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INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

REVIEW OF THE OFFICIAL RECOMMENDATIONS OF THE CIE FOR THE COLOURS OF SIGNAL LIGHTS

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REVIEW OF THE OFFICIAL RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON ILLUMINATION FOR THE COLOURS OF SIGNAL LIGHTS

SUMMARY

This Technical Report reviews the CIE international recommendations for the colours of signal lights. The CIE recommendations for signal colours were first adopted in 1951 and were revised in 1975. They have not since been subject to critical review in the light of new experimental evidence and changed technology. Published and unpublished reports of experiments on the recognition of signal colours were compiled and analysed. The data from those reports were brought on to a common base for dim signals ($E \leq 1 \mu\text{lx}$ and $1 \mu\text{lx} < E \leq 10 \mu\text{lx}$), moderately bright signals ($10 \mu\text{lx} < E \leq 100 \mu\text{lx}$) and bright signals ($100 \mu\text{lx} < E \leq 1000 \mu\text{lx}$ and $E > 1 \text{mlx}$) under conditions simulating both night and day observation. Some of the experiments included subjects with defective colour vision. Consideration of the data by the Committee and its expert advisors has lead to a number of recommendations for changes to the internationally accepted colour domains for signal colours, notably (1) restriction of the yellow boundary of red, abandonment of the restricted purple boundary of red and re-definition of the recommended red in signal systems used by persons with defective colour vision, (2) substantial re-definition of the colour domain for yellow including the definition of special domains for yellow signals of high and low illuminance, (3) restriction of the boundaries of the colour domain for green, (4) amendment of the colour domain for white including the definition of a preferred domain and a secondary domain that can be used when there is little chance of confusion with white lights, (5) restricting the green and white boundaries of blue to enhance recognition as well as defining a more desaturated blue that can be used when there is little chance of confusion with white and a special domain to be used for low illuminance blue signals, and (6) recommending the abandonment of violet as a signal colour. Based on this report CIE will publish an International Standard.

REVUE DES RECOMMANDATIONS OFFICIELLES DE LA COMMISSION INTERNATIONALE DE L'ECLAIRAGE SUR LES COULEURS DES SIGNAUX LUMINEUX

RESUME

Ce rapport technique passe en revue les recommandations internationales de la CIE pour les couleurs des signaux lumineux. Les recommandations de la CIE pour les couleurs des signaux furent d'abord adoptées en 1951 puis révisées en 1975. Depuis cette date, elles n'ont pas fait l'objet d'un réexamen à la lumière des nouveaux faits expérimentaux et des changements de technologie. Le Comité a rassemblé et analysé des rapports, publiés ou non, sur des expériences de reconnaissance des couleurs des signaux. Les données de ces rapports ont été rassemblées sur une base commune pour les signaux faiblement lumineux (éclairage au niveau de l'oeil de l'observateur $E \leq 1 \mu\text{lx}$ et $1 \mu\text{lx} < E \leq 10 \mu\text{lx}$), les signaux moyennement lumineux ($10 \mu\text{lx} < E \leq 100 \mu\text{lx}$) et les signaux lumineux ($100 \mu\text{lx} < E \leq 1000 \mu\text{lx}$ et $E > 1 \text{mlx}$) dans des conditions simulant l'observation aussi bien nocturne que diurne. Certaines expériences ont introduit des sujets ayant une anomalie de la vision des couleurs. La prise en considération des données par le Comité et par les experts qui l'ont conseillé ont conduit à recommander un certain nombre de changements dans les domaines des couleurs internationalement acceptés, notamment, (1) la restriction de la limite jaune du rouge, l'abandon de la limite restreinte pourpre du rouge et la redéfinition du rouge à recommander quand les systèmes de signalisation peuvent être utilisés par des personnes atteintes d'anomalies de vision des couleurs, (2) la redéfinition substantielle du domaine de couleur pour le jaune incluant la définition de domaines spéciaux pour les signaux jaunes à fort et à faible éclairage, (3) la restriction des limites du domaine de couleur pour le vert, (4) l'amendement du domaine de couleur pour le blanc incluant la définition d'un domaine de préférence et d'un domaine secondaire utilisable quand le risque de confusion avec les lumières blanches est faible, (5) la restriction des limites verte et blanche du bleu pour améliorer la reconnaissance ainsi que la définition d'un bleu plus désaturé utilisable quand le risque de confusion avec le blanc est faible et d'un domaine spécial à utiliser pour les signaux bleus produisant un faible éclairage, et (6) la recommandation d'abandonner le violet comme couleur de signaux.

