5	18,2	19,2	19,8	20,3
	8	16,3	17,4	18,2	19,2	19,7	20,3
	12	16,3	17,4	18,2	19,1	19,7	20,2

GFC	x=	2	3	4	6	8	12
y=2		14,7	15,4	15,8	16,1	16,3	16,3
	3	16,3	17,1	17,6	18,1	18,3	18,5
	4	16,9	17,8	18,4	19,1	19,4	19,6
	6	17,5	18,5	19,1	19,9	20,4	20,8
	8	17,4	18,4	19,1	19,9	20,3	20,7
	12	17,4	18,4	19,0	19,9	20,3	20,7

APPENDIX 4

Output from programs *photometry.pas* and *glareclass.pas*

Bare Fluorescent Channel [C-Planes = 8 and 12]

Winged Fluorescent Channel, cut-off at 90 degrees [A_cos and L_const]

Winged Fluorescent Channel, cut-off at 95 degrees [A_cos and L_const]

150W Pearl Incandescent Down-Lighter [A_cos]

Street Light [measured on Mirror Photometer]

Bare Fluorescent Channel [C-Planes = 8]

	g	5	15	25	35	45	55	65	75	85
Ave-Inten		213.6	210.2	204.6	195.1	184.7	172.7	159.1	140.1	118.5
	zf	0.096	0.284	0.464	0.629	0.776	0.899	0.994	1.060	1.093
Zonal Fdn		20.4	59.7	94.9	122.8	143.3	155.2	158.2	148.5	129.5

Lum Fdn = 1032 (in divisions)

	g	95	105	115	125	135	145	155	165	175
Ave-Inten		107.4	97.6	69.6	36.0	11.3	1.4	0.6	0.8	1.0
	zf	1.093	1.060	0.994	0.899	0.776	0.629	0.464	0.284	0.096
Zonal Fup		117.4	103.5	69.2	32.4	8.8	0.9	0.3	0.2	0.1

Lum Fup = 332.8 (in divisions)

total lum flux = 1365 (in divisions)

FFR
0.322

dLOR uLOR LOR
0.656 0.212 0.868

Direct Ratios for this luminaire for different R.I

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
D.R	0.280	0.331	0.402	0.446	0.526	0.585	0.624	0.687	0.731

The BZ classification of this luminaire for different RI:

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
BZ no.	7	7	6	7	6	6	6	6	6

Azimuth Angle, C =0.0 degrees

Ga	0								
Io	218								
Ga	5	10	15	20	25	30	35	40	45
I	217	216	218	216	219	220	221	225	228
Ga	50	55	60	65	70	75	80	85	90
I	229	230	230	228	223	218	212	201	194
Ga	95	100	105	110	115	120	125	130	135
I	192	185	185	182	159	133	108	81	54
Ga	140	145	150	155	160	165	170	175	180
I	30	7	1	2	0	0	2	2	1

Azimuth Angle, C =45.0 degrees

Ga	0								
Io	214								
Ga	5	10	15	20	25	30	35	40	45
I	213	211	209	206	203	197	194	188	184
Ga	50	55	60	65	70	75	80	85	90
I	178	173	170	166	158	152	142	131	121
Ga	95	100	105	110	115	120	125	130	135
I	115	115	93	74	56	37	18	1	1
Ga	140	145	150	155	160	165	170	175	180
I	1	2	1	0	0	1	1	2	1

Azimuth Angle, C =90.0 degrees

Ga	0								
Io	213								
Ga	5	10	15	20	25	30	35	40	45
I	212	209	205	199	191	180	170	157	141
Ga	50	55	60	65	70	75	80	85	90
I	127	107	89	72	52	32	16	6	1
Ga	95	100	105	110	115	120	125	130	135
I	0	1	0	0	2	1	1	0	1
Ga	140	145	150	155	160	165	170	175	180
I	1	0	2	1	0	1	0	0	1

Azimuth Angle, C =135.0 degrees

Ga	0								
Io	213								
Ga	5	10	15	20	25	30	35	40	45
I	214	211	211	207	206	204	198	193	187
Ga	50	55	60	65	70	75	80	85	90
I	186	181	177	174	168	158	149	137	127
Ga	95	100	105	110	115	120	125	130	135
I	122	119	95	78	57	36	16	3	2
Ga	140	145	150	155	160	165	170	175	180
I	0	0	1	0	2	2	0	0	0

Azimuth Angle, C =180.0 degrees

Ga	0								
Io	213								
Ga	5	10	15	20	25	30	35	40	45
I	213	215	213	214	216	215	215	220	221
Ga	50	55	60	65	70	75	80	85	90
I	224	223	224	221	220	213	205	195	188
Ga	95	100	105	110	115	120	125	130	135
I	181	181	172	152	127	101	71	50	25
Ga	140	145	150	155	160	165	170	175	180
I	6	0	1	0	0	1	1	0	0

Azimuth Angle, C =225.0 degrees

Ga	0								
Io	213								
Ga	5	10	15	20	25	30	35	40	45
I	213	212	209	205	202	199	193	187	181
Ga	50	55	60	65	70	75	80	85	90
I	179	175	170	165	162	155	145	133	121
Ga	95	100	105	110	115	120	125	130	135
I	119	118	113	93	74	56	36	17	4
Ga	140	145	150	155	160	165	170	175	180
I	1	0	1	0	2	0	0	1	1

Azimuth Angle, C =270.0 degrees

Ga	0								
Io	213								
Ga	5	10	15	20	25	30	35	40	45
I	211	210	206	201	193	184	171	159	143
Ga	50	55	60	65	70	75	80	85	90
I	128	109	87	72	50	31	13	3	1
Ga	95	100	105	110	115	120	125	130	135
I	1	0	0	1	0	0	0	1	0
Ga	140	145	150	155	160	165	170	175	180
I	0	1	1	0	1	0	1	1	1

Azimuth Angle, C =315.0 degrees

Ga	0								
Io	215								
Ga	5	10	15	20	25	30	35	40	45
I	216	214	211	209	207	202	199	196	193
Ga	50	55	60	65	70	75	80	85	90
I	189	184	181	175	170	162	153	142	129
Ga	95	100	105	110	115	120	125	130	135
I	129	124	123	105	82	59	38	20	3
Ga	140	145	150	155	160	165	170	175	180
I	2	1	0	2	1	1	0	2	0

The luminaire description was: A Winged Fluorescent Channel with cut-off at 90 degrees (cut-off at g = 90)

The luminaire was described as having an L_const characteristic

number of cplane lobes = 8
 lobe angular spacing = 45

Lum Flux Down 851

Factor f1 = 1000/Lumfluxdn = 1.176

g \ c	0	45	90	135	180	225	270	315
0	220	217	217	216	217	218	217	218
5	221	217	216	216	218	216	215	217
10	221	216	214	217	217	216	216	218
15	222	216	212	216	218	214	212	216
20	221	213	207	213	217	212	206	215
25	218	210	200	212	215	207	200	214
30	218	204	193	205	214	203	188	209
35	218	199	183	200	214	197	185	205
40	216	196	171	196	213	190	170	197
45	213	190	160	190	211	186	156	193
50	215	186	144	184	210	179	141	187
55	210	181	127	178	207	172	125	184
60	202	173	109	171	198	167	106	173
65	174	165	91	165	176	158	88	167
70	121	147	73	147	126	137	67	153
75	61	101	52	101	63	90	48	119
80	21	43	32	46	20	31	28	60
85	7	14	10	17	7	12	9	23
90	0	4	1	3	0	1	0	7

IGI table (experimental) for CROSSWISE layout

16.2	16.6	16.8	16.9	16.9	16.9
18.5	19.0	19.3	19.5	19.6	19.6
19.7	20.3	20.7	21.0	21.1	21.2
21.0	21.7	22.1	22.6	22.8	23.0
21.6	22.4	22.8	23.4	23.7	23.9
22.2	23.0	23.6	24.2	24.6	24.9

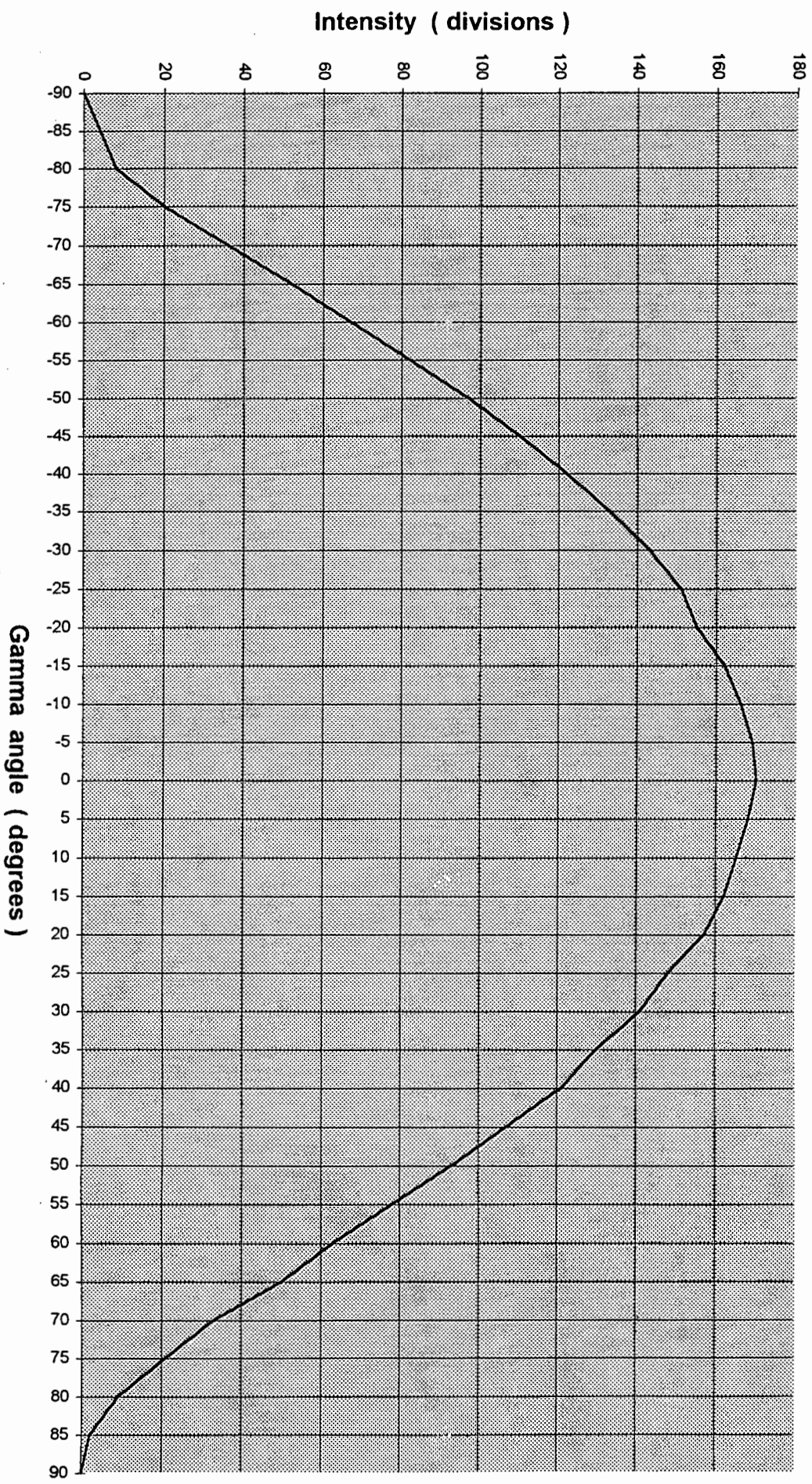
IGI table (experimental) for ENDWISE layout

14.7	15.3	15.7	16.1	16.3	16.4
16.2	17.0	17.5	18.1	18.3	18.5
16.8	17.8	18.4	19.1	19.4	19.7
17.3	18.4	19.1	20.0	20.4	20.9
17.5	18.6	19.4	20.3	20.9	21.4
17.7	18.8	19.6	20.6	21.3	22.0

