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CIE

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# TECHNICAL REPORT



# Method of Measuring and Specifying Colour Rendering Properties of Light Sources

**CIE 13.3-1995**

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|---|---|---|---|
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This Technical Report has been prepared by CIE Division 1 Vision and Colour' and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document is an in its technical content unchanged, editorially updated version of CIE 13.2-1974, it reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

Ce rapport technique a été préparé par la Division 1 Vision et couleur' et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le document est une edition éditorialement nouvelle, mais inchangée dans son contenu, de CIE 13.2-1974, traite des connaissances courantes et de l'expérience dans le domaine spécifique indiqué de la lumière et de l'éclairage, et il est établi pour l'usage des membres de la CIE et autres groupements intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Pour connaitre d'éventuels amendements, consulter les plus récents comptes rendus de la CIE ou le CIE NEWS.

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# FOREWORD

This Technical Report is based on CIE 13.2-1974, misprints of the original publication have been corrected, the tables and terminology have been updated. Two software programs are now also available at the CIE Central Bureau (disk CIE D008), enabling the calculation of the colour rendering indices by a personal computer.

Credit for the content of the publication is however due to its original authors, as stated in CIE 13.2-1974:

| | | |
|---|---|---|
| President: | Münch, W | Germany |
| Secretary: | Richter, M | Germany |
| Experts: | Azuma, T | Japan |
| | Barthés, E | France |
| | Einhorn, HD | South Africa |
| | Halstead, M | Great Britain |
| | Jerome, CW | USA |
| | Kerf, J de | Belgium |
| | Krtil, J | Czechoslovakia |
| | Ouweltjes, JL | Netherlands |
| | Siljeholm, G(✞ 1970) | Sweden |
| Correspondants: | Agustsson, D | Island |
| | Airola, A | Finland |
| | Bruckmüller, O | Austria |
| | Buchmann, B | Denmark |
| | Fuentes, A | Chile |
| | Mäder, F | Switzerland |
| | Matveev, AB | USSR |
| | Petrovic, Z | Yougoslavia |
| | Robertson, AR | Canada |
| | Röed, J | Norway |
| | Sanchez, A | Spain |
| | Shaw, JE | Australia |
| | Somkuti, A | Hungary |
| | Stanioch, W | Poland |
| | Tchetchik, A | Israel |
| | Vandoni, C | Italy |
| | Vlatchkov, P | Bulgaria |

Updating and editing of the present edition was done by:

| | |
|---|---|
| Walter, W | USA |
| Sylveszer, P | Hungary |
| Schanda, J | CIE Central Bureau |

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SUMMARY

**Method of Measuring and Specifying Colour Rendering Properties of Light Sources**

The CIE recommended in 1965 the procedure of measuring and specifying colour rendering properties of light sources, based on a test colour sample method. This method was updated in 1974 taking the chromatic adaptation shift into account. During the past 20 years several misprints were observed and corrected reprints were published from time to time. CIE 13.3 - 1995 is the corrected version of 13.2 - 1974 that has been brought up to date to present spectroradiometric and calculation practice. The technical recommendations have not been changed,

Two computer programs to calculate the CIE colour rendering indices according to the present publication are available for "DOS"-computers to be run in a DOS or in an "MS-WINDOWS" environment as CIE D008.

This Technical Report establishes the CIE recommended method of measuring and specifying colour rendering properties of light sources based on resultant colour shifts of test objects, referred to as the "Test-colour Method". It is the fundamental method for appraisal of colour rendering properties of light sources, and is recommended for type testing as well as for testing individual lamps.

This specification applies to most general purpose illuminants (e.g. tungsten filament lamps, tubular fluorescent lamps, and all other kinds of gaseous discharge electrical lamps except sources of predominantly monochromatic radiation such as low pressure sodium, etc.). This method may also be applied to modified daylight.

The rating consists of a General Colour Rendering Index which may be supplemented by a set of Special Colour Rendering Indices. The derivation of the Special Colour Rendering Indices is based on a general comparison of the length of colour difference vectors in the CIE 1964 Uniform Space.

To apply the recommended Test-Colour Method the resultant colour shifts for suitably chosen test-colour samples must be calculated. A set of eight test-colour samples is specified by their spectral radiance factors for calculating the General Colour Rendering Index. These samples cover the hue circle, are moderate in saturation, and are approximately the same in lightness. Data for six additional test-colour samples representing a strong red, yellow, green and blue as well as representing complexion and foliage colours are also supplied. From the colour shifts Colour Rendering Indices may be found.

RESUME

**Méthode de mesure et de spécification des qualités de rendu des couleurs des sources de *lumière***

La CIE a recommandé en 1965 la méthode de mesure et de spécification des qualités de rendu des couleurs par les sources de lumière, basée sur la méthode des couleurs-tests. Cette méthode a été mise à jour en 1974, en tenant compte de la distorsion de couleur pour l'adaptation. Pendant les dernières 20 années, plusieurs fautes d'impression ont été observées, et des reproductions corrigées ont été publiées de temps en temps. CIE 13.3-1995 est la version corrigée de 13.2-1974, qui a été mise à jour pour tenir compte de la pratique actuelle de spectroradiométrie et de calculation. Les recommendations techniques n'ont pas été changées.

Deux programmes d'ordinateur (CIE D008) pour calculer les indices de rendu des couleurs CIE conformément à la publication présente sont disponibles pour utilisation sur ordinateurs "DOS" sous DOS ou "MS-WINDOWS".

Ce rapport technique décrit la méthode recommandée par la CIE pour mesurer et spécifier les qualités de rendu des couleurs des sources de lumière. Elle est basée sur les distorsions totales de la couleur des objets-tests, et est appelée en abrégé "Méthode des couleurs-tests". Cette méthode est la méthode fondamentale pour l'appréciation des qualités de rendu des couleurs des sources de lumière, elle est recommandée aussi bien pour l'étude d'un type de lampe, que pour l'examen d'une lampe particulière.

Cette recommendation s'applique aux sources de lumière d'emploi général (p.e., lampes à filament de tungstène, lampes fluorescentes tubulaires, aussi bien qu'aux autres sortes de lampes électriques à décharge dans les gaz, excepté les sources de rayonnement essentiellement monochromatique, telles que les lampes à vapeur de sodium basse pression, etc.). Elle s'applique également à la lumière du jour modifiée artificiellement.

Il est recommandé d'évaluer au moyen d'un Indice Général de Rendu des Couleurs complété par un groupe d'Indices Particuliers de Rendu des Couleurs. La détermination des Indices Particuliers de Rendu des Couleurs repose sur la comparaison des longueurs des droites représentant les différences de couleur dans l'Espace Chromatique Uniforme CIE 1964.

Pour appliquer la méthode des couleurs-tests, on doit calculer les distorsions totales de la couleur de couleurs-tests convenablement choisis. Un groupe de huit couleurs-tests est spécifié par les facteurs spectraux de luminance énergétique pour calculer l'Indice Général de Rendu des Couleurs. Ces valeurs comprennent une série de teintes de saturation modérée se rangeant en cercle et ayant approximativement la même clarté. Les valeurs pour d'autres échantillons de couleurs-tests correspondant à un rouge, jaune, vert et bleu saturés, ainsi qu'à la couleur du teint et celle du feuillage, sont également données. Les Indices de Rendu des Couleurs sont obtenus à partir des distorsions totales de la couleur.

## ZUSAMMENFASSUNG

### Verfahren zur Messung und Kennzeichnung der Farbwiedergabe-Eigenschaften von Lichtquellen

Die CIE hat 1965 die Methode zur Messung und Kennzeichnung von Farbwiedergabe-Eigenschaften von Lichtquellen empfohlen, basierend auf einer Testfarbmethode. Diese Methode wurde 1974 auf den neuesten Stand gebracht, wobei die Farbumstimmungsadaptation berücksichtigt wurde. In den letzten 20 Jahren wurden mehrere Druckfehler festgestellt und von Zeit zu Zeit wurden korrigierte Neuauflagen veröffentlicht. CIE 13.3-1995 ist die korrigierte Version von 13.2-1974, die auf den neuesten Stand der derzeitigen Praxis der Spektroradiometrie und Berechnung gebracht wurde. Die technischen Empfehlungen blieben unverändert.