Sur la base de ce rapport, la CIE publiera une norme internationale.

ÜBERPRÜFUNG DER OFFIZIELLEN EMPFEHLUNGEN DER INTERNATIONALEN BELEUCHTUNGSKOMMISSION FÜR DIE FARBEN VON SIGNALLICHTERN

ZUSAMMENFASSUNG

Dieser Technische Bericht überprüft die internationalen CIE-Empfehlungen für die Farben von Signallichtern. Die CIE-Empfehlungen für Signalfarben waren zuerst 1951 angenommen und 1975 überarbeitet worden. Seitdem waren sie Gegenstand kritischer Überprüfungen im Licht neuer experimenteller Befunde und geänderter Technologie. Publierte und nicht publizierte Berichte von Experimenten über die Erkennung von Signalfarben wurden zusammengestellt und analysiert. Die Daten dieser Berichte wurden auf einen gemeinsamen Nenner gebracht für dunkle Signale ($E \leq 1 \mu\text{x}$ und $1 \mu\text{x} < E \leq 10 \mu\text{x}$), mäßig helle Signale ($10 \mu\text{x} < E \leq 100 \mu\text{x}$) und helle Signale ($100 \mu\text{x} < E \leq 1000 \mu\text{x}$ und $E > 1 \text{ mlx}$) für Situationen, die sowohl Nacht- als auch Tagesbeobachtung simulierten. Einige Experimente umfaßten auch Beobachter mit anomalem Farbsehvermögen. Berücksichtigung der Daten des Komitees und seiner beratenden Experten hat zu einer Anzahl von Empfehlungen für Änderungen der international angenommenen Berichte von Signalfarben geführt, besonders: 1. Eine Einschränkung des roten Farbbereichs gegenüber Gelb, eine Aufgabe des eingeschränkten Rotbereichs gegenüber Purpurrot und eine Neufestlegung des empfohlenen roten Farbbereichs für Signalsysteme, die von farbenfehlsichtigen Personen benutzt werden. 2. Eine wesentliche Neufestlegung des gelben Farbbereichs unter Einschluß der Festlegung spezieller Farbbereiche für gelbe Signallichter hoher und niedriger Beleuchtungsstärken. 3. Eine Einschränkung des grünen Farbbereichs. 4. Eine Berichtigung des weißen Farbbereichs, die die Festlegung eines bevorzugten Weißbereichs und eines zweiten Weißbereichs einschließt, der dann benutzt werden kann, wenn eine geringe Wahrscheinlichkeit für die Verwechslung mit weißen Lichtern besteht. 5. Eine Einschränkung des blauen Farbbereichs gegenüber Grün und Weiß, sowohl zur Verbesserung der Farberkennung als auch der Festlegung eines entsättigten Blau, das dann benutzt werden kann, wenn eine geringe Wahrscheinlichkeit der Verwechslung mit Weiß besteht, und ein spezieller Farbbereich für blaue Signale mit geringer Lichtstärke. 6. Eine Empfehlung zur Aufgabe des violetten Farbbereichs für Signalfarben. Basierend auf diesem Bericht wird die CIE eine internationale Norm veröffentlichen.

1 FOREWORD

The CIE first adopted international recommendations for the colours of signal lights at the 1951 Session of the CIE. These were regarded as provisional, and official recommendations were published in 1959 (CIE 2, 1959) after further discussion at the 1955 quadrennial CIE session. The official recommendations were revised in 1975 (CIE 2.2, 1975) on the basis of experience in the application of the 1959 recommendations and some additional research.

At the 21st Quadrennial Meeting of the CIE held in Venice in 1987, it was agreed by Division 4 of the CIE (the Division concerned with lighting and signalling for transport) that there should be an investigation into the desirability of a further revision of the recommendations in the light of the considerable body of new research into the recognition of signal colours. A Technical Committee (TC 4-14) under the chairmanship of Professor B L Cole (Australia) was established to carry out this task.