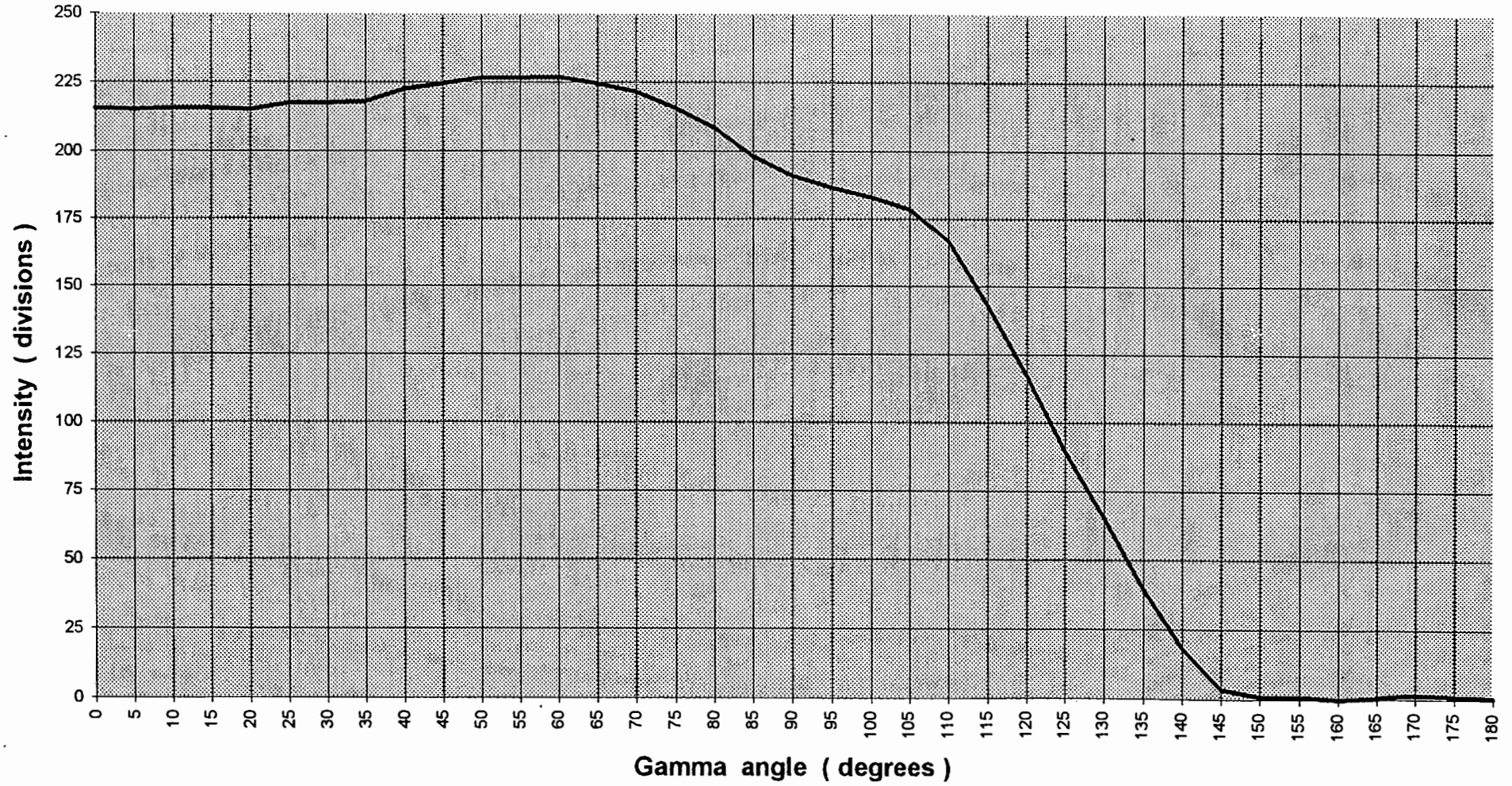
GLARE CLASS IS : **G10 CROSSWISE**

GLARE CLASS IS : **GFC ENDWISE**

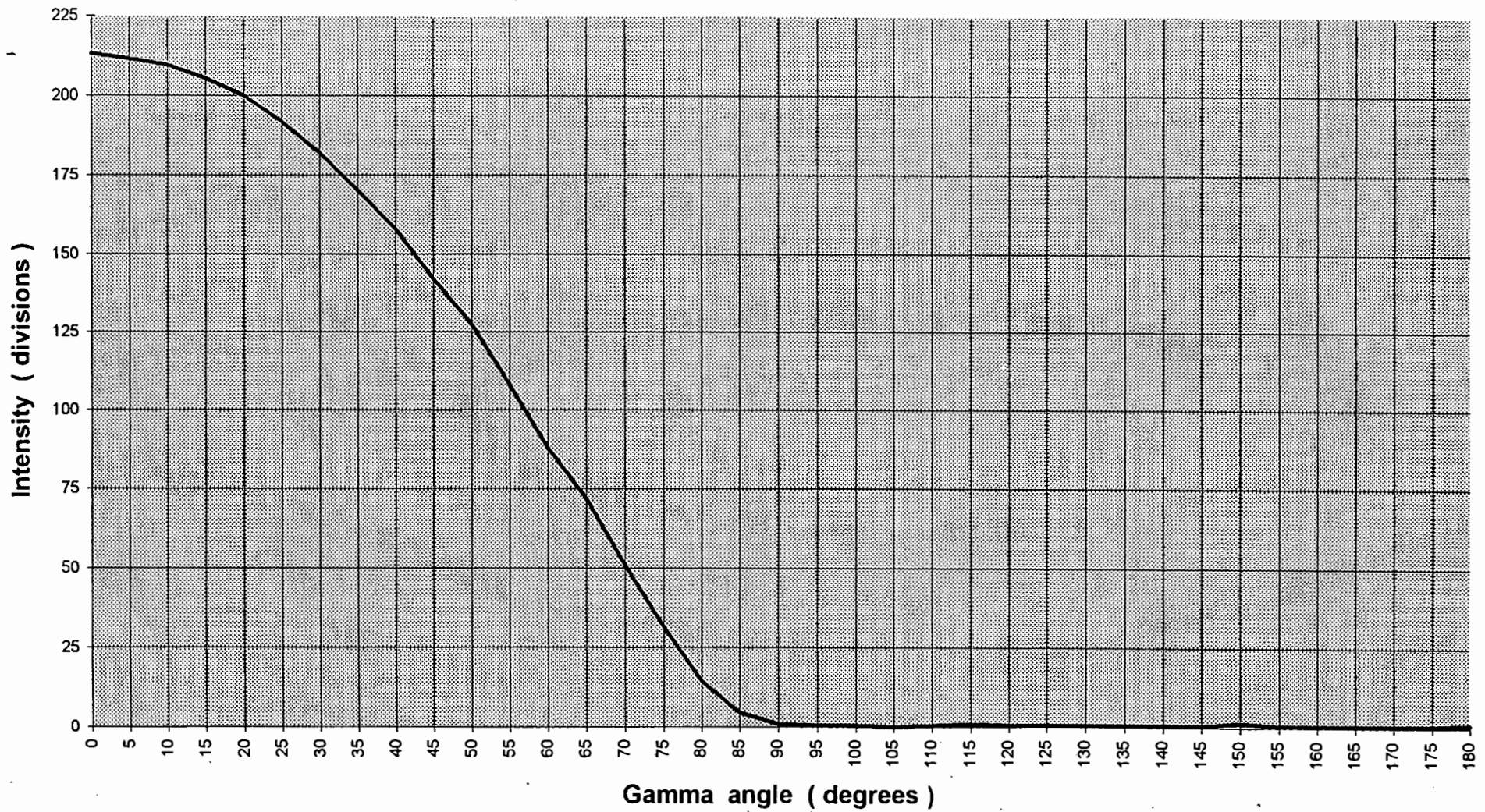
LAMP AXIAL INTENSITY (C = 90)



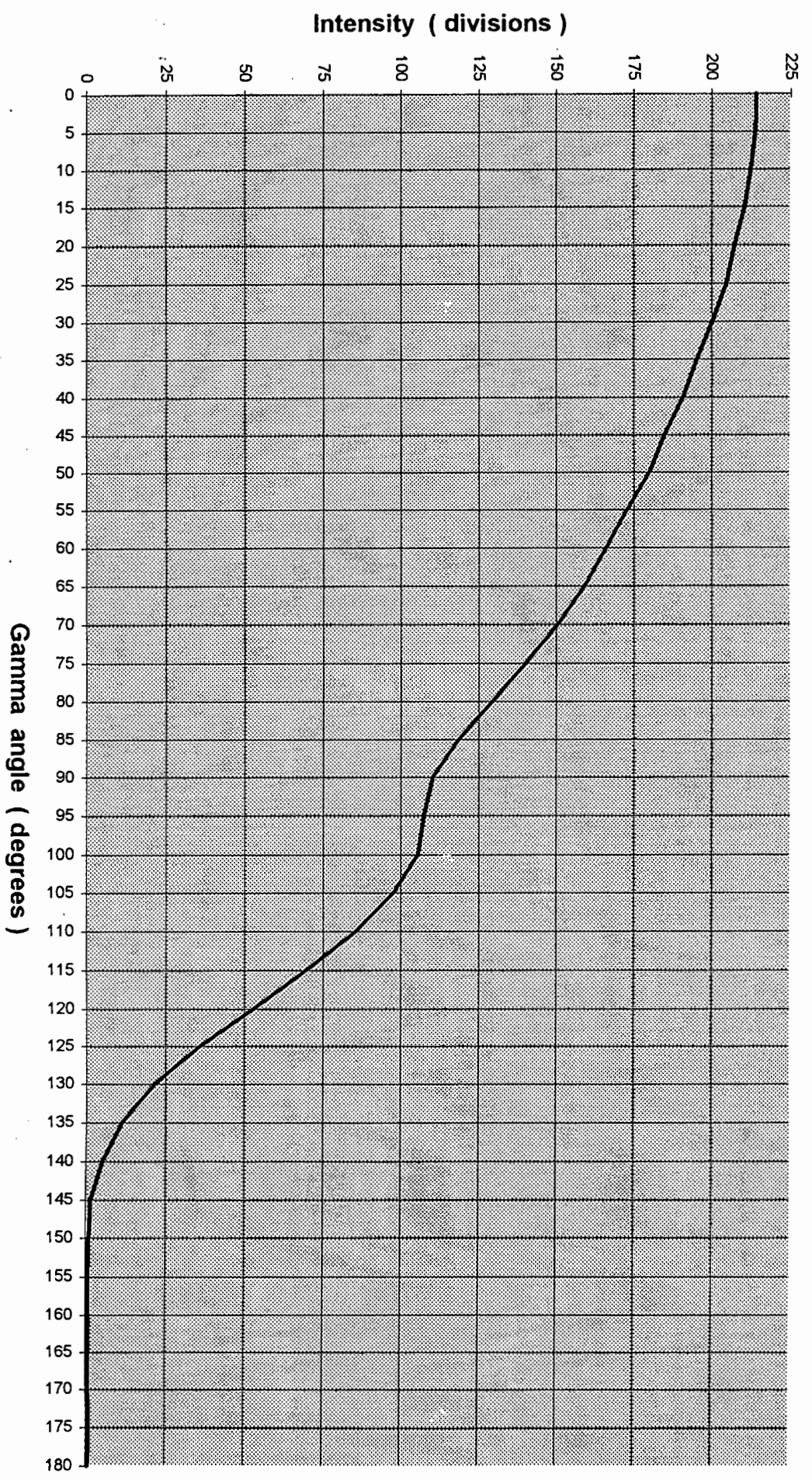
LUMINAIRE NORMAL INTENSITIES
(Ave C = 0 , C = 90)



LUMINAIRE AXIAL INTENSITIES (Ave C = 90 , C = 270)



AVERAGED LUMINAIRE INTENSITIES



Sheet1

C	0	45	90	135	180	225	270	315		average
gamma										
0	218	214	213	213	213	213	213	215		214
5	217	213	212	214	213	213	211	216		214
10	216	211	209	211	215	212	210	214		212
15	218	209	205	211	213	209	206	211		210
20	216	206	199	207	214	205	201	209		207
25	219	203	191	206	216	202	193	207		205
30	220	197	180	204	215	199	184	202		200
35	221	194	170	198	215	193	171	199		195
40	225	188	157	193	220	187	159	196		191
45	228	184	141	187	221	181	143	193		185
50	229	178	127	186	224	179	128	189		180
55	230	173	107	181	223	175	109	184		173
60	230	170	89	177	224	170	87	181		166
65	228	166	72	174	221	165	72	175		159
70	223	158	52	168	220	162	50	170		150
75	218	152	32	158	213	155	31	162		140
80	212	142	16	149	205	145	13	153		129
85	201	131	6	137	195	133	3	142		119
90	194	121	1	127	188	121	1	129		110
95	192	115	0	122	181	119	1	129		107
100	185	115	1	119	181	118	0	124		105
105	185	93	0	95	172	113	0	123		98
110	182	74	0	78	152	93	1	105		86
115	159	56	2	57	127	74	0	82		70
120	133	37	1	36	101	56	0	59		53
125	108	18	1	16	71	36	0	38		36
130	81	1	0	3	50	17	1	20		22
135	54	1	1	2	25	4	0	3		11
140	30	1	1	0	6	1	0	2		5
145	7	2	0	0	0	0	1	1		1
150	1	1	2	1	1	1	1	0		1
155	2	0	1	0	0	0	0	2		1
160	0	0	0	2	0	2	1	1		1
165	0	1	1	2	1	0	0	1		1
170	2	1	0	0	1	0	1	0		1
175	2	2	0	0	0	1	1	2		1
180	1	1	1	0	0	1	1	0		1

Bare Fluorescent Channel [C-Planes = 12]

g	5	15	25	35	45	55	65	75	85
Ave-Inten	215.0	212.0	205.8	196.9	186.4	174.2	160.1	143.2	121.7
zf	0.096	0.284	0.464	0.629	0.776	0.899	0.994	1.060	1.093
Zonal Fdn	20.6	60.2	95.4	123.9	144.6	156.5	159.2	151.8	133.1

Lum Fdn = 1045 (in divisions)

g	95	105	115	125	135	145	155	165	175
Ave-Inten	106.9	94.5	61.4	31.7	9.0	1.0	0.8	0.7	0.7
zf	0.096	0.284	0.464	0.629	0.776	0.899	0.994	1.060	1.093
Zonal Fup	116.8	100.1	61.1	28.5	7.0	0.6	0.3	0.2	0.1

Lum Fup = 95.5 (in divisions)

total lum flux = 1141 (in divisions)

FFR
0.0914

dLOR **uLOR** **LOR**
0.667 0.061 0.728

Direct Ratios for this luminaire for different R.I

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
D.R	0.279	0.330	0.400	0.444	0.524	0.583	0.622	0.685	0.729

The BZ classification of this luminaire for different RI:

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
BZ no.	7	7	6	7	6	6	6	6	6

Azimuth Angle, C =0.0 degrees

Ga	0								
Io	215								
Ga	5	10	15	20	25	30	35	40	45
I	216	217	216	216	217	219	221	221	224
Ga	50	55	60	65	70	75	80	85	90
I	226	226	226	224	220	215	207	199	189
Ga	95	100	105	110	115	120	125	130	135
I	182	183	172	150	126	99	74	50	22
Ga	140	145	150	155	160	165	170	175	180
I	2	0	2	0	1	0	1	1	1

Azimuth Angle, C =30.0 degrees

Ga	0								
Io	217								
Ga	5	10	15	20	25	30	35	40	45
I	217	218	216	212	212	212	209	209	207
Ga	50	55	60	65	70	75	80	85	90
I	207	208	205	203	200	192	183	174	163
Ga	95	100	105	110	115	120	125	130	135
I	161	157	157	144	119	95	71	47	25
Ga	140	145	150	155	160	165	170	175	180
I	9	0	3	1	2	2	2	1	0

Azimuth Angle, C =60.0 degrees

Ga	0								
Io	216								
Ga	5	10	15	20	25	30	35	40	45
I	214	211	210	205	196	191	184	174	164
Ga	50	55	60	65	70	75	80	85	90
I	154	144	133	126	118	110	99	84	72
Ga	95	100	105	110	115	120	125	130	135
I	72	59	41	26	11	1	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	1	0	1	1	1	1	0	1

Azimuth Angle, C =90.0 degrees

Ga	0								
Io	215								
Ga	5	10	15	20	25	30	35	40	45
I	216	213	207	200	194	185	172	159	144
Ga	50	55	60	65	70	75	80	85	90
I	127	110	89	70	50	31	13	5	1
Ga	95	100	105	110	115	120	125	130	135
I	1	1	2	1	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	2	3	2	2	2	1	0	0	1

Azimuth Angle, C =120.0 degrees

Ga	0								
Io	216								
Ga	5	10	15	20	25	30	35	40	45
I	213	213	209	206	202	195	187	178	170
Ga	50	55	60	65	70	75	80	85	90
I	161	149	141	133	124	116	103	90	77
Ga	95	100	105	110	115	120	125	130	135
I	75	76	63	43	27	12	2	1	1
Ga	140	145	150	155	160	165	170	175	180
I	1	0	0	0	0	0	1	1	0

Azimuth Angle, C =150.0 degrees

Ga	0								
Io	214								
Ga	5	10	15	20	25	30	35	40	45
I	216	215	214	216	216	213	211	213	212
Ga	50	55	60	65	70	75	80	85	90
I	211	210	211	207	204	195	189	178	168
Ga	95	100	105	110	115	120	125	130	135
I	161	162	151	125	102	76	54	29	10
Ga	140	145	150	155	160	165	170	175	180
I	1	2	3	0	1	0	0	0	0