Zwei Computerprogramme zur Berechnung der CIE Farbwiedergabe-Indizes, entsprechend der vorliegenden Publikation, sind als CIE D008 für "DOS"-Computer, die unter DOS oder "MS-WINDOWS" laufen, erhältlich.

Diese Empfehlung legt die von der CIE vorgeschlagene Methode zur Messung und Kennzeichnung von Farbwiedergabe-Eigenschaften von Lichtquellen fest. Sie beruht auf der Farbverschiebung einer Serie von Testfarben, hier kurz Testfarbenverfahren genannt. Diese Methode ist das grundlegende Verfahren zur Bewertung der Farbwiedergabe-Eigenschaften von Lichtquellen. Sie wird sowohl für die Typprüfung als auch für die Untersuchung einzelner Lampen empfohlen.

Diese Empfehlung gilt für die meisten für allgemeine Beleuchtungszwecke angewendeten Lichtquellen (z.B. Glühlampen, Leuchtstofflampen, sowie alle anderen Arten von Entladungslampen, jedoch nicht für vorwiegend monochromatische Lichtquellen, wie Natriumdampf-Niederdrucklampen, etc.). Sie kann auch für künstlich verändertes Tageslicht angewendet werden.

Es wird empfohlen, für die Bewertung einen Allgemeinen Farbwiedergabe-Index zu verwenden, der durch eine Serie von Speziellen Farbwiedergabe-Indizes ergänzt wird. Die Speziellen Farbwiedergabe-Indizes sollen auf einem Vergleich der Entfernungen der Farbörter im gleichförmigen Farbenraum CIE 1964 beruhen.

Zur Anwendung des empfohlenen Testfarbenverfahrens werden die Farbverschiebungen geeignet ausgewählter Testfarben bestimmt. Ein Satz von acht Testfarben ist durch die dazugehörigen Werte der spektralen Strahldichtefaktoren festgelegt zur Berechnung des Allgemeinen Farbwiedergabe-Index. Diese Testfarben stellen einen Farbtonkreis mittlerer Sättigung dar und haben alle nahezu gleichen Hellbezugswert. Daten für weitere Testfarben, u.zw. für gesättigtes Rot, Gelb, Grün und Blau sowie Hautfarbe und Blattgrün werden ebenfalls mitgeteilt. Aus den Farbverschiebungen ermittelt man die Farbwiedergabe-Indizes.

## 1. INTRODUCTION

The CIE recommended in 1948 an eight band method to calculate the colour rendering of light sources [1]. In 1951 the CIE requested National Committees (NCs) to further investigate the question of colour rendering of light sources [2] and established a Technical Committee (TC) for this purpose in 1955 [3].

The scope of this Committee was [4]:

> *"To establish methods of measuring and specifying the colour rendering and colour matching properties of light sources".*

It also considered that the desired method should be one broad enough to deal with all light sources of whatever design, and that the method should not be restricted as to purpose.

In order to achieve the above aims the following working program was agreed on:

> *1. To clarify and define the terminology of "Colour Rendering of Light Sources" in relation to all aspects of "colour rendering".*
>
> *2. To establish methods of measuring and specifying the colour rendering of light sources, taking into account proposed and applied methods of measuring and specifying the colour rendering of light sources as well as the requirements for practical methods of specification in lighting practice, especially all related work of National Committees.*
>
> *2.1. To derive an abbreviated method for the estimation of colour rendering, involving the CIE spectral band method provisionally recommended in 1948; to find the range of validity of such method.*
>
> *2.2. To derive methods of measuring and specifying the colour rendering of light sources based on colour shift of a group of test objects (surfaces), involving the derivation of a single-number approximate colour rendering rating of the light source to be tested, supplemented by a more rigorous multi-number rating and/or type of graphical representation.*
>
> *2.3. To derive further methods if there is any necessity.*
>
> *2.4. To establish, if possible, tolerances, for light sources with regard to colour rendering.*

The committee published an interim report on terminology in 1964 [5], and decided that ultimately only one method will be recommended for specifying colour rendering [4,6]. To achieve this goal the TC requested NCs to experiment both with the spectral band method and with the colour shift method. Such experiments have shown [7] that the spectral band method does not work very well with "de Luxe" type fluorescent lamps, but the test colour method gave results in good agreement with visual appraisal.

Based on the work of D. NICKERSON [8], W. MÜNCH and K. SCHULTZ [9] as well as of I. HENNICKE [10] the committee decided to use only eight test colour samples. The following Munsell samples were selected:

| | | | |
|---|---|---|---|
| 7,5 | R 6/4 | 5 | YR 8/4 |
| 5 | Y 6/4 | 5 | GY 4/4 |
| 5 | GY 6/8 | 5 | Y 8/10 |
| 2,5 | G 6/6 | 4,5 | G 5/8 |
| 10 | BG 6/4* | 3 | PB 3/11 |
| 5 | PB 6/8 | 4,5 | R 4/13 |
| 2,5 | P 6/8 | 10 | B 6/4 |
| 10 | P 6/8 | 5 | P 6/8 |

* Replacing 10 B6/4 which was originally proposed.

The Committee stressed their opinion at their meeting at Evian in 1962:

*a) that there is no need to include in the specification any reference illuminant realisable in practice;*

*b) that one should take into account the effect of chromatic adaptation choosing the best way to do it;*

*c) to evaluate the colour shift in a system, which allows for consideration of lightness shift also;*

*d) that it is very convenient to have a single rating figure (general colour rendering index) but that more attention should be paid to the special colour rendering indices thus supplementing the information given by the general colour rendering index;*

*e) that it should be suggested to abandon a graphic representation for the first time.*

Based on above considerations the Committee submitted a draft recommendation at its meeting in Vienna [6], noting that a more rigorous treatment of chromatic adaptation as well as colour differences would be needed to be able to consider wider colour differences between the lamp to be tested and the reference illuminant.

The fist edition of the *CIE recommended method of measuring and specifying colour rendering properties of light sources, based on a test colour sample method* was published in 1965 [11] as CIE 13-1965.

In 1967 the Committee was entrusted [12] to prepare a second edition of publication 13, mainly to include a correction for the adaptive colour shift. This work was based on the experiments by OUWELTJES [13], and MÜNCH and SCHULTZ [14], and was done by applying a VON KRIES type transformation with a reference stimulus given by JUDD [15]. It was pointed out that even this corrected form of colour rendering calculation was applicable only when the colour difference between the test and the reference lamp was not too large.

The Committee agreed in 1970 that the chromaticity of the illuminant to be tested should be transformed to that of the reference illuminant. This involves a small step transformation which will be less sensitive to small variations in the reference stimuli and to the actual precision of the transformation than a large step transformation would be.

The basis of assessment for the *Colour Rendering Index* is now the resultant colour shift after chromatic adaptation has been accounted for by the adaptive colour shift.

The indices are calculated three-dimensionally. This provides a common basis for both the *General and Special Colour Rendering Indices.*

Comments regarding the meaning of the *Colour Rendering Indices* were added, dealing with the uncertainties in the determination of $R$, influences of test conditions, just perceptible differences in terms of $R$ and interchangeability of lamps with regard to their colour rendering properties.

Also a footnote regarding $T_c$ was added. This footnote concerns the definition of $T_c$ given in the International Lighting Vocabulary [16].