This is the final report which takes into account correspondence with committee members and the decisions made at the meetings of the Committee held on July 4, 1991 during the Melbourne CIE Session and at the inter-sessional meeting of Division 4 held in Prague on September 5, 1992.

Based on this report CIE is publishing an International Standard on "Colours of Signal Lights" *)

2 TERMS OF REFERENCE

To review the experimental reports on the recognition of coloured signal lights, especially those published after Publication 2.2 was finalised and to prepare a report which makes recommendations for the revision of Publication 2.2 .

*)

This standard is at the time of publishing this report in the stage of "Draft CIE Standard", its number is CIE DS 004:1994. It is expected that this standard will become a joint standard with ISO and will then get also an ISO Standard number. Interested parties should consult the current CIE List of Publications for further information.

3 INTRODUCTION

3.1 Object of the CIE recommendations for the colours of signal lights

The object of the CIE recommendations for the colours of signal lights (CIE 2.2, 1975) is to provide guidance for regulatory authorities on the colours that can be recognised reliably and to promote uniform practice within countries and internationally. The recommendations have been widely followed by national and international regulatory authorities so that to a very large extent these objectives have been well served.

3.2 Background

The 1959 recommendations were based on the experiments carried out in the 1930s and 1940s by McNicholas (1936), Holmes (1941) and Hill (1947) and on the technical and practical knowledge of the experts serving on the CIE committees that prepared the recommendations. Account was also taken of current practices and standards as well as the practical limitations of coloured signal glasses and signal assemblies and the need to generate signals of sufficient intensity. In the original recommendations and in the later revision, compromises were reached between the requirements of *"certainty of recognition of the color signal under varying conditions, adequate visual range of the light from the signal, practical tolerances for the manufacture of the equipment including the light source and the color medium, and the relation of the color of the signal to other colored lights, either in the signalling system or extraneous to it."* (CIE 2.2, 1975)

The 1975 revised recommendations took account of some new work by Blaise (Blaise, 1960; 1965) as well as experience in the application of the recommendations. The principal revisions were to change the way the restricted colour areas were specified, to introduce a colour area for violet colours, to extend the blue boundary for white to include the chromaticity of a xenon source, and to make improvements to the text.

Figures 1A, B and C show the boundaries of the colour areas recommended in Publication 2.2 (1975) for red, yellow, white, green, blue and violet signal colours.

Table 1 summarises the experimental conditions of the three studies that form the basis of the 1975 recommendations. All three studies used colour vision normal male subjects who made observations under dark adapted conditions, simulating observation at night.

TABLE 1 Experimental conditions of the studies underlying the CIE recommendations for the colours of signal lights

	Year	Number of subjects*	Adaptation	Source size	Illuminance (μlx)	Duration (s)
McNicholas Series I	1936	32	Dark adapted (outside at night)	2,2" - 22"	1,5 to 35,75	5
Holmes	1941	varied (Source size and illuminance differed for each set of experiments)	Dark adapted	0,7' - 39'	1,75 to 989	1
Hill	1947	9	Dark adapted	36"	30,4 to 0,8	1,5