Azimuth Angle, C =180.0 degrees

Ga	0								
Io	217								
Ga	5	10	15	20	25	30	35	40	45
I	216	216	217	218	218	220	221	224	225
Ga	50	55	60	65	70	75	80	85	90
I	227	229	229	226	223	220	211	203	195
Ga	95	100	105	110	115	120	125	130	135
I	183	185	179	157	131	106	79	53	30
Ga	140	145	150	155	160	165	170	175	180
I	8	2	1	2	1	0	1	2	1

Azimuth Angle, C =210.0 degrees

Ga	0								
Io	218								
Ga	5	10	15	20	25	30	35	40	45
I	216	215	216	213	211	211	209	209	209
Ga	50	55	60	65	70	75	80	85	90
I	208	207	208	204	201	197	186	178	169
Ga	95	100	105	110	115	120	125	130	135
I	159	161	149	127	101	80	55	32	13
Ga	140	145	150	155	160	165	170	175	180
I	0	0	0	1	0	1	2	0	1

Azimuth Angle, C =240.0 degrees

Ga	0								
Io	216								
Ga	5	10	15	20	25	30	35	40	45
I	213	212	209	204	199	191	183	174	163
Ga	50	55	60	65	70	75	80	85	90
I	155	144	134	126	118	110	99	87	75
Ga	95	100	105	110	115	120	125	130	135
I	72	62	45	30	16	5	0	1	2
Ga	140	145	150	155	160	165	170	175	180
I	0	1	2	1	2	2	2	1	2

Azimuth Angle, C =270.0 degrees

Ga	0								
Io	215								
Ga	5	10	15	20	25	30	35	40	45
I	214	213	208	203	193	184	172	160	144
Ga	50	55	60	65	70	75	80	85	90
I	128	110	91	73	51	32	18	7	0
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	1	2	1	1	2	1
Ga	140	145	150	155	160	165	170	175	180
I	1	2	2	1	1	0	3	1	1

Azimuth Angle, C =300.0 degrees

Ga	0								
Io	213								
Ga	5	10	15	20	25	30	35	40	45
I	215	212	209	206	200	193	185	177	167
Ga	50	55	60	65	70	75	80	85	90
I	156	146	137	128	120	110	98	86	74
Ga	95	100	105	110	115	120	125	130	135
I	66	56	37	23	10	1	1	0	0
Ga	140	145	150	155	160	165	170	175	180
I	1	0	1	0	1	0	0	1	0

Azimuth Angle, C =330.0 degrees

Ga	0								
Io	215								
Ga	5	10	15	20	25	30	35	40	45
I	214	213	213	213	212	211	209	208	208
Ga	50	55	60	65	70	75	80	85	90
I	207	207	203	201	197	191	181	170	160
Ga	95	100	105	110	115	120	125	130	135
I	151	153	138	115	92	67	43	20	4
Ga	140	145	150	155	160	165	170	175	180
I	2	1	1	0	0	1	1	0	1

The luminaire description was: A **Bare Fluorescent Channel (BFC)**

The luminaire was described as having an **L_const** characteristic

number of cplane lobes = 12
lobe angular spacing = 30

Lum Flux Down = 1045 (in divisions)
Factor fl = 1000/Lumfluxdn = 0.957

g \ c	0	30	60	90	120	150	180	210	240	270	300	330
0	215	217	216	215	216	214	217	218	216	215	213	215
5	216	217	214	216	213	216	216	216	213	214	215	214
10	217	218	211	213	213	215	216	215	212	213	212	213
15	216	216	210	207	209	214	217	216	209	208	209	213
20	216	212	205	200	206	216	218	213	204	203	206	213
25	217	212	196	194	202	216	218	211	199	193	200	212
30	219	212	191	185	195	213	220	211	191	184	193	211
35	221	209	184	172	187	211	221	209	183	172	185	209
40	221	209	174	159	178	213	224	209	174	160	177	208
45	224	207	164	144	170	212	225	209	163	144	167	208
50	226	207	154	127	161	211	227	208	155	128	156	207
55	226	208	144	110	149	210	229	207	144	110	146	207
60	226	205	133	89	141	211	229	208	134	91	137	203
65	224	203	126	70	133	207	226	204	126	73	128	201
70	220	200	118	50	124	204	223	201	118	51	120	197
75	215	192	110	31	116	195	220	197	110	32	110	191
80	207	183	99	13	103	189	211	186	99	18	98	181
85	199	174	84	5	90	178	203	178	87	7	86	170
90	189	163	72	1	77	168	195	169	75	0	74	160

IGI table (experimental) for CROSSWISE layout

16.2	16.6	16.8	16.9	16.9	16.9
18.5	19.1	19.4	19.6	19.7	19.7
19.7	20.4	20.7	21.1	21.2	21.3
20.9	21.7	22.1	22.6	22.9	23.0
21.6	22.4	22.9	23.4	23.7	24.0
22.2	23.0	23.6	24.2	24.6	25.0

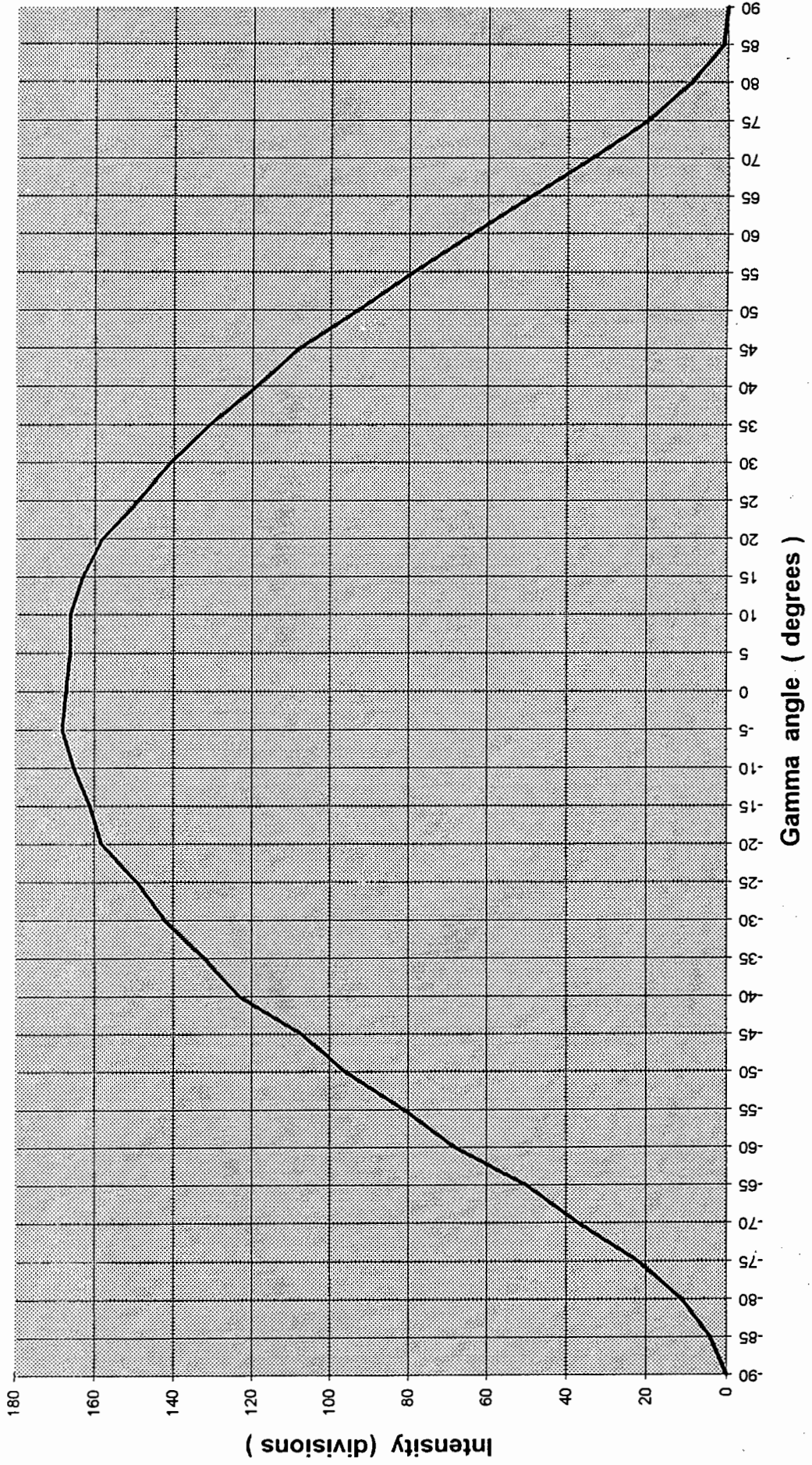
IGI table (experimental) for ENDWISE layout

14.5	15.2	15.6	16.1	16.2	16.4
16.0	16.9	17.4	18.0	18.2	18.4
16.7	17.6	18.2	19.0	19.3	19.6
17.1	18.2	18.9	19.8	20.3	20.8
17.3	18.4	19.2	20.2	20.8	21.3
17.4	18.6	19.4	20.5	21.1	21.8

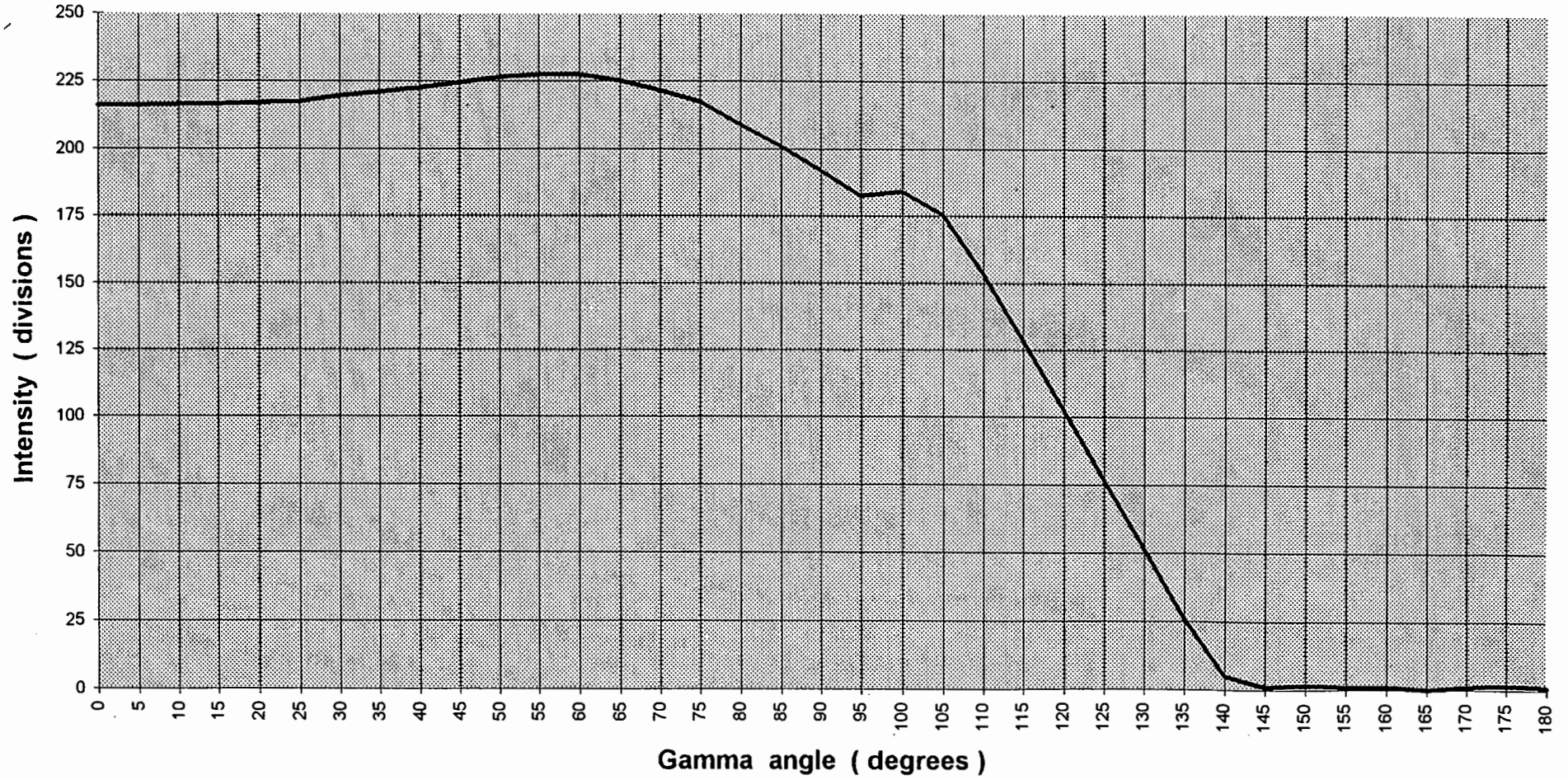
GLARE CLASS IS : **G10 CROSSWISE**

GLARE CLASS IS : **GFC ENDWISE**

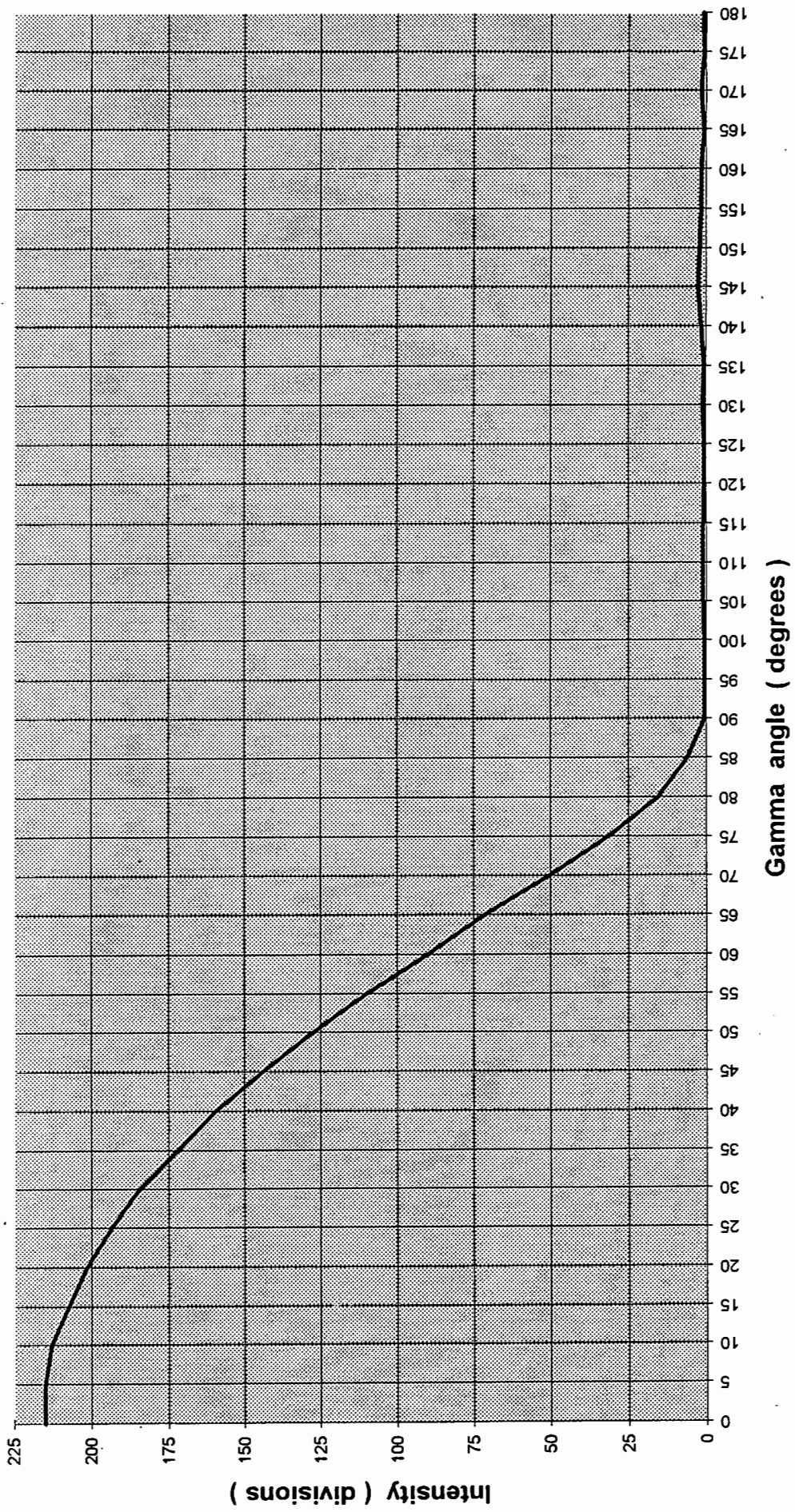
LAMP AXIAL INTENSITY (C = 90)