Moreover, the Committee stated that it was desirable to obtain an improved method for allowing for chromatic adaptation which could apply to illuminants having large chromaticity differences between them, but this would necessitate more knowledge about chromatic adaptation. The method was improved substantially by using the suggested small step transformation as it reduced the dependence of the Colour Rendering Index on the temperature scale of the reference illuminants.

Some further amendments compared to CIE 13-1965 were also undertaken, bringing the document in line with CIE's fundamental publication on colour [17].

The 2nd edition of CIE 13 was published in 1974 [18]. This publication contained a large number of tables that helped in using the method when doing the calculation on paper. Unfortunately some misprints both in the text, the equations and the tables were observed after printing was completed, resulting in several corrections published during the years, leading up to a "Corrected Reprint 1993" with Revision1, May 1994.

The terminology also changed during the 20 years since publication of CIE 13.2. It therefore became necessary to publish a new edition, which does not change the calculation method. As this edition has the status of a "Technical Report" and not of a "Recommendation" or "Standard" it is printed only in one language (English) and contains only those tables that are necessary to perform the calculations using modern computer techniques (i.e. tables containing derived data form other tables have been omitted).

The CIE Central Bureau provides also two application software programs programs on a disk:

- CIE13_3D.EXE is a program that calculates the special colour rendering indices and the general colour rendering index on an IBM PC or compatible running under DOS 3.2 or higher.

- CIE13_3W.EXE is a modification of the above program to be run on an IBM PC 386 or 486 or compatible under MS-WINDOWS 3.1.

Using one of these programs the calculation method described in the publication can be fully implemented.

The disk also contains data files in a separate subdirectory useful for one to develop his or her own color rendering index program.

These tables are extracts of CIE DISK D002-1991 "CIE Colorimetry and Colour Rendering Tables".

Another subdirectory presents general information on CIE publications and software.

## 2. PURPOSE

This specification establishes the CIE recommended method of measuring and specifying colour rendering properties of light sources based on resultant colour shifts of test objects, named *Test-Colour Method* for short.

This method is to be considered as the fundamental method for appraisal of colour rendering properties of light sources and is recommended for type testing as well as for testing individual lamps.

*For definitions of terms used in this specifications and not specified in the ILV [16], see Appendix 1 of this publication.*

## 3. SCOPE

This specification applies to most general purpose illuminants (e.g. tungsten filament lamps, tubular and compact fluorescent lamps, and all other kinds of gaseous discharge electrical lamps except sources of predominantly monochromatic radiation such as low pressure sodium). This method may also be applied to modified daylight.

## 4. RATING

It is recommended that the rating shall consist of a *General Colour Rendering Index* which may be supplemented by a set of *Special Colour Rendering Indices.*

The derivation of the *Special Colour Rendering Indices* shall be based on a general comparison of the lengths of colour difference vectors in the 1964 Uniform Space [17]*, and shall be carried out according to the method described in sections 5 and 6.

## 5. RATING PROCEDURE

### *5.1. General remarks*

To apply the recommended *Test-Colour Method* the resultant colour shifts for suitably chosen test-colour samples (see section 5.4.) must be calculated. For doing this, fisrst the CIE 1931 tristimulus values of the various test-colours must be determined for both the illuminant to be tested and the reference illuminant. The next step is to transform these tristimulus values into co-ordinates of the 1960 UCS diagram* [17].

The adaptive colour shift is accounted for by a VON KRIES transformation with the fundamental primaries given by JUDD [15]. The difference between the chromaticities of the illuminant to be tested and the reference illuminant should be small enough to achieve a satisfactory approximation of the effect of chromatic adaptation (see section 5.3).

Then the colour differences of the test-colour samples will be calculated in the 1964 Uniform Space [17].

### *5.2. Reference Illuminant*

The appraisal of colour rendering properties of a light source shall always be referred to a *Reference Illuminant*, which may be defined mathematically. This reference illuminant shall be of the same or nearly the same chromaticity as the lamp to be tested.

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* The 1960 UCS diagram and 1964 Uniform Space are declared as obsolete recommendations in CIE 15.2-1986, but have been retained for the time being for calculating colour rendering indices and correlated colour temperature (see next page) .

For tolerances in the choice of reference illuminants, see section 5.3.

Unless otherwise specified, the reference illuminant for light sources with correlate colour temperature below 5 000 K shall be a Planckian radiator and from 5 000 K one of a series of spectral power distributions of phases of daylight [17].

For special cases, CIE or other specific standard illuminants may serve as reference illuminant.

In all cases a full description in terms of spectral power distribution for wavelength intervals no greater than 10 nm over the visible spectrum shall be supplied for reference illuminants.

*5.3. Tolerances for reference illuminant*

The reference illuminant is intended to be of the same or nearly the same chromaticity as the lamp to be tested. It shall be selected so that the chromaticity difference DC is smaller than $5{,}4.10^{-3}$, if this is possible. This tolerance is suggested as a practical limit of difference.

The chromaticity difference DC between the lamp to be tested ($u_k$, $v_k$) and the reference illuminant ($u_r$, $v_r$) will be calculated as

$$DC = [(u_k - u_r)^2 + (v_k - v_r)^2]^{1/2} \qquad (5\text{-}1)$$

The tolerance of $DC = 5{,}4.10^{-3}$ corresponds to about 15 $MK^{-1}$ (*reciprocal megakelvin*) along the Planckian locus.

If the chromaticity difference between the lamp to be tested and the reference illuminant is greater than the tolerance of $DC = 5{,}4.10^{-3}$ the resulting Colour Rendering Indices may be expected to become less accurate. In all cases the reference illuminant shall be indicated in brackets after the rating figure [e.g. $R_a$ = 90(D65)].

*5.4. Test-colour samples*

A set of eight CIE-1974 test-colour samples ($T_i$, $i$ = 1 ... 8)** is specified by the spectral radiance factors in Section 8, Table 1. These samples cover the hue circle, are moderate in saturation, and are approximately the same in lightness.

Data for further CIE-1974 test-colour samples ($T_i$, $i$ = 9 ... 14)** representing a strong red, yellow, green and blue and representing complexion and foliage colours, are supplied in Section 8, Table 2. These samples vary widely in lightness and saturation.

---

** **CIE test colour samples:**

| No. | Approximate Munsell notation | Colour appearance under daylight [19] |
|---|---|---|
| 1 | 7,5 R 6/4 | Light greyish red |
| 2 | 5 Y 6/4 | Dark greyish yellow |
| 3 | 5 GY 6/8 | Strong yellow green |
| 4 | 2,5 G 6/6 | Moderate yellowish green |
| 5 | 10 BG 6/4 | Light bluish green |
| 6 | 5 PB 6/8 | Light blue |
| 7 | 2,5 P 6/8 | Light violet |
| 8 | 10 P 6/8 | Light reddish purple |
| 9 | 4,5 R 4/13 | Strong red |
| 10 | 5 Y 8/10 | Strong yellow |
| 11 | 4,5 G 5/8 | Strong green |
| 12 | 3 PB 3/11 | Strong blue |
| 13 | 5 YR 8/4 | Light yellowish pink (human complexion) |
| 14 | 5 GY 4/4 | Moderate olive green (leaf green) |

Other individual test-colour samples ($T_i$, $i$ > 14) may also be used. They must always be specified by accurate spectral radiance factor data.

For calculating *Special Colour Rendering Indices* recommended by this method data of any individual test-colour samples may be used (see section 6.2), whilst the calculation of the *General Colour Rendering Index* is recommended to be based on data of the first eight CIE-1974 test-colour samples only (see section 6.3.).

*In cases where spectral radiance factors are required at smaller steps than given in Section 8, Tables 1 and 2, linear interpolation should be used.*

**Note:**

The original Tables 1 and 2 of CIE 13.2 - 1974 contained spectral radiance factors also at the major mercury emission lines. As present spectroradiometric practice does not separate the line emission from the continuum emission the spectral radiance factors at the mercury emission lines have been omitted from the Tables 1 and 2 of CIE 13.3 - 1994.