*All subjects were males with normal colour vision

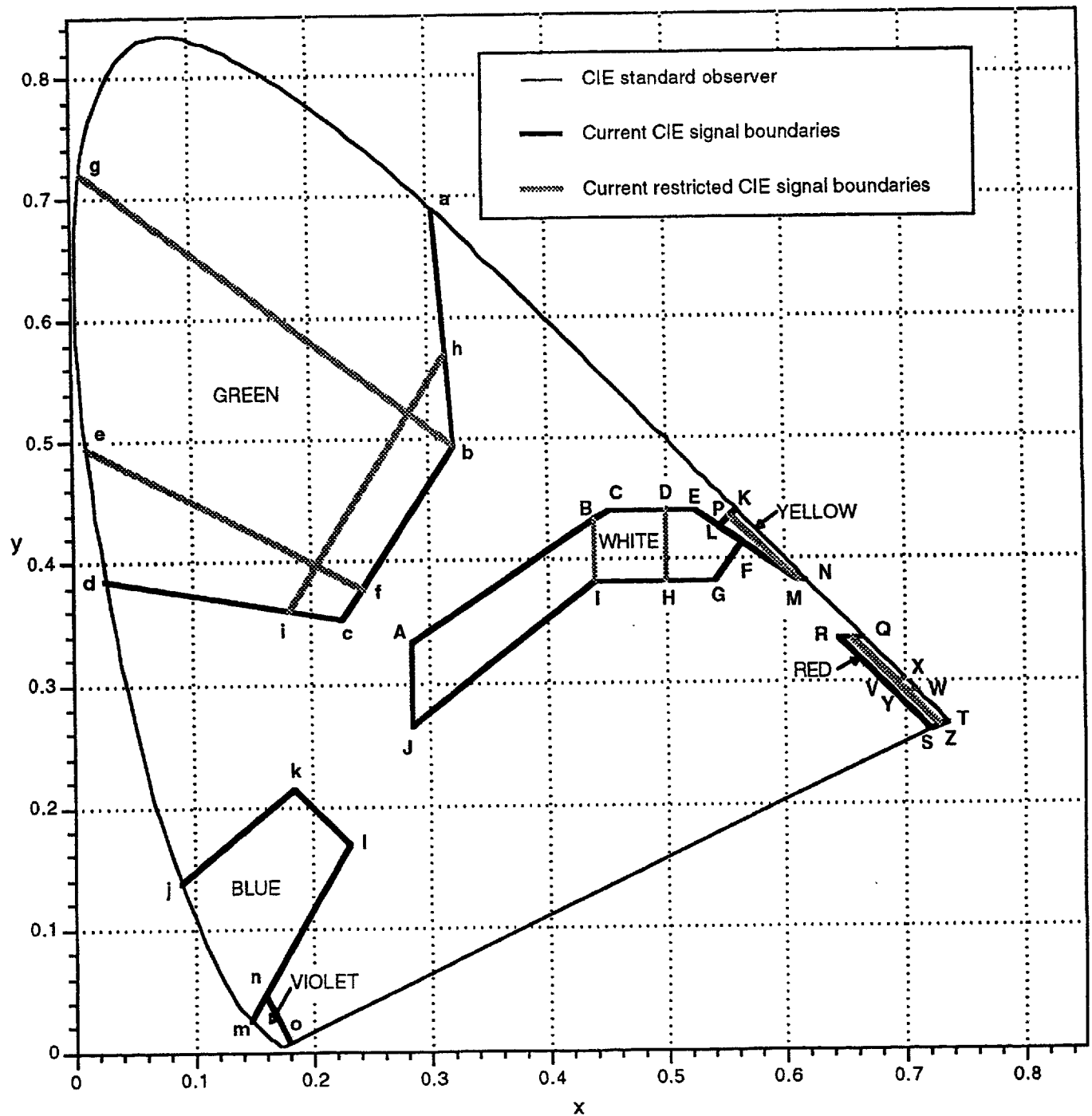


Figure 1 A Boundaries for colours of signal lights currently recommended by the CIE
(Colors of Signal Lights CIE Publication 2.2-1975)