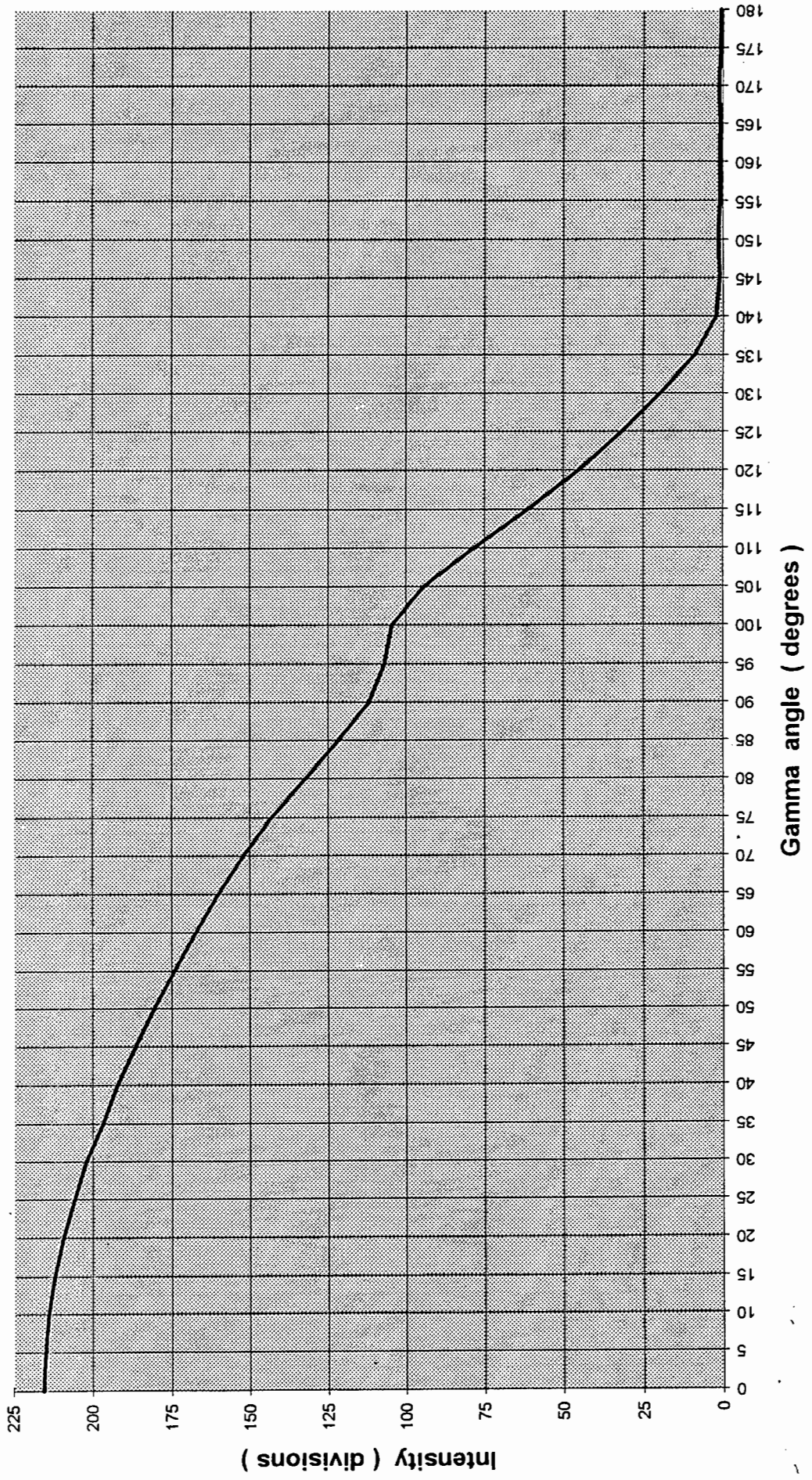
LUMINAIRE NORMAL INTENSITIES
(Ave C = 0 , C = 180)



LUMINAIRE AXIAL INTENSITIES
(Ave C = 90 , C = 270)



AVERAGED LUMINAIRE INTENSITIES



Sheet1

C	0	30	60	90	120	150	180	210	240	270	300	330	average
gamma													
0	215	217	216	215	216	214	217	218	216	215	213	215	216
5	216	217	214	216	213	216	216	216	213	214	215	214	215
10	217	218	211	213	213	215	216	215	212	213	212	213	214
15	216	216	210	207	209	214	217	216	209	208	209	213	212
20	216	212	205	200	206	216	218	213	204	203	206	213	209
25	217	212	196	194	202	216	218	211	199	193	200	212	206
30	219	212	191	185	195	213	220	211	191	184	193	211	202
35	221	209	184	172	187	211	221	209	183	172	185	209	197
40	221	209	174	159	178	213	224	209	174	160	177	208	192
45	224	207	164	144	170	212	225	209	163	144	167	208	186
50	226	207	154	127	161	211	227	208	155	128	156	207	181
55	226	208	144	110	149	210	229	207	144	110	146	207	174
60	226	205	133	89	141	211	229	208	134	91	137	203	167
65	224	203	126	70	133	207	226	204	126	73	128	201	160
70	220	200	118	50	124	204	223	201	118	51	120	197	152
75	215	192	110	31	116	195	220	197	110	32	110	191	143
80	207	183	99	13	103	189	211	186	99	18	98	181	132
85	199	174	84	5	90	178	203	178	87	7	86	170	122
90	189	163	72	1	77	168	195	169	75	0	74	160	112
95	182	161	72	1	75	161	183	159	72	0	66	151	107
100	183	157	59	1	76	162	185	161	62	0	56	153	105
105	172	157	41	2	63	151	179	149	45	0	37	138	95
110	150	144	26	1	43	125	157	127	30	1	23	115	79
115	126	119	11	0	27	102	131	101	16	2	10	92	61
120	99	95	1	0	12	76	106	80	5	1	1	67	45
125	74	71	0	0	2	54	79	55	0	1	1	43	32
130	50	47	0	0	1	29	53	32	1	2	0	20	20
135	22	25	0	0	1	10	30	13	2	1	0	4	9
140	2	9	0	2	1	1	8	0	0	1	1	2	2
145	0	0	1	3	0	2	2	0	1	2	0	1	1
150	2	3	0	2	0	3	1	0	2	2	1	1	1
155	0	1	1	2	0	0	2	1	1	1	0	0	1
160	1	2	1	2	0	1	1	0	2	1	1	0	1
165	0	2	1	1	0	0	0	1	2	0	0	1	1
170	1	2	1	0	1	0	1	2	2	3	0	1	1
175	1	1	0	0	1	0	2	0	1	1	1	0	1
180	1	0	1	1	0	0	1	1	2	1	0	1	1

Winged Fluorescent Channel, cut-off at 90 degrees

[A_{\cos} and L_{const}]

	g	5	15	25	35	45	55	65	75	85
Ave-Inten		217.0	215.7	209.5	200.1	187.4	173.0	148.0	79.4	12.4
	zf	0.096	0.284	0.464	0.629	0.776	0.899	0.994	1.060	1.093
Zonal Fdn		20.7	61.3	97.1	125.9	145.3	155.5	147.1	84.1	13.5

Lum Fdn = 851 (in divisions)

	g	95	105	115	125	135	145	155	165	175
Ave-Inten		1.9	0.6	0.1	0.4	0.5	0.0	0.8	0.3	0.9
	zf	1.093	1.060	0.994	0.899	0.776	0.629	0.464	0.284	0.096
Zonal Fup		2.0	0.7	0.1	0.3	0.4	0.0	0.3	0.1	0.1

Lum Fup = 4.1 (in divisions)

total lum flux = 855 (in divisions)

FFR
0.0048

dLOR uLOR LOR
0.727 0.003 0.731

Direct Ratios for this luminaire for different R.I

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
D.R	0.347	0.410	0.495	0.548	0.634	0.697	0.736	0.794	0.832

The BZ classification of this luminaire for different RI:

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
BZ no.	6	5	5	5	5	5	5	5	5

Azimuth Angle, C =0.0 degrees

Ga	0								
Io	220								
Ga	5	10	15	20	25	30	35	40	45
I	221	221	222	221	218	218	218	216	213
Ga	50	55	60	65	70	75	80	85	90
I	215	210	202	174	121	61	21	7	0
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	0	0	0	1	0	0
Ga	140	145	150	155	160	165	170	175	180
I	1	0	1	1	0	1	0	0	0

Azimuth Angle, C =45.0 degrees

Ga	0								
Io	217								
Ga	5	10	15	20	25	30	35	40	45
I	217	216	216	213	210	204	199	196	190
Ga	50	55	60	65	70	75	80	85	90
I	186	181	173	165	147	101	43	14	4
Ga	95	100	105	110	115	120	125	130	135
I	3	1	2	1	0	0	1	0	2
Ga	140	145	150	155	160	165	170	175	180
I	0	0	0	1	0	0	0	0	1

Azimuth Angle, C =90.0 degrees

Ga	0								
Io	217								
Ga	5	10	15	20	25	30	35	40	45
I	216	214	212	207	200	193	183	171	160
Ga	50	55	60	65	70	75	80	85	90
I	144	127	109	91	73	52	32	10	1
Ga	95	100	105	110	115	120	125	130	135
I	1	0	1	0	0	1	0	1	0
Ga	140	145	150	155	160	165	170	175	180
I	0	0	2	2	0	0	0	1	1

Azimuth Angle, C =135.0 degrees

Ga	0								
Io	216								
Ga	5	10	15	20	25	30	35	40	45
I	216	217	216	213	212	205	200	196	190
Ga	50	55	60	65	70	75	80	85	90
I	184	178	171	165	147	101	46	17	3
Ga	95	100	105	110	115	120	125	130	135
I	3	4	1	0	0	0	1	0	1
Ga	140	145	150	155	160	165	170	175	180
I	0	0	2	0	1	0	0	2	0

Azimuth Angle, C =180.0 degrees

Ga	0								
Io	217								
Ga	5	10	15	20	25	30	35	40	45
I	218	217	218	217	215	214	214	213	211
Ga	50	55	60	65	70	75	80	85	90
I	210	207	198	176	126	63	20	7	0
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	0	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	1	0	0	0	1	0	1	2	0

Azimuth Angle, C =225.0 degrees

Ga	0								
Io	218								
Ga	5	10	15	20	25	30	35	40	45
I	216	216	214	212	207	203	197	190	186
Ga	50	55	60	65	70	75	80	85	90
I	179	172	167	158	137	90	31	12	1
Ga	95	100	105	110	115	120	125	130	135
I	4	2	1	0	0	0	0	0	1
Ga	140	145	150	155	160	165	170	175	180
I	0	0	0	1	1	0	0	0	0

Azimuth Angle, C =270.0 degrees

Ga	0								
Io	217								
Ga	5	10	15	20	25	30	35	40	45
I	215	216	212	206	200	188	185	170	156
Ga	50	55	60	65	70	75	80	85	90
I	141	125	106	88	67	48	28	9	0
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	0	1	0	0	1	0
Ga	140	145	150	155	160	165	170	175	180
I	1	0	1	1	0	1	0	1	0

Azimuth Angle, C =315.0 degrees

Ga	0								
Io	218								
Ga	5	10	15	20	25	30	35	40	45
I	217	218	216	215	214	209	205	197	193
Ga	50	55	60	65	70	75	80	85	90
I	187	184	173	167	153	119	60	23	7
Ga	95	100	105	110	115	120	125	130	135
I	4	1	0	0	0	1	0	1	0
Ga	140	145	150	155	160	165	170	175	180
I	1	0	0	0	1	0	1	1	1

The luminaire description was: A Winged Fluorescent Channel with cut-off at 90 degrees (cut-off at g = 90)

The luminaire was described as having an A_{cos} characteristic

number of cplane lobes = 8

lobe angular spacing = 45

Lum Flux Down 851

Factor f1 = 1000/Lumfluxdn = 1.176

g \ c	0	45	90	135	180	225	270	315
0	220	217	217	216	217	218	217	218
5	221	217	216	216	218	216	215	217
10	221	216	214	217	217	216	216	218
15	222	216	212	216	218	214	212	216
20	221	213	207	213	217	212	206	215
25	218	210	200	212	215	207	200	214
30	218	204	193	205	214	203	188	209
35	218	199	183	200	214	197	185	205
40	216	196	171	196	213	190	170	197
45	213	190	160	190	211	186	156	193
50	215	186	144	184	210	179	141	187
55	210	181	127	178	207	172	125	184
60	202	173	109	171	198	167	106	173
65	174	165	91	165	176	158	88	167
70	121	147	73	147	126	137	67	153
75	61	101	52	101	63	90	48	119
80	21	43	32	46	20	31	28	60
85	7	14	10	17	7	12	9	23
90	0	4	1	3	0	1	0	7