*5.5. Determination of CIE 1931 tristimulus values of the test-colour samples [17]*

From a suitably accurate spectroradiometric measurement (see section 7.2 and 7.3) of the lamp to be tested combined with the spectral radiance factor data of the CIE - 1974 test-colour samples as given in Table 1 and 2, CIE 1931 tristimulus values $X$, $Y$, $Z$, CIE 1931 chromaticity co-ordinates $x$, $y$ of test samples and the light sources resp. shall be determined. All chromaticities whether calculated or measured shall be given to four decimal places.

*5.6. Transformation into 1960 UCS co-ordinates [17].*

Colorimetric data must now be transformed from the CIE 1931 values ( $X$, $Y$, $Z$, $x$ ,$y$) to the ($u$,$v$) co-ordinate of the 1960 diagram by means of the following formulae:

$$u = 4X/(X + 15Y + 3Z)$$

$$v = 6Y/(X + 15Y + 3Z) \qquad \text{(5-2a)}$$

or

$$u = 4x/(-2x + 12y + 3)$$

$$v = 6y/(-2x + 12y + 3) \qquad \text{(5-2b)}$$

*5.7. Consideration of adaptive (perceived) colour shift [17].*

To account for the adaptive colour shift due to the different state of chromatic adaptation under the lamp to be tested $k$ and under the reference illuminant $r$ the following formulae shall be applied:

$$u'_{k,i} = \frac{10{,}872 + 0{,}404\frac{c_r}{c_k}c_{k,i} - 4\frac{d_r}{d_k}d_{k,i}}{16{,}518 + 1{,}481\frac{c_r}{c_k}c_{k,i} - \frac{d_r}{d_k}d_{k,i}} \qquad \text{(5-3)}$$

$$v'_{k,i} = \frac{5{,}520}{16{,}518 + 1{,}481\frac{c_r}{c_k}c_{k,i} - \frac{d_r}{d_k}d_{k,i}}$$

The values $u'_{k,i}$ and $v'_{ki}$ are the chromaticity co-ordinates of a test-colour sample $i$ after consideration of the adaptive colour shift, obtained by moving the light source to be tested to the reference illuminant, i.e. $u'_k = u_r$, $v'_k = v_r$ and should not be mixed up with CIE 1976 $u',v'$ co-ordinates.

The functions $c$ and $d$ for use in equation (2) shall be calculated for the light source to be tested $u_k$, $v_k$ (giving $c_k$, $d_k$) and the test colour samples $i$ under the light source to be tested $u_{k,i}$, $v_{k,i}$ (giving $c_{k,i}$, $d_{k,i}$) according to the following formulae:

$$c = \frac{1}{v}(4 - u - 10v)$$

$$d = \frac{1}{v}(1{,}708v + 0{,}404 - 1{,}481u) \qquad (5\text{-}4)$$

*5.8. Transformation into 1964 Uniform Space co-ordinates [17]*

Colorimetric data must now be transformed into the 1964 Uniform Space co-ordinates by using the following formulae:

$$W^*_{r,i} = 25\,(Y_{r,i})^{1/3} - 17; \qquad W^*_{k,i} = 25\,(Y_{k,i})^{1/3} - 17$$
$$U^*_{r,i} = 13W^*_{r,i}\,(u_{r,i} - u_r); \qquad U^*_{k,i} = 13W^*_{k,i}\,(u'_{k,i} - u'_k) \qquad (5\text{-}5)$$
$$V^*_{r,i} = 13W^*_{r,i}\,(v_{r,i} - v_r); \qquad V^*k,i = 13W^*_{k,i}\,(v'_{k,i} - v'_k)$$

The values $u'_k = u_r$, $v'_k = v_r$ are the chromaticity co-ordinates of the light source to be tested after consideration of the adaptive colour shift. The values $Y_{r,i}$ and $Y_{k,i}$ must be normalised so that $Y_r = Y_k = 100$.

*5.9. Determination of the resultant colour shift*

To calculate the difference between the correlate of the perceived colour of a test-colour sample $i$ illuminated by the light source to be tested $k$ and that of the same sample illuminated by the reference illuminant $r$ the *1964 Colour-Difference Formula* [17] shall be used:

$$\Delta E_i = \sqrt{(U^*_{r,i} - U^*_{k,i})^2 + (V^*_{r,i} - V^*_{k,i})^2 + (W^*_{r,i} - W^*_{k,i})^2}$$
$$= \sqrt{(\Delta U^*_i)^2 + (\Delta V^*_i)^2 + (\Delta W^*_i)^2} \qquad (5\text{-}6)$$

## 6. CALCULATION OF COLOUR RENDERING INDICES

*6.1. Designation of Colour Rendering Index*

The *Colour Rendering Index* is designated by the letter ***R***. The "*Special Colour rendering Indices*" derived in accordance with clause 6.2 are designated by the symbol $R_i$ ($i$ = 1,2, 3 ... corresponding to the number of any individual test-colour sample that may be studied). The *General Colour Rendering Index* derived in accordance with 6.3 is designated by the symbol $R_a$.

*6.2. Calculation of Special Colour Rendering Indices*

The *Special Colour Rendering Index* $R_i$, based on $DE_i$ obtained from formula (5-6) for any individual test-colour sample, is to be derived by use of the following formula:

$$R_i = 100 - 4{,}6\ DE_i \qquad (6\text{-}1)$$

rounding the result to the nearest whole number.

In case of figure 5 being in the first decimal place with subsequent zeros on the following places, the result should be rounded off or down to the next even number.

*The index has been scaled so that 100 represents identity of colour co-ordinates of a test-colour sample under the source to be tested and its reference standard, and a General Colour Rendering Index of about 50 is assigned to a standard warm white fluorescent lamp used in earlier studies tested against an incandescent lamp as reference. This scale adjustment is achieved by use of the factor 4,6 in equation (6-1).*

*6.3. Calculation of the General Colour Rendering Index*

The *General Colour Rendering Index* $R_a$ is to be derived as the arithmetical mean of the eight Special Colour Rendering Indices $R_i$ for the CIE-1974 test-colour samples Nos. 1 ... 8.

$$R_a = \frac{1}{8}\sum_{i=1}^{8} R_i \qquad (6\text{-}2)$$

## 7. EXPLANATORY COMMENTS

*7.1. Meaning of the Colour Rendering Indices*

In order to describe fully the colour rendering properties of a light source a series of *Special Colour Rendering Indices* is necessary. As stated in section 4, the derivation of the (special) *Colour Rendering Indices* is based on a general comparison of the lengths of colour difference vectors in the *1964 Uniform Space*, i.e. the amounts of the colour shifts. The importance of the directions of the colour shifts is recognised but not included in the *Colour Rendering Indices.*

The average of the indices for certain selected CIE -1974 test-colours samples (Nos. 1 ... 8) yields the *General Colour Rendering Index* (see section 6.3.). This mean indicates in general the average deviation of the colour rendition of the lamp to be tested from that of the reference illuminant.

The index is not an absolute figure. For example, a daylight lamp 6 500 K and a warm white lamp 3 000 K having equal *General Colour Rendering Indices* close to 100 will differ about as much as their respective reference illuminants, in this case the CIE phase of daylight D65 and the Planckian radiator 3 000 K. These reference illuminants are - compared with each other - different in their colour rendering and this will also necessarily apply to the two light sources to be tested, even if they have the same *General Colour Rendering Index.*

*7.2 Uncertainties in the determination of R*

Experience has shown that *Colour Rendering Indices* depend on the choice of reference illuminants and therefore, on the value of the correlated colour temperature, $T_c$ (to calculate correlated colour temperature see [20 ... 33]), of the reference illuminant. The corrected value of *R* should be regarded as that obtained when this value of $T_c$ is made equal to the correlated colour temperature of the lamp to be tested.