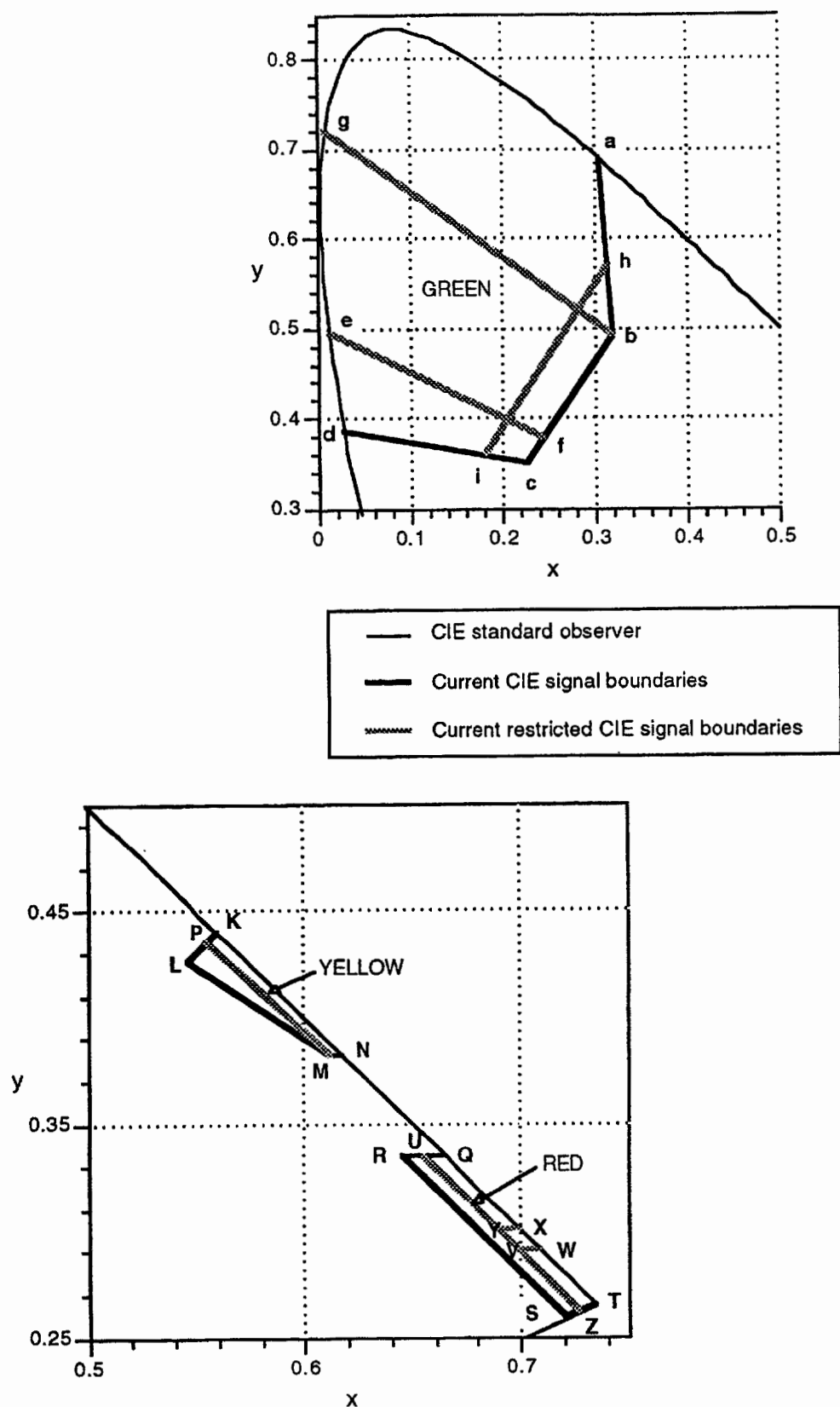


Figure 1 B Boundaries for green, red and yellow signal lights currently recommended by the CIE

(Colors of Signal Lights CIE Publication 2.2-1975)