IGI table (experimental) for CROSSWISE layout

19.0	19.5	19.7	19.8	19.8	19.8
20.9	21.5	21.8	22.0	22.1	22.0
21.3	22.0	22.3	22.7	22.7	22.7
21.4	22.1	22.5	22.9	23.0	23.1
21.4	22.1	22.5	22.9	23.1	23.1
21.4	22.1	22.5	22.9	23.1	23.2

IGI table (experimental) for ENDWISE layout

17.0	17.9	18.4	18.8	18.8	18.8
18.6	19.6	20.2	20.7	20.8	20.8
19.2	20.3	20.9	21.5	21.6	21.6
19.6	20.7	21.3	21.9	22.1	22.2
19.7	20.8	21.5	22.1	22.3	22.4
19.8	20.8	21.5	22.1	22.4	22.5

GLARE CLASS IS : G5 CROSSWISE

GLARE CLASS IS : G5 ENDWISE

The luminaire description was: **A Bare Fluorescent Channel (BFC)**

The luminaire was described as having an **L_const** characteristic

number of cplane lobes = 8
lobe angular spacing = 45

Lum Flux Down 1033 (in divisions)
Factor f1 = 1000/Lumfluxdn = 0.969

g \ c	0	45	90	135	180	225	270	315
0	218	214	213	213	213	213	213	215
5	217	213	212	214	213	213	211	216
10	216	211	209	211	215	212	210	214
15	218	209	205	211	213	209	206	211
20	216	206	199	207	214	205	201	209
25	219	203	191	206	216	202	193	207
30	220	197	180	204	215	199	184	202
35	221	194	170	198	215	193	171	199
40	225	188	157	193	220	187	159	196
45	228	184	141	187	221	181	143	193
50	229	178	127	186	224	179	128	189
55	230	173	107	181	223	175	109	184
60	230	170	89	177	224	170	87	181
65	228	166	72	174	221	165	72	175
70	223	158	52	168	220	162	50	170
75	218	152	32	158	213	155	31	162
80	212	142	16	149	205	145	13	153
85	201	131	6	137	195	133	3	142
90	194	121	1	127	188	121	1	129

IGI table (experimental) for CROSSWISE layout

17.4	17.8	18.0	18.1	18.2	18.1
19.1	19.6	19.9	20.2	20.2	20.2
19.7	20.3	20.6	21.0	21.1	21.1
20.0	20.7	21.1	21.4	21.6	21.7
20.0	20.7	21.2	21.6	21.8	21.9
20.1	20.8	21.2	21.7	21.9	22.0

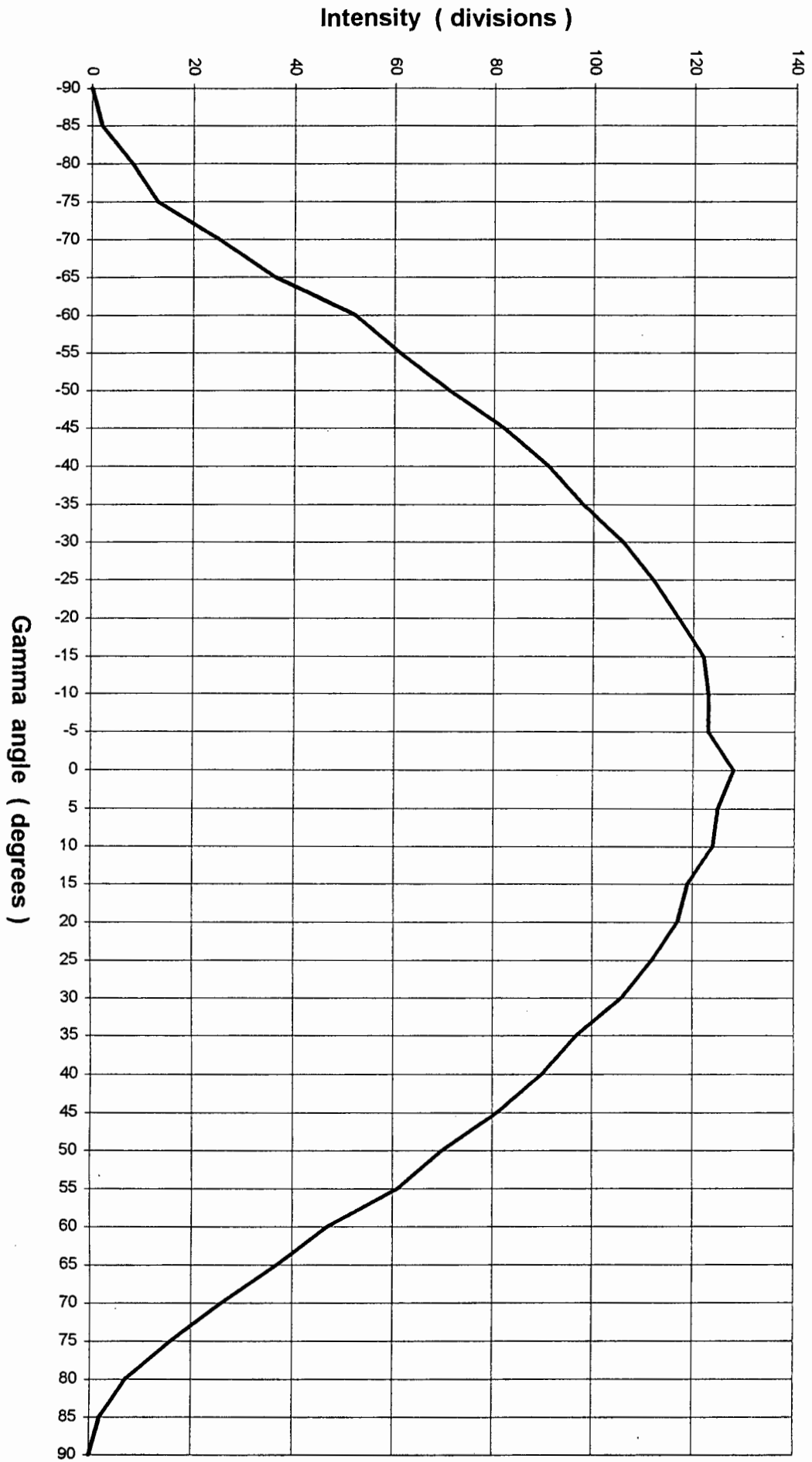
IGI table (experimental) for ENDWISE layout

16.4	17.0	17.3	17.6	17.6	17.6
18.0	18.7	19.1	19.5	19.6	19.6
18.6	19.4	19.9	20.3	20.5	20.5
19.1	20.0	20.5	21.0	21.2	21.3
19.3	20.2	20.7	21.2	21.5	21.6
19.4	20.3	20.8	21.4	21.6	21.8