Experience has shown that differences in spectral power distribution due to present methods of measurement (see section 5.5) may cause uncertainties of the order of 1 to 3 units in *Ra*.

Particular attention should, therefore, be paid to the precise determination of the spectral power distribution of the light source to be tested.

It has been found that the value of *R* may be influenced by the spectrum range taken to represent the visual spectrum (e.g. 400 ... 700 nm, 380 ... 830 nm), and also by the spectral intervals employed in the computation.

Spectral intervals of at most 5 nm are recommended. (This is a change compared to CIE 13.2-1974, where for fluorescent lamps also a spectral interval of 10 nm was permitted. Experience has shown that with modern spectroradiometric methods and computer controlled spectral data gathering the 5 nm interval became industry standard. By using the 5 nm interval measuring technique it is not necessary to handle continuum and line spectra in two parts. Therefore also the test sample data are not given anymore for the mercury lines, see 5.4.)

Where there is any doubt, a smaller interval is recommended. The spectral radiance factors for the CIE-1974 test-colour samples (Section 8, Tables 1 and 2) are given from 360 to 830 nm in steps of 5 nm, with the instruction that linear interpolation will be used for smaller intervals (see section 5.4.).

*7.3. Influence of test conditions*

Uncertainties may also be caused by the manner of operation of lamps and by the geometry of measurements of the spectral power distribution (e.g. as with a measurement of luminous flux, luminous intensity, luminance or illuminance).

Each index holds for the particular set of conditions under which the source is operated. Differences arising from variation of test conditions are not due to the method itself. The choice of the test conditions should depend on the final purpose.

For comparison purposes the geometric-optical arrangement used in the measurement should be indicated as well as the data of operation, such as position of burning, electrical parameters, etc.

*7.4. Just perceptible differences in term of R*

Both practical experience and the knowledge about D*E* (the base of the index scale) as a measure or threshold [17] indicate that differences in $R_i$ of about five units will correspond to visually perceptible colour differences under the best conditions, provided that the directions of the colour shifts are nearly the same. No such simple rule can be given for $R_a$. It is obtained as the average of eight $R_i$ values, and even when two light sources have exactly the same $R_a$, differences about 5 units or more in one or more of the $R_i$'s may still be possible, so that their colour rendering properties will be different for the object colours in question. Where the $R_a$ values are close to 100, the $R_i$ values are unlikely to show variation large enough to result in noticeable colour differences. But, as the value of $R_a$ decreases from 100, the corresponding special indices $R_i$ show increasing spread.

It should also be kept in mind that although the value $R_i$ does determine the length of this colour difference vector, it gives no information about the direction of the vector (see section 7.1.). Therefore, if the $R_i$ values for a given sample are 95 under two light sources of equal chromaticity, this does not imply that the sample has equal colour appearance under the two light sources. If the directions of the vectors are exactly opposite, there will be a colour difference corresponding to 10 units in the Colour Rendering Index Scale.

*7.5. Interchangeability of lamps with regard to their colour rendering properties*

Due to the reasons given in section 7.4 equivalence of $R_a$ for two lamps does not guarantee identical colour rendering properties for them because averaging different Special Colour Rendering Indices may result in the same value of $R_a$. Also the same value of the Special Colour Rendering Indices may be caused by colour shifts in different directions, although the amounts of the shifts are the same. Therefore, the General Colour Rendering Index $R_a$ does not guarantee full interchangeability of individual lamps from the point of view of their colour rendering properties, even in the case where the colour appearances of these lamps are the same within certain tolerances.

To meet this difficulty a set of Special Colour Rendering Indices has to be specified within some tolerances which - together with specified values of the chromaticity of the light sources - guarantee interchangeability regarding colour rendering. The assessment of inter-changeability will improve as the number of Special Colour Rendering Indices increases and the sizes of permitted tolerances are decreased. If interchangeability regarding colour rendering has to be guaranteed using only one index like $R_a$, a spectral power distribution representative of that of the lamp to be tested can be used as reference illuminant against which the lamp to be tested is evaluated.

## 8. TABLES

Table 1 : Spectral radiance factor $\beta_i(\lambda)$ of CIE-1974 test-colour samples Nos. 1...8 (TCS01...08), to be used in calculating the General Colour Rendering Index.