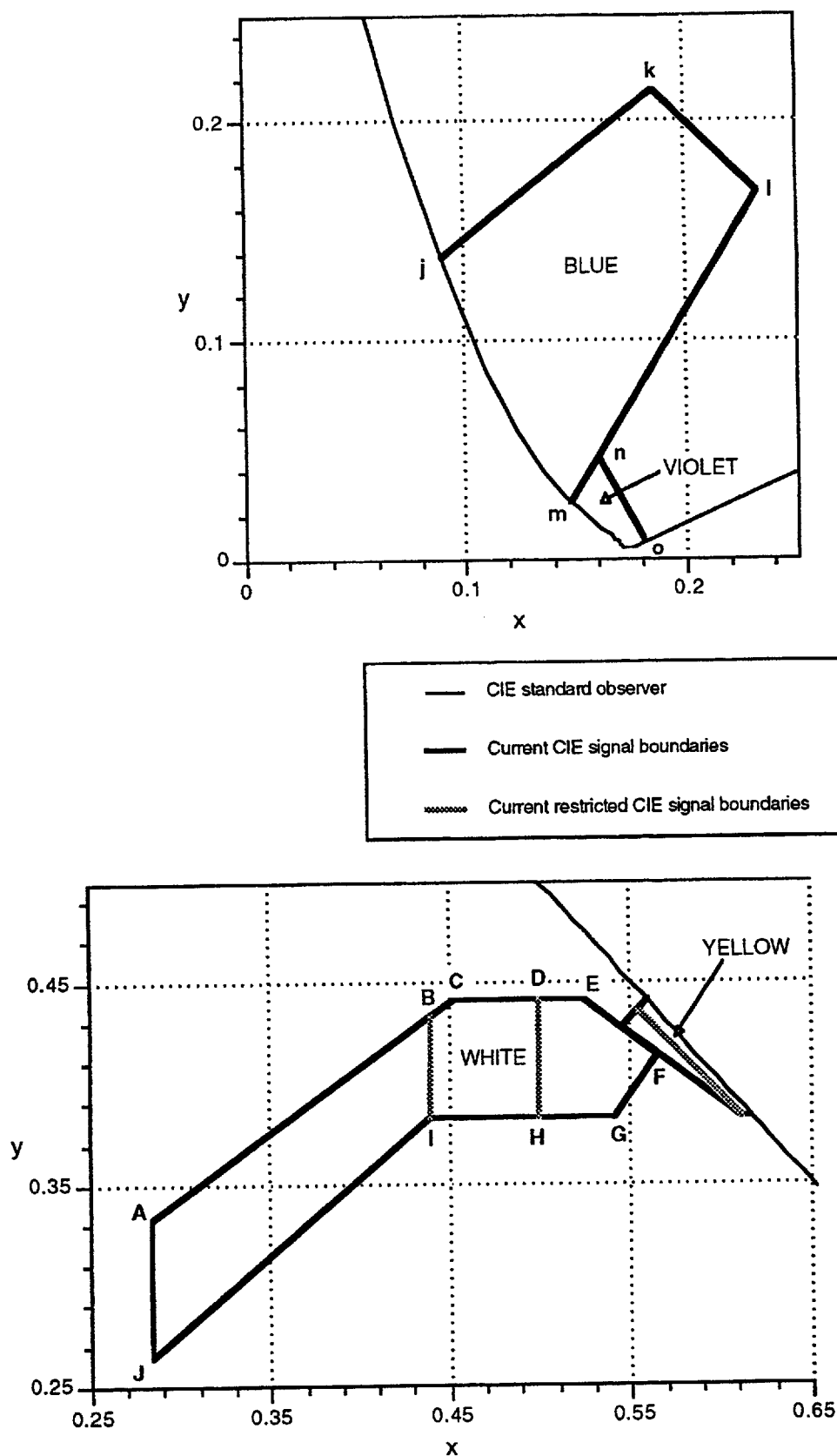


Figure 1 C Boundaries for blue, violet, white and yellow signal lights currently recommended by the CIE
(Colors of Signal Lights CIE Publication 2.2-1975)

4 METHOD

A comprehensive bibliography was compiled by computer search of bibliographic data bases, by citation in other references and through the contributions of the members of the Committee who drew attention particularly to technical reports not published in the open literature.

The references in the bibliography were read and those that provided quantitative information on the recognition of signal colours and which adequately specified the chromaticities of the colours used in the experiments, were identified as key references that could be of assistance to the task of the Committee. The experiments reported in the key references used a wide range of conditions. Most required subjects to make observations in the dark but a few used light adapted conditions. Stimulus size, stimulus illuminance in the the plane of the subject's eye and duration of observation time all varied.

A summary of the principal experimental conditions for each of the investigations described in the key references was made and this summary is given in the Appendix.

Some signals have to be seen at long distances usually at night and have low illuminances at the plane of the observer's eye; other signals are intended to be recognised at shorter ranges and often have very much higher illuminances. Table 2 gives typical visual ranges and illuminances for signals used at sea, for aviation and railway signals and signals used for the control of road traffic.