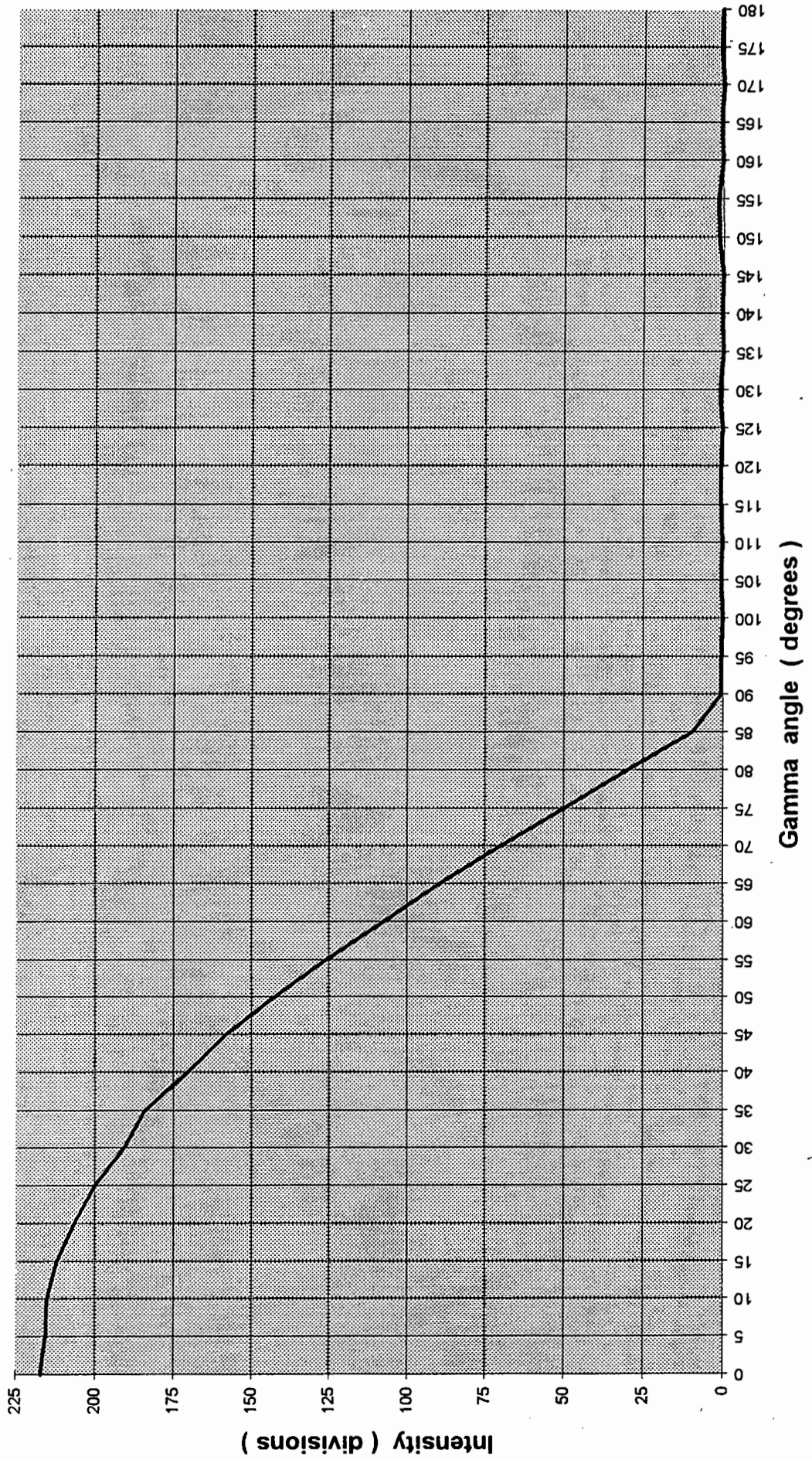
GLARE CLASS IS : G5 CROSSWISE

GLARE CLASS IS : G45 ENDWISE

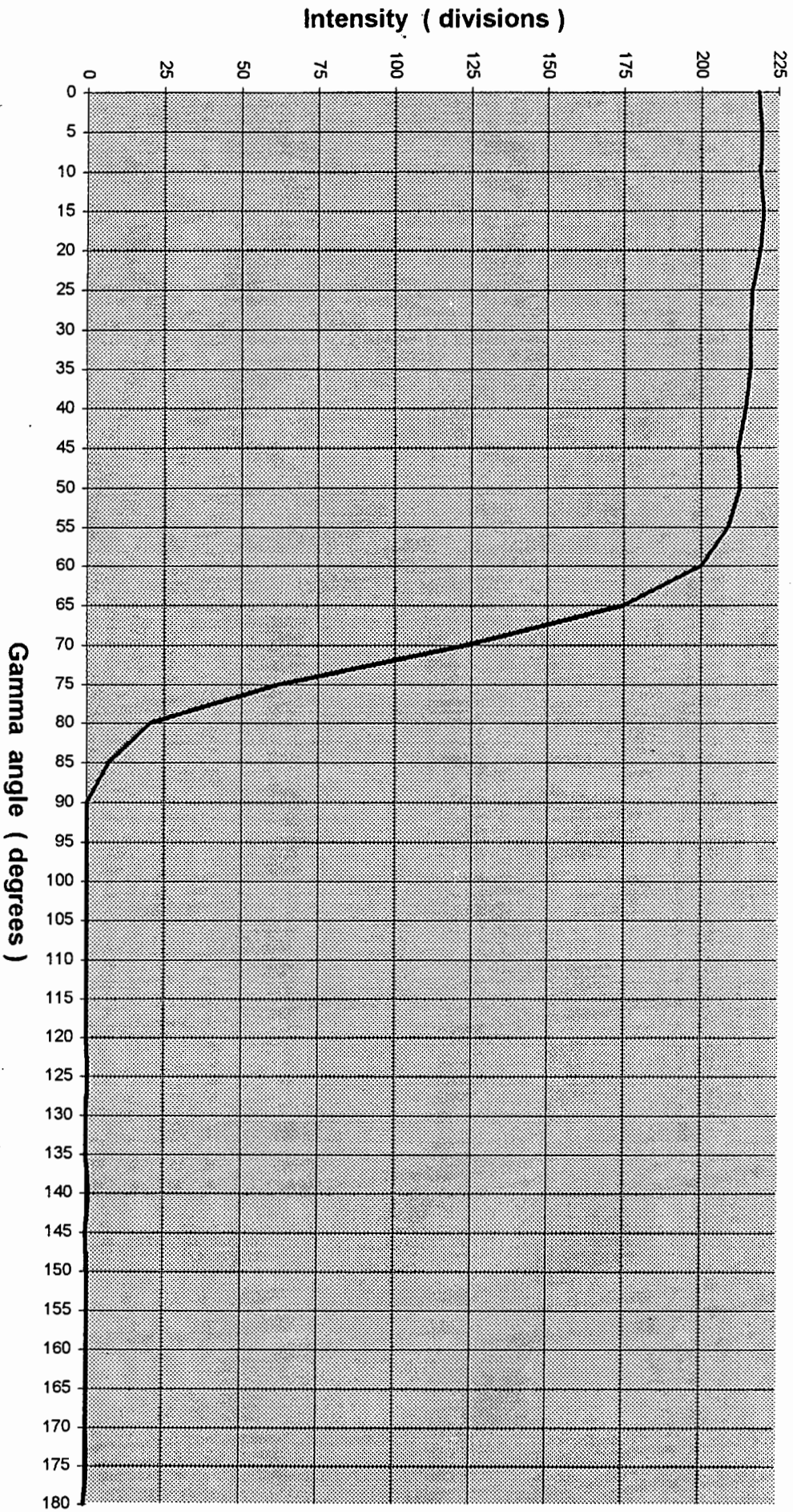
LAMP AXIAL INTENSITY



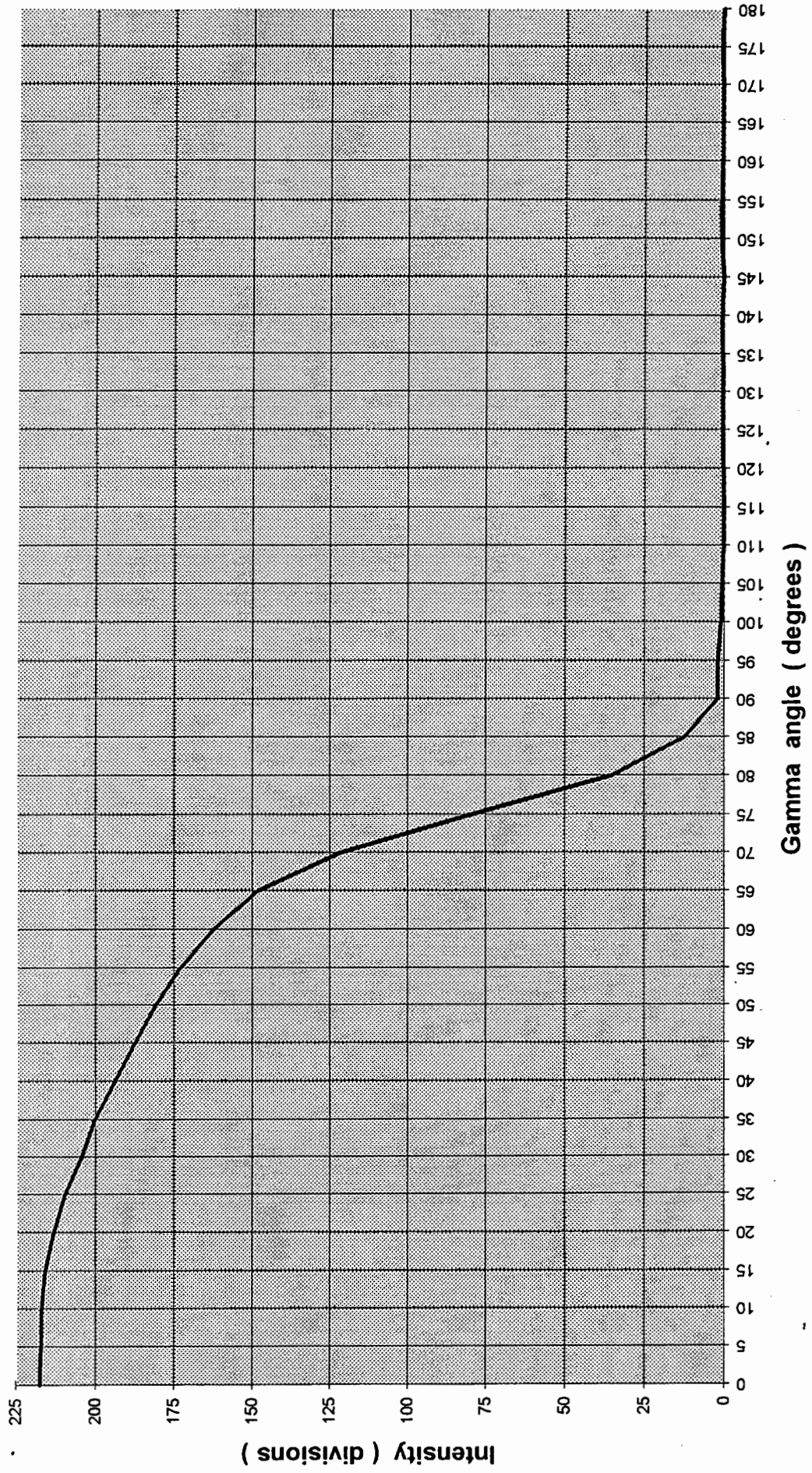
LUMINAIRE AXIAL INTENSITIES
(Ave C = 90 , C = 270)



LUMINAIRE NORMAL INTENSITIES
(Ave C = 0 , C = 180)



AVERAGED LUMINAIRE INTENSITIES



Sheet1

C	0	45	90	135	180	225	270	315		average
gamma										
0	220	217	217	216	217	218	217	218		218
5	221	217	216	216	218	216	215	217		217
10	221	216	214	217	217	216	216	218		217
15	222	216	212	216	218	214	212	216		216
20	221	213	207	213	217	212	206	215		213
25	218	210	200	212	215	207	200	214		210
30	218	204	193	205	214	203	188	209		204
35	218	199	183	200	214	197	185	205		200
40	216	196	171	196	213	190	170	197		194
45	213	190	160	190	211	186	156	193		187
50	215	186	144	184	210	179	141	187		181
55	210	181	127	178	207	172	125	184		173
60	202	173	109	171	198	167	106	173		162
65	174	165	91	165	176	158	88	167		148
70	121	147	73	147	126	137	67	153		121
75	61	101	52	101	63	90	48	119		79
80	21	43	32	46	20	31	28	60		35
85	7	14	10	17	7	12	9	23		12
90	0	4	1	3	0	1	0	7		2
95	0	3	1	3	0	4	0	4		2
100	0	1	0	4	0	2	0	1		1
105	0	2	1	1	0	1	0	0		1
110	0	1	0	0	0	0	0	0		0
115	0	0	0	0	0	0	1	0		0
120	0	0	1	0	0	0	0	1		0
125	1	1	0	1	0	0	0	0		0
130	0	0	1	0	0	0	1	1		0
135	0	2	0	1	0	1	0	0		1
140	1	0	0	0	1	0	1	1		1
145	0	0	0	0	0	0	0	0		0
150	1	0	2	2	0	0	1	0		1
155	1	1	2	0	0	1	1	0		1
160	0	0	0	1	1	1	0	1		1
165	1	0	0	0	0	0	1	0		0
170	0	0	0	0	1	0	0	1		0
175	0	0	1	2	2	0	1	1		1
180	0	1	1	0	0	0	0	1		0

Winged Fluorescent Channel, cut-off at 95 degrees

[A_cos and L_const]

g	5	15	25	35	45	55	65	75	85
Ave-Inten	207.4	204.8	198.4	189.3	179.4	166.3	149.7	114.3	41.2
zf	0.096	0.284	0.464	0.629	0.776	0.899	0.994	1.060	1.093
Zonal Fdn	19.8	58.2	92.0	119.1	139.2	149.5	148.9	121.1	45.0

Lum Fdn = 893 (in divisions)

g	95	105	115	125	135	145	155	165	175
Ave-Inten	2.0	0.3	0.2	0.3	0.0	0.3	0.1	0.3	0.4
zf	1.093	1.060	0.994	0.899	0.776	0.629	0.464	0.284	0.096
Zonal Fup	2.2	0.4	0.2	0.2	0.0	0.2	0.0	0.1	0.0

Lum Fup = 3.2 (in divisions)

total lum flux = 896 (in divisions)

FFR
0.0036

dLOR **uLOR** **LOR**
0.772 0.003 0.774

Direct Ratios for this luminaire for different R.I

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
D.R	0.314	0.372	0.450	0.499	0.585	0.647	0.688	0.750	0.792

The BZ classification of this luminaire for different RI:

RI	0.8	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
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Azimuth Angle, C =90.0 degrees

Ga	0								
Io	208								
Ga	5	10	15	20	25	30	35	40	45
I	208	205	202	197	192	180	170	160	144
Ga	50	55	60	65	70	75	80	85	90
I	130	113	97	79	60	38	21	7	0
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	0	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	0	0	0	1	0	1	1	0

Azimuth Angle, C =120.0 degrees

Ga	0								
Io	207								
Ga	5	10	15	20	25	30	35	40	45
I	207	205	203	200	194	187	180	173	164
Ga	50	55	60	65	70	75	80	85	90
I	154	148	139	130	121	107	78	37	6
Ga	95	100	105	110	115	120	125	130	135
I	5	3	2	0	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	0	1	0	0	0	0	0	0

Azimuth Angle, C =150.0 degrees

Ga	0								
Io	209								
Ga	5	10	15	20	25	30	35	40	45
I	209	207	208	206	204	202	201	200	198
Ga	50	55	60	65	70	75	80	85	90
I	197	194	192	182	168	138	92	44	4
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	0	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	2	1	0	0	0	0	0	0

Azimuth Angle, C =180.0 degrees

Ga	0								
Io	208								
Ga	5	10	15	20	25	30	35	40	45
I	207	207	207	207	205	206	206	209	210
Ga	50	55	60	65	70	75	80	85	90
I	209	207	203	193	177	143	96	48	7
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	0	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	0	0	1	1	0	1	0	1

Azimuth Angle, C =210.0 degrees

Ga	0								
Io	210								
Ga	5	10	15	20	25	30	35	40	45
I	210	207	206	204	202	201	200	198	197
Ga	50	55	60	65	70	75	80	85	90
I	196	194	191	182	167	139	95	47	8
Ga	95	100	105	110	115	120	125	130	135
I	5	0	0	0	0	2	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	0	0	0	0	0	0	0	1

Azimuth Angle, C =240.0 degrees

Ga	0								
Io	207								
Ga	5	10	15	20	25	30	35	40	45
I	205	207	202	198	194	187	180	170	162
Ga	50	55	60	65	70	75	80	85	90
I	151	139	132	124	115	105	81	44	9
Ga	95	100	105	110	115	120	125	130	135
I	5	2	2	0	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	1	0	0	0	0	0	1	0

The luminaire description was: **Winged Fluorescent Channel with cut-off above $g = 90$ degrees (cut-off at $g = 95$)**

The luminaire was described as having an **A_{cos}** characteristic

number of cplane lobes = 12
 lobe angular spacing = 30

Lum Flux Down = 893
 Factor f1 = 1000/Lumfluxdn = 1.120

g \ c	0	30	60	90	120	150	180	210	240	270	300	330
0	208	209	209	208	207	209	208	210	207	209	207	208
5	208	207	208	208	207	209	207	210	205	206	207	207
10	208	205	206	205	205	207	207	207	207	206	206	206
15	206	206	204	202	203	208	207	206	202	203	205	206
20	206	204	199	197	200	206	207	204	198	196	202	205
25	207	201	191	192	194	204	205	202	194	189	197	205
30	208	199	186	180	187	202	206	201	187	184	189	201
35	206	197	179	170	180	201	206	200	180	172	182	199
40	209	197	171	160	173	200	209	198	170	161	175	200
45	209	194	161	144	164	198	210	197	162	148	167	199
50	209	195	153	130	154	197	209	196	151	133	160	195
55	204	193	143	113	148	194	207	194	139	118	147	196
60	201	189	135	97	139	192	203	191	132	99	139	189
65	196	184	128	79	130	182	193	182	124	81	133	185
70	180	168	118	60	121	168	177	167	115	61	124	170
75	152	144	107	38	107	138	143	139	105	39	112	148
80	110	103	80	21	78	92	96	95	81	24	89	109
85	58	54	41	7	37	44	48	47	44	8	53	53
90	16	10	5	0	6	4	7	8	9	0	13	13

IGI table (experimental) for CROSSWISE layout

18.7	19.2	19.4	19.5	19.5	19.5
21.5	22.1	22.4	22.6	22.7	22.7
22.8	23.5	23.9	24.2	24.3	24.4
24.0	24.7	25.2	25.6	25.8	26.0
24.5	25.2	25.7	26.3	26.5	26.7
24.8	25.6	26.2	26.8	27.1	27.3

IGI table (experimental) for ENDWISE layout

16.0	16.9	17.6	18.2	18.5	18.7
17.6	18.7	19.5	20.3	20.7	20.9
18.2	19.5	20.3	21.3	21.8	22.1
18.6	20.0	21.0	22.1	22.7	23.2
18.7	20.1	21.1	22.4	23.0	23.6
18.8	20.2	21.2	22.5	23.2	23.9

GLARE CLASS IS : **G10 CROSSWISE**

GLARE CLASS IS : **G5 ENDWISE**

The luminaire description was: **Winged Fluorescent Channel with cut-off above 90 degrees (cut-off at g = 95)**

The luminaire was described as having an **L_const** characteristic

number of cplane lobes = 12
 lobe angular spacing = 30

Lum Flux Down 893
 Factor f1 = 1000/Lumfluxdn = 1.120

g \ c	0	30	60	90	120	150	180	210	240	270	300	330
0	208	209	209	208	207	209	208	210	207	209	207	208
5	208	207	208	208	207	209	207	210	205	206	207	207
10	208	205	206	205	205	207	207	207	207	206	206	206
15	206	206	204	202	203	208	207	206	202	203	205	206
20	206	204	199	197	200	206	207	204	198	196	202	205
25	207	201	191	192	194	204	205	202	194	189	197	205
30	208	199	186	180	187	202	206	201	187	184	189	201
35	206	197	179	170	180	201	206	200	180	172	182	199
40	209	197	171	160	173	200	209	198	170	161	175	200
45	209	194	161	144	164	198	210	197	162	148	167	199
50	209	195	153	130	154	197	209	196	151	133	160	195
55	204	193	143	113	148	194	207	194	139	118	147	196
60	201	189	135	97	139	192	203	191	132	99	139	189
65	196	184	128	79	130	182	193	182	124	81	133	185
70	180	168	118	60	121	168	177	167	115	61	124	170
75	152	144	107	38	107	138	143	139	105	39	112	148
80	110	103	80	21	78	92	96	95	81	24	89	109
85	58	54	41	7	37	44	48	47	44	8	53	53
90	16	10	5	0	6	4	7	8	9	0	13	13

IGI table (experimental) for CROSSWISE layout

16.9	17.3	17.5	17.6	17.7	17.6
19.0	19.6	19.9	20.1	20.2	20.2
20.0	20.7	21.0	21.4	21.5	21.5
20.9	21.7	22.1	22.5	22.7	22.8
21.3	22.1	22.5	23.0	23.3	23.4
21.6	22.4	22.9	23.4	23.7	24.0