| lambda | TCS01 | TCS02 | TCS03 | TCS04 | TCS05 | TCS06 | TCS07 | TCS08 |
|---|---|---|---|---|---|---|---|---|
| 360 | 0,116 | 0,053 | 0,058 | 0,057 | 0,143 | 0,079 | 0,150 | 0,075 |
| 365 | 0,136 | 0,055 | 0,059 | 0,059 | 0,187 | 0,081 | 0,177 | 0,078 |
| 370 | 0,159 | 0,059 | 0,061 | 0,062 | 0,233 | 0,089 | 0,218 | 0,084 |
| 375 | 0,190 | 0,064 | 0,063 | 0,067 | 0,269 | 0,113 | 0,293 | 0,090 |
| 380 | 0,219 | 0,070 | 0,065 | 0,074 | 0,295 | 0,151 | 0,378 | 0,104 |
| 385 | 0,239 | 0,079 | 0,068 | 0,083 | 0,306 | 0,203 | 0,459 | 0,129 |
| 390 | 0,252 | 0,089 | 0,070 | 0,093 | 0,310 | 0,265 | 0,524 | 0,170 |
| 395 | 0,256 | 0,101 | 0,072 | 0,105 | 0,312 | 0,339 | 0,546 | 0,240 |
| 400 | 0,256 | 0,111 | 0,073 | 0,116 | 0,313 | 0,410 | 0,551 | 0,319 |
| 405 | 0,254 | 0,116 | 0,073 | 0,121 | 0,315 | 0,464 | 0,555 | 0,416 |
| 410 | 0,252 | 0,118 | 0,074 | 0,124 | 0,319 | 0,492 | 0,559 | 0,462 |
| 415 | 0,248 | 0,120 | 0,074 | 0,126 | 0,322 | 0,508 | 0,560 | 0,482 |
| 420 | 0,244 | 0,121 | 0,074 | 0,128 | 0,326 | 0,517 | 0,561 | 0,490 |
| 425 | 0,240 | 0,122 | 0,073 | 0,131 | 0,330 | 0,524 | 0,558 | 0,488 |
| 430 | 0,237 | 0,122 | 0,073 | 0,135 | 0,334 | 0,531 | 0,556 | 0,482 |
| 435 | 0,232 | 0,122 | 0,073 | 0,139 | 0,339 | 0,538 | 0,551 | 0,473 |
| 440 | 0,230 | 0,123 | 0,073 | 0,144 | 0,346 | 0,544 | 0,544 | 0,462 |
| 445 | 0,226 | 0,124 | 0,073 | 0,151 | 0,352 | 0,551 | 0,535 | 0,450 |
| 450 | 0,225 | 0,127 | 0,074 | 0,161 | 0,360 | 0,556 | 0,522 | 0,439 |
| 455 | 0,222 | 0,128 | 0,075 | 0,172 | 0,369 | 0,556 | 0,506 | 0,426 |
| 460 | 0,220 | 0,131 | 0,077 | 0,186 | 0,381 | 0,554 | 0,488 | 0,413 |
| 465 | 0,218 | 0,134 | 0,080 | 0,205 | 0,394 | 0,549 | 0,469 | 0,397 |
| 470 | 0,216 | 0,138 | 0,085 | 0,229 | 0,403 | 0,541 | 0,448 | 0,382 |
| 475 | 0,214 | 0,143 | 0,094 | 0,254 | 0,410 | 0,531 | 0,429 | 0,366 |
| 480 | 0,214 | 0,150 | 0,109 | 0,281 | 0,415 | 0,519 | 0,408 | 0,352 |
| 485 | 0,214 | 0,159 | 0,126 | 0,308 | 0,418 | 0,504 | 0,385 | 0,337 |
| 490 | 0,216 | 0,174 | 0,148 | 0,332 | 0,419 | 0,488 | 0,363 | 0,325 |
| 495 | 0,218 | 0,190 | 0,172 | 0,352 | 0,417 | 0,469 | 0,341 | 0,310 |
| 500 | 0,223 | 0,207 | 0,198 | 0,370 | 0,413 | 0,450 | 0,324 | 0,299 |
| 505 | 0,225 | 0,225 | 0,221 | 0,383 | 0,409 | 0,431 | 0,311 | 0,289 |
| 510 | 0,226 | 0,242 | 0,241 | 0,390 | 0,403 | 0,414 | 0,301 | 0,283 |
| 515 | 0,226 | 0,253 | 0,260 | 0,394 | 0,396 | 0,395 | 0,291 | 0,276 |
| 520 | 0,225 | 0,260 | 0,278 | 0,395 | 0,389 | 0,377 | 0,283 | 0,270 |
| 525 | 0,225 | 0,264 | 0,302 | 0,392 | 0,381 | 0,358 | 0,273 | 0,262 |
| 530 | 0,227 | 0,267 | 0,339 | 0,385 | 0,372 | 0,341 | 0,265 | 0,256 |
| 535 | 0,230 | 0,269 | 0,370 | 0,377 | 0,363 | 0,325 | 0,260 | 0,251 |
| 540 | 0,236 | 0,272 | 0,392 | 0,367 | 0,353 | 0,309 | 0,257 | 0,250 |
| 545 | 0,245 | 0,276 | 0,399 | 0,354 | 0,342 | 0,293 | 0,257 | 0,251 |
| 550 | 0,253 | 0,282 | 0,400 | 0,341 | 0,331 | 0,279 | 0,259 | 0,254 |
| 555 | 0,262 | 0,289 | 0,393 | 0,327 | 0,320 | 0,265 | 0,260 | 0,258 |
| 560 | 0,272 | 0,299 | 0,380 | 0,312 | 0,308 | 0,253 | 0,260 | 0,264 |
| 565 | 0,283 | 0,309 | 0,365 | 0,296 | 0,296 | 0,241 | 0,258 | 0,269 |
| 570 | 0,298 | 0,322 | 0,349 | 0,280 | 0,284 | 0,234 | 0,256 | 0,272 |
| 575 | 0,318 | 0,329 | 0,332 | 0,263 | 0,271 | 0,227 | 0,254 | 0,274 |
| 580 | 0,341 | 0,335 | 0,315 | 0,247 | 0,260 | 0,225 | 0,254 | 0,278 |
| 585 | 0,367 | 0,339 | 0,299 | 0,229 | 0,247 | 0,222 | 0,259 | 0,284 |
| 590 | 0,390 | 0,341 | 0,285 | 0,214 | 0,232 | 0,221 | 0,270 | 0,295 |
| 595 | 0,409 | 0,341 | 0,272 | 0,198 | 0,220 | 0,220 | 0,284 | 0,316 |
| 600 | 0,424 | 0,342 | 0,264 | 0,185 | 0,210 | 0,220 | 0,302 | 0,348 |
| 605 | 0,435 | 0,342 | 0,257 | 0,175 | 0,200 | 0,220 | 0,324 | 0,384 |
| 610 | 0,442 | 0,342 | 0,252 | 0,169 | 0,194 | 0,220 | 0,344 | 0,434 |
| 615 | 0,448 | 0,341 | 0,247 | 0,164 | 0,189 | 0,220 | 0,362 | 0,482 |
| 620 | 0,450 | 0,341 | 0,241 | 0,160 | 0,185 | 0,223 | 0,377 | 0,528 |
| 625 | 0,451 | 0,339 | 0,235 | 0,156 | 0,183 | 0,227 | 0,389 | 0,568 |
| 630 | 0,451 | 0,339 | 0,229 | 0,154 | 0,180 | 0,233 | 0,400 | 0,604 |

Table 1 cont.

| lambda | TCS01 | TCS02 | TCS03 | TCS04 | TCS05 | TCS06 | TCS07 | TCS08 |
|---|---|---|---|---|---|---|---|---|
| 635 | 0,451 | 0,338 | 0,224 | 0,152 | 0,177 | 0,239 | 0,410 | 0,629 |
| 640 | 0,451 | 0,338 | 0,220 | 0,151 | 0,176 | 0,244 | 0,420 | 0,648 |
| 645 | 0,451 | 0,337 | 0,217 | 0,149 | 0,175 | 0,251 | 0,429 | 0,663 |
| 650 | 0,450 | 0,336 | 0,216 | 0,148 | 0,175 | 0,258 | 0,438 | 0,676 |
| 655 | 0,450 | 0,335 | 0,216 | 0,148 | 0,175 | 0,263 | 0,445 | 0,685 |
| 660 | 0,451 | 0,334 | 0,219 | 0,148 | 0,175 | 0,268 | 0,452 | 0,693 |
| 665 | 0,451 | 0,332 | 0,224 | 0,149 | 0,177 | 0,273 | 0,457 | 0,700 |
| 670 | 0,453 | 0,332 | 0,230 | 0,151 | 0,180 | 0,278 | 0,462 | 0,705 |
| 675 | 0,454 | 0,331 | 0,238 | 0,154 | 0,183 | 0,281 | 0,466 | 0,709 |
| 680 | 0,455 | 0,331 | 0,251 | 0,158 | 0,186 | 0,283 | 0,468 | 0,712 |
| 685 | 0,457 | 0,330 | 0,269 | 0,162 | 0,189 | 0,286 | 0,470 | 0,715 |
| 690 | 0,458 | 0,329 | 0,288 | 0,165 | 0,192 | 0,291 | 0,473 | 0,717 |
| 695 | 0,460 | 0,328 | 0,312 | 0,168 | 0,195 | 0,296 | 0,477 | 0,719 |
| 700 | 0,462 | 0,328 | 0,340 | 0,170 | 0,199 | 0,302 | 0,483 | 0,721 |
| 705 | 0,463 | 0,327 | 0,366 | 0,171 | 0,200 | 0,313 | 0,489 | 0,720 |
| 710 | 0,464 | 0,326 | 0,390 | 0,170 | 0,199 | 0,325 | 0,496 | 0,719 |
| 715 | 0,465 | 0,325 | 0,412 | 0,168 | 0,198 | 0,338 | 0,503 | 0,722 |
| 720 | 0,466 | 0,324 | 0,431 | 0,166 | 0,196 | 0,351 | 0,511 | 0,725 |
| 725 | 0,466 | 0,324 | 0,447 | 0,164 | 0,195 | 0,364 | 0,518 | 0,727 |
| 730 | 0,466 | 0,324 | 0,460 | 0,164 | 0,195 | 0,376 | 0,525 | 0,729 |
| 735 | 0,466 | 0,323 | 0,472 | 0,165 | 0,196 | 0,389 | 0,532 | 0,730 |
| 740 | 0,467 | 0,322 | 0,481 | 0,168 | 0,197 | 0,401 | 0,539 | 0,730 |
| 745 | 0,467 | 0,321 | 0,488 | 0,172 | 0,200 | 0,413 | 0,546 | 0,730 |
| 750 | 0,467 | 0,320 | 0,493 | 0,177 | 0,203 | 0,425 | 0,553 | 0,730 |
| 755 | 0,467 | 0,318 | 0,497 | 0,181 | 0,205 | 0,436 | 0,559 | 0,730 |
| 760 | 0,467 | 0,316 | 0,500 | 0,185 | 0,208 | 0,447 | 0,565 | 0,730 |
| 765 | 0,467 | 0,315 | 0,502 | 0,189 | 0,212 | 0,458 | 0,570 | 0,730 |
| 770 | 0,467 | 0,315 | 0,505 | 0,192 | 0,215 | 0,469 | 0,575 | 0,730 |
| 775 | 0,467 | 0,314 | 0,510 | 0,194 | 0,217 | 0,477 | 0,578 | 0,730 |
| 780 | 0,467 | 0,314 | 0,516 | 0,197 | 0,219 | 0,485 | 0,581 | 0,730 |
| 785 | 0,467 | 0,313 | 0,520 | 0,200 | 0,222 | 0,493 | 0,583 | 0,730 |
| 790 | 0,467 | 0,313 | 0,524 | 0,204 | 0,226 | 0,500 | 0,585 | 0,731 |
| 795 | 0,466 | 0,312 | 0,527 | 0,210 | 0,231 | 0,506 | 0,587 | 0,731 |
| 800 | 0,466 | 0,312 | 0,531 | 0,218 | 0,237 | 0,512 | 0,588 | 0,731 |
| 805 | 0,466 | 0,311 | 0,535 | 0,225 | 0,243 | 0,517 | 0,589 | 0,731 |
| 810 | 0,466 | 0,311 | 0,539 | 0,233 | 0,249 | 0,521 | 0,590 | 0,731 |
| 815 | 0,466 | 0,311 | 0,544 | 0,243 | 0,257 | 0,525 | 0,590 | 0,731 |
| 820 | 0,465 | 0,311 | 0,548 | 0,254 | 0,265 | 0,529 | 0,590 | 0,731 |
| 825 | 0,464 | 0,311 | 0,552 | 0,264 | 0,273 | 0,532 | 0,591 | 0,731 |
| 830 | 0,464 | 0,310 | 0,555 | 0,274 | 0,280 | 0,535 | 0,592 | 0,731 |