TABLE 2 Signal lights used in transport systems

Transport system	Type of signal	Typical intensity (cd)	Typical viewing distance (km)	Typical illuminance (μlx)
Maritime	Masthead	5 - 94	4 - 12	0,2 - 0,5
	Navigation lights	5 - 12	4 - 6	0,2 - 0,3
	Lighthouse	>200	20 - 30	0,2 - 0,3
	Buoys	>5	2 - 5	0,2 - 0,3
Rail	Signal lights			
	(i) High intensity	300 - 600	3 - 5	>10
	(ii) Suburban	150 - 250	1 - 2	>40
Aviation	Signal gun	>30,000	3 - 6	>3 000
	Obstruction lights			
	(i) Steady	15 - 20 000	2 - 5	0,6 - 5 000
	(ii) Flashing	2 000 - 200 000	3 - 20	5 - 20 000
	Runway lights	15 - 10 000	0,1 - 5	
	Approach lights	60 - 20 000	0,1 - 5	
	Taxiway lights	20 - 200	0,1 - 0,5	80 - 20 000
	Navigation lights	5 - 40	2 - 5	0,2 - 10
	Presence light	25	5 - 10	0,4 - 1
Road	Traffic lights	100	0,1	>10 000
	Tail lights	2	0,1	>200
	Stop light	20	0,1	>2 000

Source: Adapted from Vingrys (1984) and Smith (1990)

Using this information as a guide, the data from the experiments reported in the key references have been grouped according to signal illuminance and adaptation condition:

(a) Dark adapted (Night observation)

- (i) Illuminance $\leq 1 \mu\text{lx}$ typical of recognition of signal lights at distances of 2 - 30 km at night, as encountered commonly in maritime signalling and to a lesser degree in aviation signalling.
- (ii) Illuminance 1 to 10 μlx typical of some aviation signals.
- (iii) Illuminance 10 to 100 μlx typical of railway signals, and some aviation signals.

- (iv) Illuminance 0,1 to 1 mlx typical of motor vehicle signals and some aviation signals.
- (v) Illuminance larger than 1 mlx typical of road traffic signals and some aviation signals.

(b) *Light adapted (Day observation)*

As there were only five experiments in this condition, all illuminance levels were grouped together.

For each investigation reported in the key references, the signal colours used were plotted on large scale 1931 CIE diagrams together with a notation for each point indicating the probability of correct recognition of the colour reported by the experiment. For each experiment separately, probability contours were drawn by eye for red, yellow, green, blue and white colours provided there was data for a sufficient number of colours to enable the construction of probability contours.

In order to compare the results of the different studies, the 90% probability of recognition contours were estimated for red, yellow, green, blue and white signal colours and transferred to a separate 1931 CIE chromaticity diagram for each of the experimental conditions listed above.

These plots are reproduced as Figures 2 to 7 in which the legends list the references from which the information in each figure was obtained.

The 90% probability of correct recognition contours were plotted because it is only those colours that are recognised with reasonably high certainty that are of importance for practical visual signalling and for the purposes of this review. Colours that are called red, yellow, green, blue and white on less than 90% of occasions are of little value as signal colours.

For some of the experiments reviewed, there were insufficient data points to enable a reliable estimate of a 90% contour. In these cases the chromaticity co-ordinates of any individual colour that was recognised with a probability of 90% or more were plotted.

5 DISCUSSION AND RECOMMENDATIONS

5.1 Red signal colours

The yellow boundary of red

Figures 2 to 7 show that while the CIE colour area for red generally lies within the 90% probability contours, many of the 90% contours cross the red colour area inside the yellow boundary of red suggesting that orange-reds within the recommended CIE boundary are not reliably recognised as red. It must also be borne in mind that the contours are for 90% correct recognition and for most practical applications a higher degree of reliability is expected.

Most users of the CIE recommendations will assume that any red colour lying within the recommended colour area will be reliably recognised as red but in fact this is not the case: orangish-reds may be incorrectly identified on more than 10% of occasions. The present yellow boundary of red is misleading by suggesting that it defines the colour area of reds that are reliably recognised.

There is therefore good reason to consider moving the yellow boundary of the red colour area to a longer dominant wavelength.