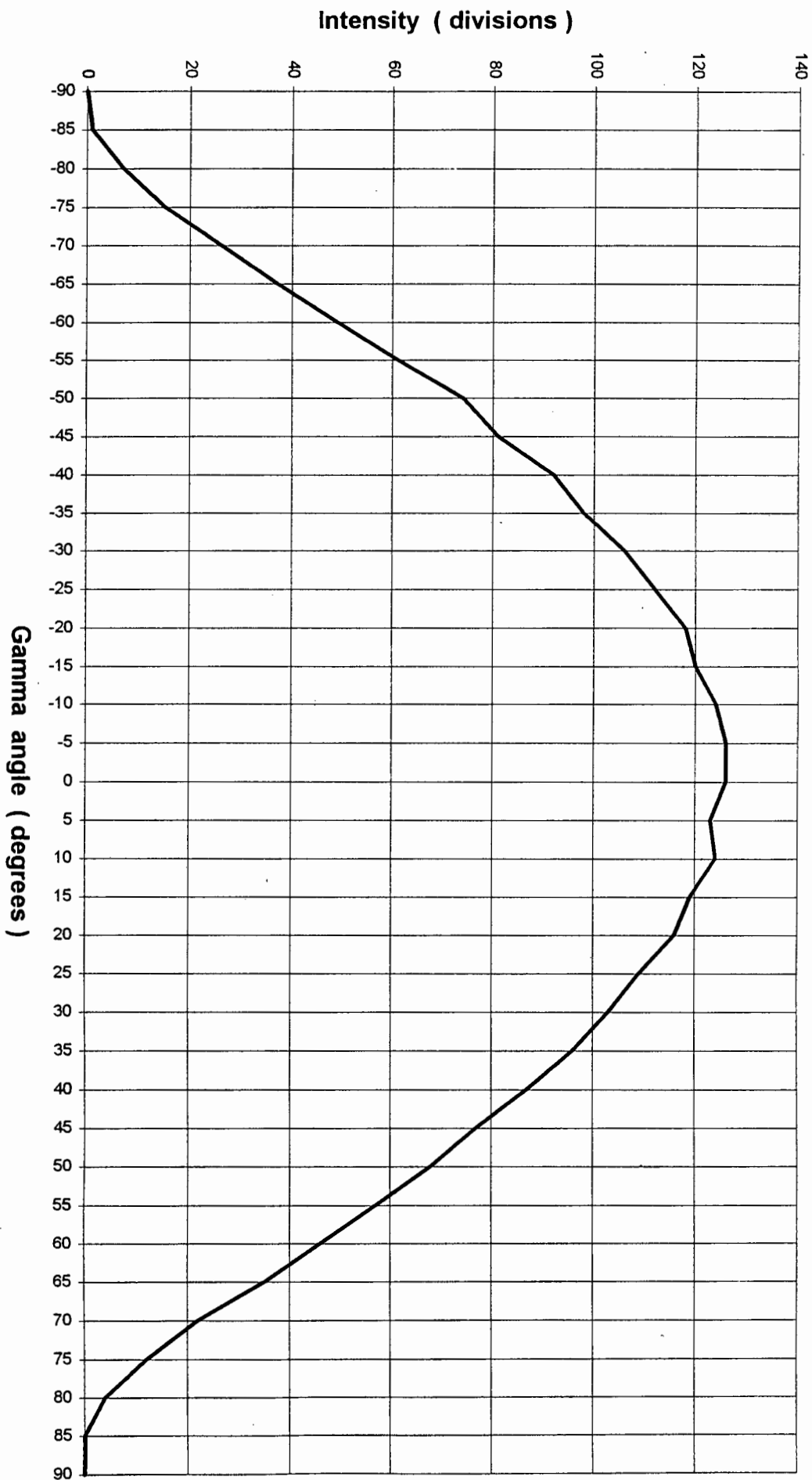
IGI table (experimental) for ENDWISE layout

15.5	16.2	16.6	16.9	17.0	17.1
17.1	17.9	18.4	18.9	19.1	19.2
17.8	18.7	19.3	19.9	20.1	20.3
18.3	19.3	20.0	20.7	21.0	21.3
18.5	19.5	20.2	21.0	21.4	21.8
18.6	19.6	20.3	21.2	21.7	22.1

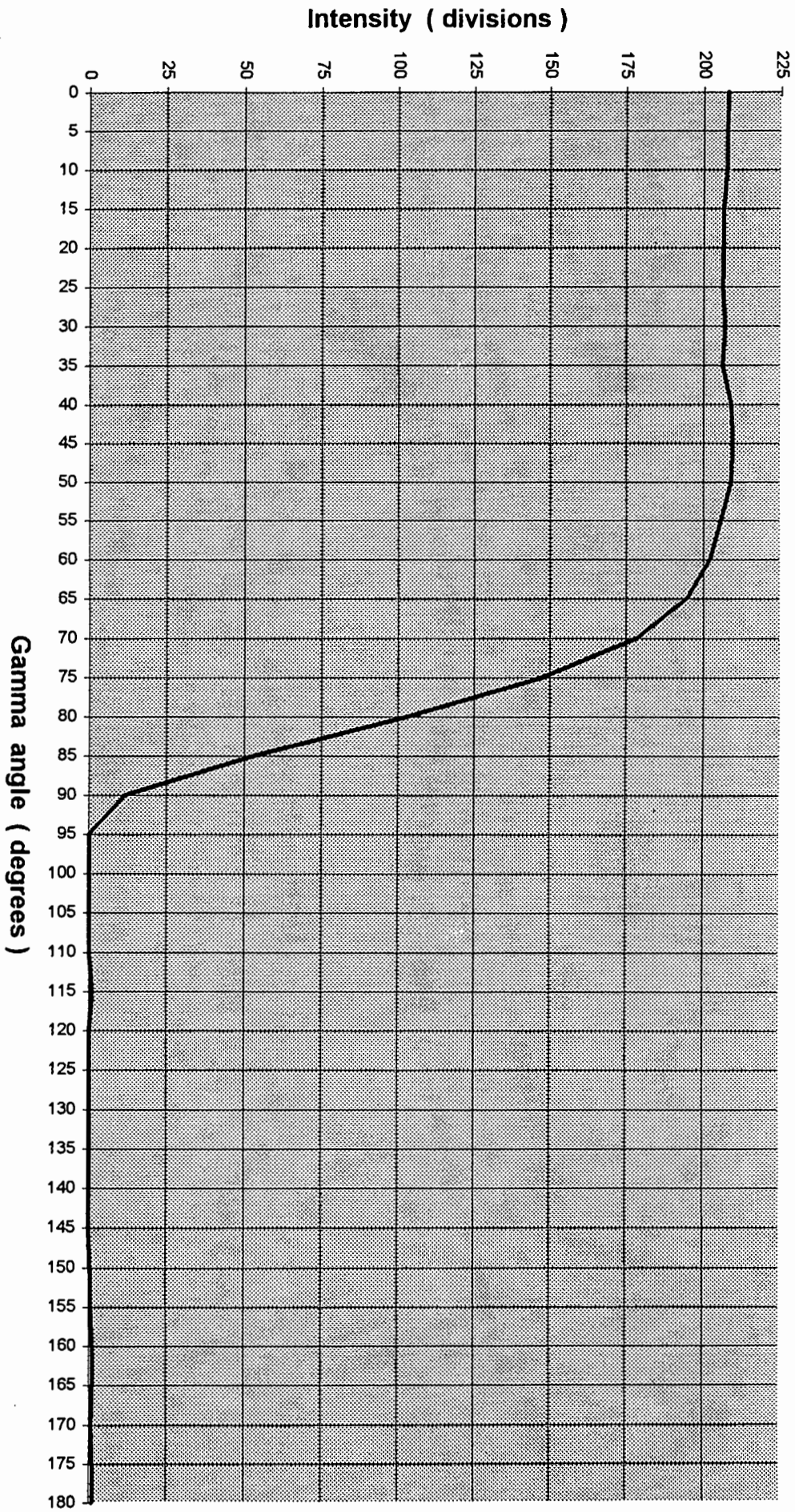
GLARE CLASS IS : G5 CROSSWISE

GLARE CLASS IS : G45 ENDWISE

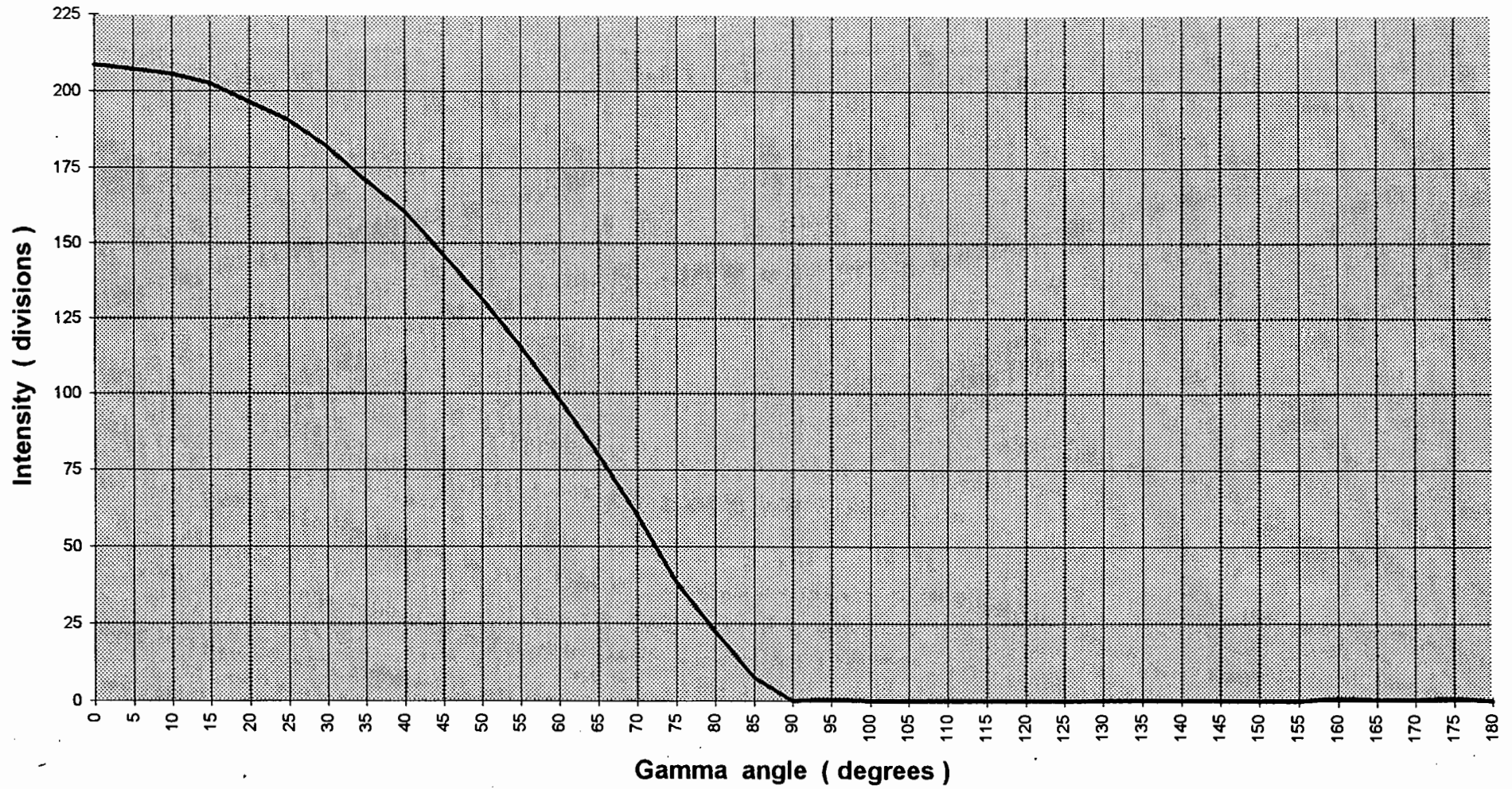
LAMP AXIAL INTENSITY (C = 90)



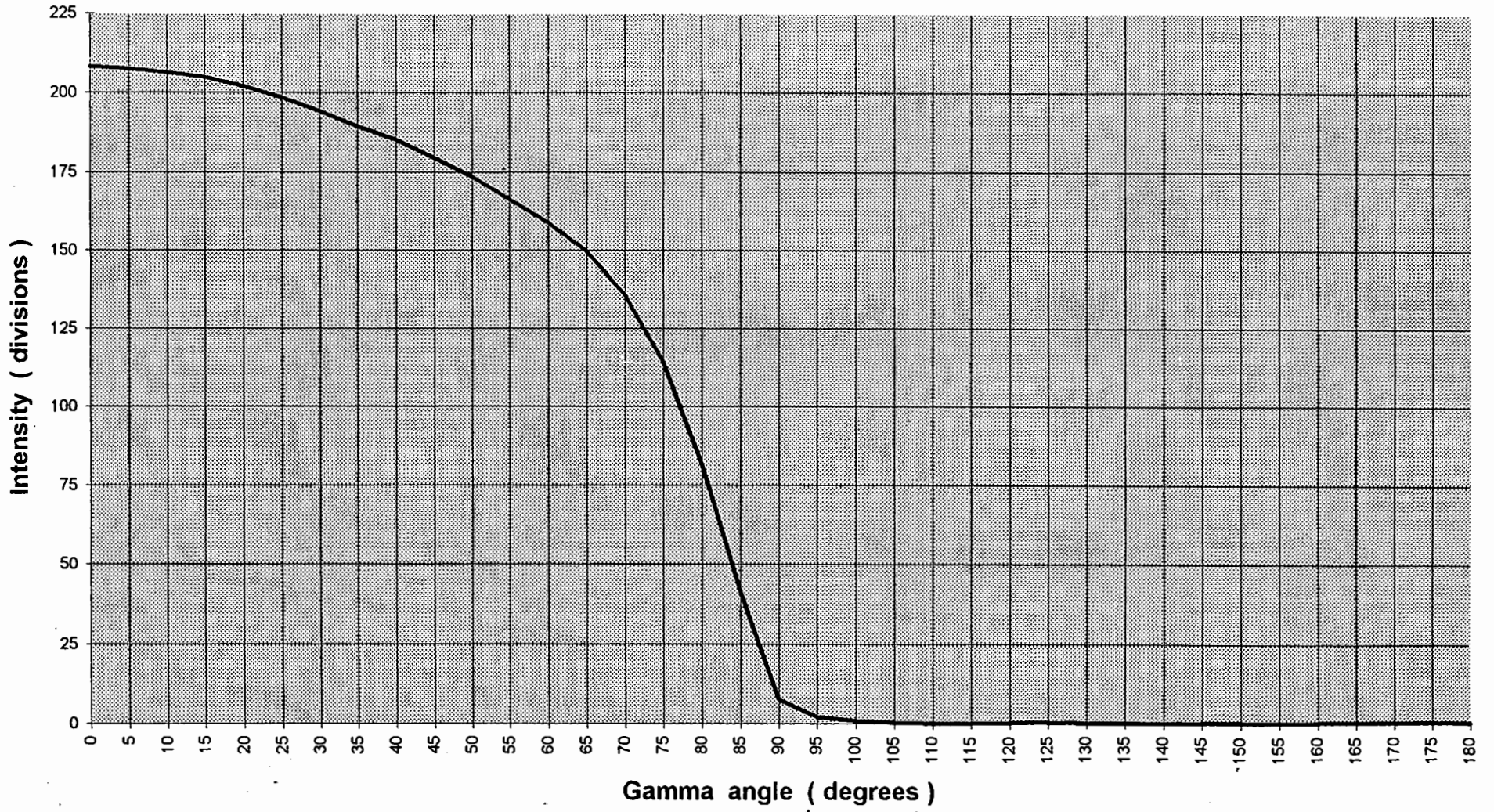
LUMINAIRE NORMAL INTENSITIES
(Ave C = 0 , C = 180)



LUMINAIRE AXIAL INTENSITIES
(Ave C = 90 , C = 270)