Table 2: Spectral radiance factor $\beta_i(\lambda)$ of CIE -1974 test-colour samples Nos. 9...14

| lambda | TCS9 | TCS10 | TCS11 | TCS12 | TCS13 | TCS14 |
|---|---|---|---|---|---|---|
| 360 | 0,069 | 0,042 | 0,074 | 0,189 | 0,071 | 0,036 |
| 365 | 0,072 | 0,043 | 0,079 | 0,175 | 0,076 | 0,036 |
| 370 | 0,073 | 0,045 | 0,086 | 0,158 | 0,082 | 0,036 |
| 375 | 0,070 | 0,047 | 0,098 | 0,139 | 0,090 | 0,036 |
| 380 | 0,066 | 0,050 | 0,111 | 0,120 | 0,104 | 0,036 |
| 385 | 0,062 | 0,054 | 0,121 | 0,103 | 0,127 | 0,036 |
| 390 | 0,058 | 0,059 | 0,127 | 0,090 | 0,161 | 0,037 |
| 395 | 0,055 | 0,063 | 0,129 | 0,082 | 0,211 | 0,038 |
| 400 | 0,052 | 0,066 | 0,127 | 0,076 | 0,264 | 0,039 |
| 405 | 0,052 | 0,067 | 0,121 | 0,068 | 0,313 | 0,039 |
| 410 | 0,051 | 0,068 | 0,116 | 0,064 | 0,341 | 0,040 |
| 415 | 0,050 | 0,069 | 0,112 | 0,065 | 0,352 | 0,041 |
| 420 | 0,050 | 0,069 | 0,108 | 0,075 | 0,359 | 0,042 |
| 425 | 0,049 | 0,070 | 0,105 | 0,093 | 0,361 | 0,042 |
| 430 | 0,048 | 0,072 | 0,104 | 0,123 | 0,364 | 0,043 |
| 435 | 0,047 | 0,073 | 0,104 | 0,160 | 0,365 | 0,044 |
| 440 | 0,046 | 0,076 | 0,105 | 0,207 | 0,367 | 0,044 |
| 445 | 0,044 | 0,078 | 0,106 | 0,256 | 0,369 | 0,045 |
| 450 | 0,042 | 0,083 | 0,110 | 0,300 | 0,372 | 0,045 |
| 455 | 0,041 | 0,088 | 0,115 | 0,331 | 0,374 | 0,046 |
| 460 | 0,038 | 0,095 | 0,123 | 0,346 | 0,376 | 0,047 |
| 465 | 0,035 | 0,103 | 0,134 | 0,347 | 0,379 | 0,048 |
| 470 | 0,033 | 0,113 | 0,148 | 0,341 | 0,384 | 0,050 |
| 475 | 0,031 | 0,125 | 0,167 | 0,328 | 0,389 | 0,052 |
| 480 | 0,030 | 0,142 | 0,192 | 0,307 | 0,397 | 0,055 |
| 485 | 0,029 | 0,162 | 0,219 | 0,282 | 0,405 | 0,057 |
| 490 | 0,028 | 0,189 | 0,252 | 0,257 | 0,416 | 0,062 |
| 495 | 0,028 | 0,219 | 0,291 | 0,230 | 0,429 | 0,067 |
| 500 | 0,028 | 0,262 | 0,325 | 0,204 | 0,443 | 0,075 |
| 505 | 0,029 | 0,305 | 0,347 | 0,178 | 0,454 | 0,083 |
| 510 | 0,030 | 0,365 | 0,356 | 0,154 | 0,461 | 0,092 |
| 515 | 0,030 | 0,416 | 0,353 | 0,129 | 0,466 | 0,100 |
| 520 | 0,031 | 0,465 | 0,346 | 0,109 | 0,469 | 0,108 |
| 525 | 0,031 | 0,509 | 0,333 | 0,090 | 0,471 | 0,121 |
| 530 | 0,032 | 0,546 | 0,314 | 0,075 | 0,474 | 0,133 |
| 535 | 0,032 | 0,581 | 0,294 | 0,062 | 0,476 | 0,142 |
| 540 | 0,033 | 0,610 | 0,271 | 0,051 | 0,483 | 0,150 |
| 545 | 0,034 | 0,634 | 0,248 | 0,041 | 0,490 | 0,154 |
| 550 | 0,035 | 0,653 | 0,227 | 0,035 | 0,506 | 0,155 |
| 555 | 0,037 | 0,666 | 0,206 | 0,029 | 0,526 | 0,152 |
| 560 | 0,041 | 0,678 | 0,188 | 0,025 | 0,553 | 0,147 |
| 565 | 0,044 | 0,687 | 0,170 | 0,022 | 0,582 | 0,140 |
| 570 | 0,048 | 0,693 | 0,153 | 0,019 | 0,618 | 0,133 |
| 575 | 0,052 | 0,698 | 0,138 | 0,017 | 0,651 | 0,125 |
| 580 | 0,060 | 0,701 | 0,125 | 0,017 | 0,680 | 0,118 |
| 585 | 0,076 | 0,704 | 0,114 | 0,017 | 0,701 | 0,112 |
| 590 | 0,102 | 0,705 | 0,106 | 0,016 | 0,717 | 0,106 |
| 595 | 0,136 | 0,705 | 0,100 | 0,016 | 0,729 | 0,101 |
| 600 | 0,190 | 0,706 | 0,096 | 0,016 | 0,736 | 0,098 |
| 605 | 0,256 | 0,707 | 0,092 | 0,016 | 0,742 | 0,095 |
| 610 | 0,336 | 0,707 | 0,090 | 0,016 | 0,745 | 0,093 |
| 615 | 0,418 | 0,707 | 0,087 | 0,016 | 0,747 | 0,090 |
| 620 | 0,505 | 0,708 | 0,085 | 0,016 | 0,748 | 0,089 |
| 625 | 0,581 | 0,708 | 0,082 | 0,016 | 0,748 | 0,087 |
| 630 | 0,641 | 0,710 | 0,080 | 0,018 | 0,748 | 0,086 |

Table 2. cont.