On the other hand it can be argued that orange-reds should continue to be included in the recommended colour area for red signals because:

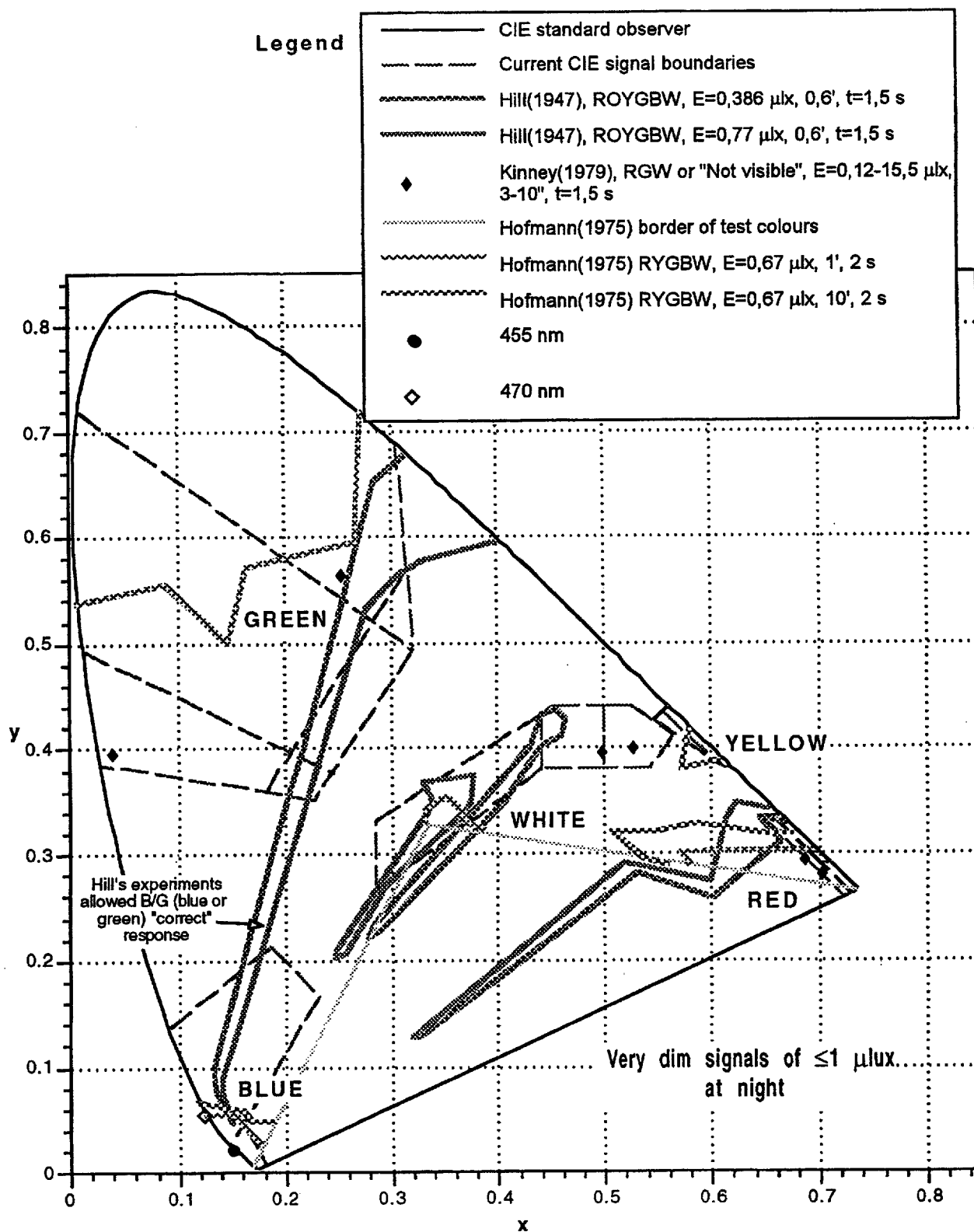


Figure 2 Recognition of coloured signal lights of illuminance ≤ 1 microlux at night
1931 CIE chromaticity diagram showing 90 % correct recognition contours

In this and subsequent figures the ' sign represents "minute of arc".