AVERAGED LUMINAIRE INTENSITIES



Sheet1

C	0	30	60	90	120	150	180	210	240	270	300	330	average
gamma													
0	208	209	209	208	207	209	208	210	207	209	207	208	208
5	208	207	208	208	207	209	207	210	205	206	207	207	207
10	208	205	206	205	205	207	207	207	207	206	206	206	206
15	206	206	204	202	203	208	207	206	202	203	205	206	205
20	206	204	199	197	200	206	207	204	198	196	202	205	202
25	207	201	191	192	194	204	205	202	194	189	197	205	198
30	208	199	186	180	187	202	206	201	187	184	189	201	194
35	206	197	179	170	180	201	206	200	180	172	182	199	189
40	209	197	171	160	173	200	209	198	170	161	175	200	185
45	209	194	161	144	164	198	210	197	162	148	167	199	179
50	209	195	153	130	154	197	209	196	151	133	160	195	174
55	204	193	143	113	148	194	207	194	139	118	147	196	166
60	201	189	135	97	139	192	203	191	132	99	139	189	159
65	196	184	128	79	130	182	193	182	124	81	133	185	150
70	180	168	118	60	121	168	177	167	115	61	124	170	136
75	152	144	107	38	107	138	143	139	105	39	112	148	114
80	110	103	80	21	78	92	96	95	81	24	89	109	82
85	58	54	41	7	37	44	48	47	44	8	53	53	41
90	16	10	5	0	6	4	7	8	9	0	13	13	8
95	0	0	4	0	5	0	0	5	5	1	4	0	2
100	0	0	2	0	3	0	0	0	2	0	2	0	1
105	0	0	0	0	2	0	0	0	2	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0	0	0
115	2	0	0	0	0	0	0	0	0	0	0	0	0
120	0	1	0	0	0	0	0	2	0	0	0	0	0
125	0	1	0	0	0	0	0	0	0	0	2	0	0
130	0	0	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	2	0	0	1	0	0	0	0
150	1	0	0	0	1	1	0	0	0	0	0	0	0
155	0	0	0	0	0	0	1	0	0	0	0	0	0
160	1	0	0	1	0	0	1	0	0	1	0	0	0
165	2	0	0	0	0	0	0	0	0	1	0	0	0
170	0	0	1	1	0	0	1	0	0	0	1	0	0
175	2	0	0	1	0	0	0	0	1	1	0	0	0
180	1	1	0	0	0	0	1	1	0	0	0	0	0

150W Pearl Incandescent Down-Lighter [A_cos]

Azimuth Angle, C =0.0 degrees

Ga	0								
Io	179								
Ga	5	10	15	20	25	30	35	40	45
I	175	166	153	140	127	120	100	74	50
Ga	50	55	60	65	70	75	80	85	90
I	29	15	7	3	2	1	2	1	1
Ga	95	100	105	110	115	120	125	130	135
I	1	1	0	1	0	0	1	0	1
Ga	140	145	150	155	160	165	170	175	180
I	0	0	1	0	0	1	0	1	1

Azimuth Angle, C =45.0 degrees

Ga	0								
Io	181								
Ga	5	10	15	20	25	30	35	40	45
I	189	197	199	191	176	156	128	87	51
Ga	50	55	60	65	70	75	80	85	90
I	27	14	8	2	1	1	1	0	0
Ga	95	100	105	110	115	120	125	130	135
I	0	1	0	0	2	0	1	0	2
Ga	140	145	150	155	160	165	170	175	180
I	0	0	1	1	1	1	1	1	0

Azimuth Angle, C =90.0 degrees

Ga	0								
Io	185								
Ga	5	10	15	20	25	30	35	40	45
I	202	221	228	219	205	181	152	106	57
Ga	50	55	60	65	70	75	80	85	90
I	28	16	7	4	1	1	0	0	0
Ga	95	100	105	110	115	120	125	130	135
I	0	1	1	0	0	0	0	0	0
Ga	140	145	150	155	160	165	170	175	180
I	0	0	0	1	0	2	1	0	0

Azimuth Angle, C =135.0 degrees

Ga	0								
Io	195								
Ga	5	10	15	20	25	30	35	40	45
I	208	217	224	219	204	179	148	106	58
Ga	50	55	60	65	70	75	80	85	90
I	29	15	8	3	1	1	1	2	1
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	0	0	0	0	1	2
Ga	140	145	150	155	160	165	170	175	180
I	0	1	0	0	0	0	0	0	0

Azimuth Angle, C =180.0 degrees

Ga	0								
Io	195								
Ga	5	10	15	20	25	30	35	40	45
I	199	195	188	173	157	141	124	93	57
Ga	50	55	60	65	70	75	80	85	90
I	31	17	7	4	2	0	2	1	0
Ga	95	100	105	110	115	120	125	130	135
I	1	1	1	0	1	0	1	0	1
Ga	140	145	150	155	160	165	170	175	180
I	0	1	0	0	0	0	0	2	1

Azimuth Angle, C =225.0 degrees

Ga	0								
Io	196								
Ga	5	10	15	20	25	30	35	40	45
I	184	167	152	136	127	119	99	75	56
Ga	50	55	60	65	70	75	80	85	90
I	37	20	10	3	2	1	1	0	1
Ga	95	100	105	110	115	120	125	130	135
I	0	0	0	2	0	0	0	1	0
Ga	140	145	150	155	160	165	170	175	180
I	2	0	1	1	0	1	1	0	0

Azimuth Angle, C =270.0 degrees

Ga	0								
Io	191								
Ga	5	10	15	20	25	30	35	40	45
I	176	159	145	131	124	115	90	68	54
Ga	50	55	60	65	70	75	80	85	90
I	35	19	10	4	2	1	1	1	1
Ga	95	100	105	110	115	120	125	130	135
I	1	0	1	0	0	0	1	1	0
Ga	140	145	150	155	160	165	170	175	180
I	1	1	1	2	1	1	1	0	0

Azimuth Angle, C =315.0 degrees

Ga	0								
Io	184								
Ga	5	10	15	20	25	30	35	40	45
I	172	160	145	132	122	114	89	68	53
Ga	50	55	60	65	70	75	80	85	90
I	33	16	8	5	2	1	0	0	0
Ga	95	100	105	110	115	120	125	130	135
I	2	0	1	1	0	1	1	0	0
Ga	140	145	150	155	160	165	170	175	180
I	1	0	2	2	0	0	0	0	0

The luminaire was: A **150W Pearl Incandescent down lighter**

The luminaire was described as having an **A_{cos}** characteristic

number of cplane lobes = 8
lobe angular spacing = 45

Lum Flux Down 276.19
Factor f1 = 1000/Lumfluxdn = 3.621

g \ c	0	45	90	135	180	225	270	315
0	179	181	185	195	195	196	191	184
5	175	189	202	208	199	184	176	172
10	166	197	221	217	195	167	159	160
15	153	199	228	224	188	152	145	145
20	140	191	219	219	173	136	131	132
25	127	176	205	204	157	127	124	122
30	120	156	181	179	141	119	115	114
35	100	128	152	148	124	99	90	89
40	74	87	106	106	93	75	68	68
45	50	51	57	58	57	56	54	53
50	29	27	28	29	31	37	35	33
55	15	14	16	15	17	20	19	16
60	7	8	7	8	7	10	10	8
65	3	2	4	3	4	3	4	5
70	2	1	1	1	2	2	2	2
75	1	1	1	1	0	1	1	1
80	2	1	0	1	2	1	1	0
85	1	0	0	2	1	0	1	0
90	1	0	0	1	0	1	1	0

IGI table (experimental) for CROSSWISE layout

14.8	14.6	14.4	14.3	14.2	14.2
14.5	14.3	14.2	14.1	14.0	14.0
14.4	14.2	14.1	14.0	13.9	13.9
14.3	14.1	14.0	13.9	13.9	13.9
14.3	14.1	14.0	13.9	13.9	13.9
14.2	14.1	14.0	13.9	13.9	13.9

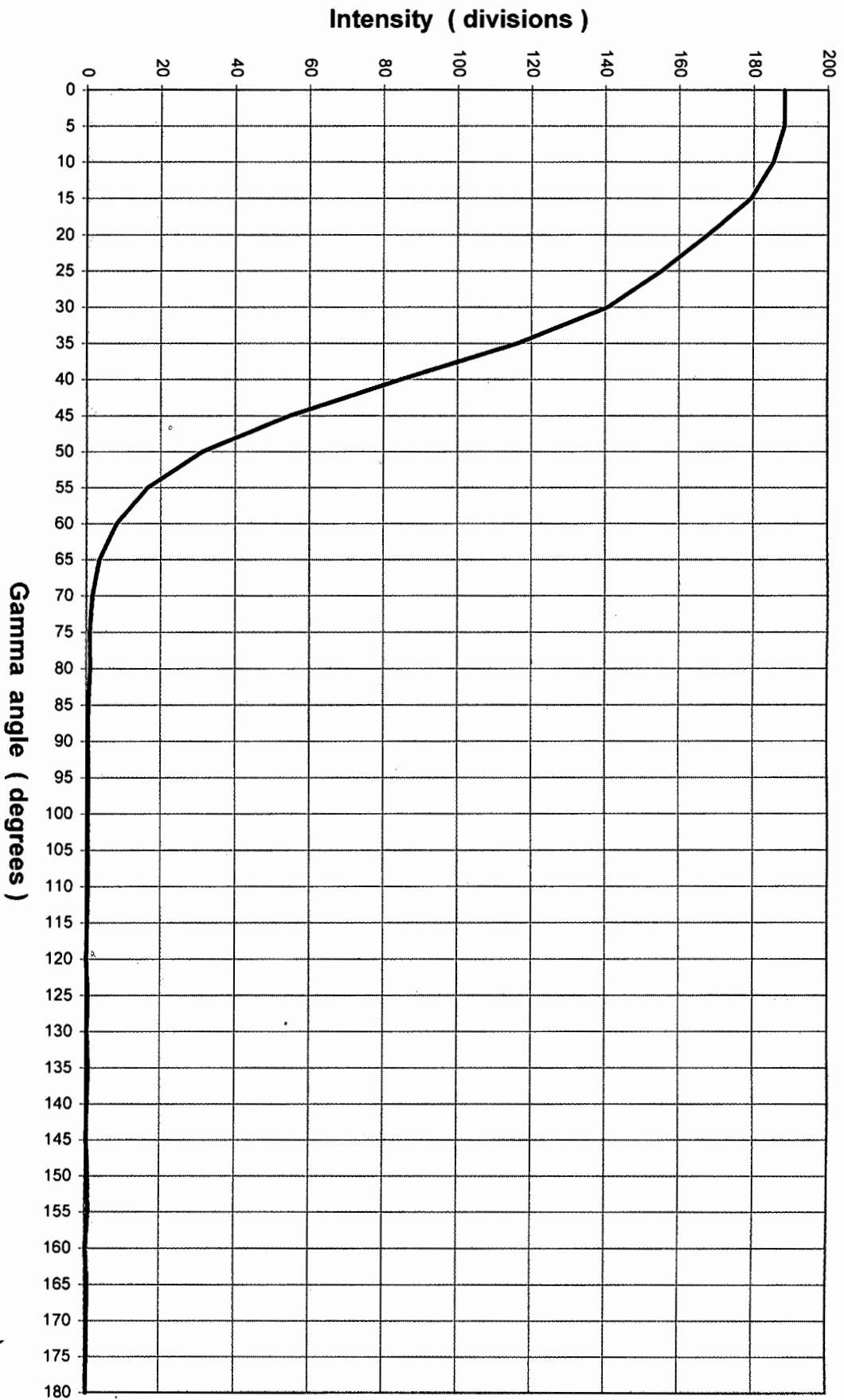
IGI table (experimental) for ENDWISE layout

15.4	15.2	15.0	14.9	14.8	14.8
15.1	14.9	14.8	14.7	14.6	14.6
15.0	14.8	14.7	14.6	14.5	14.5
14.9	14.7	14.6	14.5	14.4	14.4
14.8	14.6	14.5	14.4	14.4	14.3
14.8	14.6	14.5	14.4	14.3	14.3

GLARE CLASS IS : **G12 CROSSWISE**

GLARE CLASS IS : **G2 ENDWISE**

AVERAGED LUMINAIRE INTENSITIES



C	0	45	90	135	180	225	270	315		average
gamma										
0	179	181	185	195	195	196	191	184		188
5	175	189	202	208	199	184	176	172		188
10	166	197	221	217	195	167	159	160		185
15	153	199	228	224	188	152	145	145		179
20	140	191	219	219	173	136	131	132		168
25	127	176	205	204	157	127	124	122		155
30	120	156	181	179	141	119	115	114		141
35	100	128	152	148	124	99	90	89		116
40	74	87	106	106	93	75	68	68		85
45	50	51	57	58	57	56	54	53		55
50	29	27	28	29	31	37	35	33		31
55	15	14	16	15	17	20	19	16		17
60	7	8	7	8	7	10	10	8		8
65	3	2	4	3	4	3	4	5		4
70	2	1	1	1	2	2	2	2		2
75	1	1	1	1	0	1	1	1		1
80	2	1	0	1	2	1	1	0		1
85	1	0	0	2	1	0	1	0		1
90	1	0	0	1	0	1	1	0		1
95	1	0	0	0	1	0	1	2		1
100	1	1	1	0	1	0	0	0		1
105	0	0	1	0	1	0	1	1		1
110	1	0	0	0	0	2	0	1		1
115	0	2	0	0	1	0	0	0		0
120	0	0	0	0	0	0	0	1		0
125	1	1	0	0	1	0	1	1		1
130	0	0	0	1	0	1	1	0		0
135	1	2	0	2	1	0	0	0		1
140	0	0	0	0	0	2	1	1		1
145	0	0	0	1	1	0	1	0		0
150	1	1	0	0	0	1	1	2		1
155	0	1	1	0	0	1	2	2		1
160	0	1	0	0	0	0	1	0		0
165	1	1	2	0	0	1	1	0		1
170	0	1	1	0	0	1	1	0		1
175	1	1	0	0	2	0	0	0		1
180	1	0	0	0	1	0	0	0		0

Street Light [measured on Mirror Photometer]

W. H. C. S.

Gamma, c Table for the **gonio photometer** at an azimuth angle of C = 18

Azimuth Angle, C =180.0 degrees

Ga	0								
Io	190								
Ga	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5
I	189	192	191	191	187	186	186	183	182
Ga	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0
I	184	190	201	208	199	204	207	200	196
Ga	47.5	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5
I	198	205	212	218	224	232	237	239	248
Ga	70.0	72.5	75.0	77.5	80.0	82.5	85.0	87.5	90.0
I	253	255	253	202	102	31	8	3	11
Ga	92.5	95.0	97.5	100					
I	2	0	13	5					

Street light luminaire intensity vs gamma at c = 180