| lambda | TCS9 | TCS10 | TCS11 | TCS12 | TCS13 | TCS14 |
|---|---|---|---|---|---|---|
| 635 | 0,682 | 0,711 | 0,079 | 0,018 | 0,748 | 0,085 |
| 640 | 0,717 | 0,712 | 0,078 | 0,018 | 0,748 | 0,084 |
| 645 | 0,740 | 0,714 | 0,078 | 0,018 | 0,748 | 0,084 |
| 650 | 0,758 | 0,716 | 0,078 | 0,019 | 0,748 | 0,084 |
| 655 | 0,770 | 0,718 | 0,078 | 0,020 | 0,748 | 0,084 |
| 660 | 0,781 | 0,720 | 0,081 | 0,023 | 0,747 | 0,085 |
| 665 | 0,790 | 0,722 | 0,083 | 0,024 | 0,747 | 0,087 |
| 670 | 0,797 | 0,725 | 0,088 | 0,026 | 0,747 | 0,092 |
| 675 | 0,803 | 0,729 | 0,093 | 0,030 | 0,747 | 0,096 |
| 680 | 0,809 | 0,731 | 0,102 | 0,035 | 0,747 | 0,102 |
| 685 | 0,814 | 0,735 | 0,112 | 0,043 | 0,747 | 0,110 |
| 690 | 0,819 | 0,739 | 0,125 | 0,056 | 0,747 | 0,123 |
| 695 | 0,824 | 0,742 | 0,141 | 0,074 | 0,746 | 0,137 |
| 700 | 0,828 | 0,746 | 0,161 | 0,097 | 0,746 | 0,152 |
| 705 | 0,830 | 0,748 | 0,182 | 0,128 | 0,746 | 0,169 |
| 710 | 0,831 | 0,749 | 0,203 | 0,166 | 0,745 | 0,188 |
| 715 | 0,833 | 0,751 | 0,223 | 0,210 | 0,744 | 0,207 |
| 720 | 0,835 | 0,753 | 0,242 | 0,257 | 0,743 | 0,226 |
| 725 | 0,836 | 0,754 | 0,257 | 0,305 | 0,744 | 0,243 |
| 730 | 0,836 | 0,755 | 0,270 | 0,354 | 0,745 | 0,260 |
| 735 | 0,837 | 0,755 | 0,282 | 0,401 | 0,748 | 0,277 |
| 740 | 0,838 | 0,755 | 0,292 | 0,446 | 0,750 | 0,294 |
| 745 | 0,839 | 0,755 | 0,302 | 0,485 | 0,750 | 0,310 |
| 750 | 0,839 | 0,756 | 0,310 | 0,520 | 0,749 | 0,325 |
| 755 | 0,839 | 0,757 | 0,314 | 0,551 | 0,748 | 0,339 |
| 760 | 0,839 | 0,758 | 0,317 | 0,577 | 0,748 | 0,353 |
| 765 | 0,839 | 0,759 | 0,323 | 0,599 | 0,747 | 0,366 |
| 770 | 0,839 | 0,759 | 0,330 | 0,618 | 0,747 | 0,379 |
| 775 | 0,839 | 0,759 | 0,334 | 0,633 | 0,747 | 0,390 |
| 780 | 0,839 | 0,759 | 0,338 | 0,645 | 0,747 | 0,399 |
| 785 | 0,839 | 0,759 | 0,343 | 0,656 | 0,746 | 0,408 |
| 790 | 0,839 | 0,759 | 0,348 | 0,666 | 0,746 | 0,416 |
| 795 | 0,839 | 0,759 | 0,353 | 0,674 | 0,746 | 0,422 |
| 800 | 0,839 | 0,759 | 0,359 | 0,680 | 0,746 | 0,428 |
| 805 | 0,839 | 0,759 | 0,365 | 0,686 | 0,745 | 0,434 |
| 810 | 0,838 | 0,758 | 0,372 | 0,691 | 0,745 | 0,439 |
| 815 | 0,837 | 0,757 | 0,380 | 0,694 | 0,745 | 0,444 |
| 820 | 0,837 | 0,757 | 0,388 | 0,697 | 0,745 | 0,448 |
| 825 | 0,836 | 0,756 | 0,396 | 0,700 | 0,745 | 0,451 |
| 830 | 0,836 | 0,756 | 0,403 | 0,702 | 0,745 | 0,454 |

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## Appendix 1: TERMINOLOGY

### Colour rendering properties

Effect of a light source on the colour appearance of objects in comparison with their colour appearance under a reference illuminant for specified conditions.

### 1994 Uniform space

An approximately uniform colour space produced by plotting along three orthogonal axes $U^*$, $V^*$, and $W^*$, quantities defined in equation (1).

$$\begin{aligned} W^* &= 25\,Y^{1/3} - 17 \\ U^* &= 13\,W^*\,(u-u_0) \\ V^* &= 13\,W^*\,(v-v_0) \\ 1 &\le Y \le 100 \end{aligned} \qquad \text{(A-1)}$$

$u$, $v$ are the 1960 UCS co-ordinates (see 1960 UCS diagram), and $u_0$, $v_0$ are values of these variables for chosen achromatic colour.

*Note 1.* For object colours the choice of the co-ordinates of the illuminant for $u_0$ and $v_0$ is satisfactory.

*Note 2.* In this system the measure $\Delta E$ of the perceptual size of the difference between colour $(U^*_1, V^*_1, W^*_1)$ and colour $(U^*_2, V^*_2, W^*_2)$ is:

$$\Delta E = [(U^*_1 - U^*_2)^2 + (V^*_1 - V^*_2)^2 + (W^*_1 - W^*_2)^2]^{1/2}$$

### 1960 UCS diagram

An approximately uniform chromaticity diagram produced by plotting in rectangular co-ordinates $v$ against $u$, quantities defined in equation (1).

$$\begin{aligned} u &= 4x / (-2x + 12y + 3) = 4X / (X + 15Y + 3Z); \\ v &= 6y / (-2x + 12y + 3) = 6Y / (X + 15Y + 3Z) \end{aligned} \qquad \text{(A-2)}$$

### Reciprocal megakelvin ($MK^{-1}$)

Term used to describe correlated colour temperature differences. Its value is $10^6$ $K^{-1}$. (It replaces the obsolete and depreciated term "mired": micro-reciprocal degree.)

*Note*: Equal differences along the Planckian locus correspond to roughly equal reciprocal megakelvin differences.

**APPENDIX 2: CIE Disk D008. Computer program to calculate CRIs**

The CIE Central Bureau provides on request a disk that can be used on an IBM PC or compatible and contains in a subdirectory the tables necessary to calculate the $R_i$ and $R_a$ indices.

An other subdirectory contains two programs to be used in a "DOS" or in an "MS-WINDOWS" environment to calculate the $R_i$ and $R_a$ indices.

Although the CIE CB made all efforts to secure that these programs provide the correct values, no guarantee is taken. They are not part of the Technical Report and are not a CIE endorsed publication.

As short introduction of the programs, excerpts of the Press Release announcing them is reproduced here for your convenience.

The software available as CIE D008, Rel. 1.0 - 1995 is based on the updated method of measuring colour rendering indices. It will produce results that agree - to the uncertainty of rounding the last digits - with results calculated on the basis of CIE 13.3 - 1995.

The programs CIE13_3w.exe and CIE13_3d.exe are computer based tools for specifying colour rendering properties of light sources. The programs calculate, according to the rules described in CIE 13.3-1995, the light source chromaticity co-ordinates, the correlated colour temperature, the 14 special colour rendering indices and the general colour rendering index, using the first 8 CIE test colour samples. The program allows the use of other test colour samples as well.

The program CIE13_3w.exe runs in a Windows environment (version 3.0 or higher). CIE13_3d.exe is the same program running under DOS.

Both programs include options to save the results in a file and to print them. CIE13_3w has built in clipboard facilities to transfer data directly to word processors, spread-sheet applications or other Windows programs.