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COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE  
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INTERNATIONALE BELEUCHTUNGSKOMMISSION

# TECHNICAL REPORT

## TECHNICAL COLLECTION 1993

### Contents:

- 103/1 Colour Appearance Analysis
- 103/2 Industrial Lighting and Safety at Work
- 103/3 Reference Action Spectra for Ultraviolet Induced Erythema and Pigmentation of Different Human Skin Types
- 103/4 Biologically Effective Emissions and Hazard Potential of Desk-Top Luminaires Incorporating Tungsten Halogen Lamps
- 103/5 The Economics of Interior Lighting Maintenance
- 103/6 Clarification of Maintained Illuminance and Associated Terms

Abstracts of CIE Publications issued since 1991

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## Colour Appearance Analysis

### Foreword

The following members of TC 1-13: Colour appearance analysis took part in the discussions leading to this report. The Committee was constituted within Division 1 -Vision and Colour.

Chairman: M R Pointer

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L Mori (JPN)  
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### SUMMARY

#### COLOUR APPEARANCE ANALYSIS

Traditional colorimetry in itself is unable to define the appearance of a colour. What are required are measures that accurately correlate with the perceived hue, saturation, chroma, colourfulness, lightness and brightness of the coloured samples when seen under specified viewing conditions.

The Committee has selected two models that adequately predict the appearance of simple coloured stimuli under a light source whose chromaticity is not far from the Planckian locus and with a colour temperature between those of typical daylight and tungsten light.

Four newly formed Technical Committees will follow up the present work:

- TC 1-27 Specification of Colour Appearance for Reflective Media and Self Luminous Display Comparisons
- TC 1-32 Prediction of Corresponding Colours
- TC 1-33 Colour Rendering
- TC 1-34 Testing of Colour Appearance Models

### ZUSAMMENFASSUNG

#### UNTERSUCHUNG DES FARBEINDRUCKES

Die traditionelle Farbmessung ist von sich aus nicht fähig, den Farbeindruck einer Farbe zu definieren. Was benötigt wird, sind Maßzahlen, die genau mit den wahrgenommenen Werten von Bunton, Sättigung, Buntheit, Helligkeit u.s.w. von Farbmustern korrelieren, wenn sie unter definierten Sehbedingungen wahrgenommen werden.

Das Komitee hat zwei Modelle ausgewählt, die den Eindruck eines einfachen bunten Farbzeiges eines Farbmusters hinreichend vorhersagen, wenn dieses von einer Lichtquelle beleuchtet wird, deren Farbart nicht weit vom Planck-Kurvenzug liegt und deren Farbtemperatur zwischen der von typischem Tageslicht und der von Wolframlicht liegt.

Vier neue Technische Komitees werden sich mit diesen Arbeiten befassen:

- TC 1-27 Spezifikation des Farbeindrucks reflektierender Stoffe und Vergleiche selbstleuchtender Anzeigen
- TC 1-32 Vorhersage korrespondierender Farben
- TC 1-33 Farbwiedergabe
- TC 1-34 Prüfung von Farbeindruck-Modellen

## CIE Technical Collection 1993/1

## RESUME

## ANALYSE DE L'APPARENCE DES COULEURS

La colorimétrie traditionnelle n'est pas en mesure de définir par elle-même l'apparence d'une couleur. Ce qu'il faut ce sont des mesures qui soient en corrélation fidèle avec la teinte, la saturation, le chroma, le niveau de coloration, la clarté et la luminosité des matériaux colorés, quand ces attributs sont perçus dans des conditions d'observation spécifiées.

Le Comité a retenu deux modèles qui prédisent convenablement l'apparence de stimulus colorés simples, pour des sources de lumière dont la chromaticité n'est pas éloignée du lieu des radiateurs de Planck et dont la température de couleur est comprise entre celle de la lumière naturelle normale et celle de sources à incandescence.

Quatre Comités Techniques récemment formés poursuivront le travail actuel:

- TC 1-27: Spécification de l'apparence des couleurs en vue de comparaisons entre matériaux réfléchissants et afficheurs auto-lumineux
- TC 1-32: Prédiction des couleurs correspondantes
- TC 1-33: Rendu des couleurs
- TC 1-34: Essai des modèles d'apparence des couleurs

## 1. Introduction

Traditional colorimetry has been with us for a long time - the 1931 CIE Standard Colorimetric Observer celebrated its 50th birthday in 1981. The CIE system of colour measurement, based as it is on the colour matching functions that represent the standard observer, has stood the test of time and proved to be of immense value in helping to solve many measurement problems. However, as W D Wright, one of the 'fathers' of the standard observer has aptly pointed out; "The definition of a colour C by the equation:

$$C \equiv X(X) + Y(Y) + Z(Z)$$

expresses the fact that a certain mixture of three reference stimuli will produce the same colour sensation as C, when both are seen under the same viewing conditions. Although this specification involves an observer and is therefore a subjective relationship, it does not in itself define the appearance of C ..." [1.1].

Thus the situation can be imagined where there are two colours, both specified in terms of their tristimulus values, and it is required to know the difference in their appearances when viewed under the same specified viewing conditions. Some approximate estimates can be obtained by transforming the tristimulus values to chromaticity coordinates and plotting these coordinates on a chromaticity diagram together with the position of the appropriate white point. In this way a relative idea can be obtained as to whether one sample is, for example, redder than another, and which sample has the higher purity. No information is available, however, as to their absolute colour appearance.

In the field of lighting evaluation it is often required to know how colours will look under different light sources. Some indications can be derived from a knowledge of the CIE Colour Rendering Indices of the particular light sources [1.2], but, again, no absolute colour appearance information is available and so it is difficult to derive consistent measures of differences in colour appearance.

What are required are measures that accurately correlate with the perceived hue, saturation, chroma, colourfulness, lightness and brightness of a coloured samples when seen under specified viewing conditions.

## 2. The Committee

It was to address this problem that Technical Committee 1-13 - Colour Appearance Analysis was established in Amsterdam in 1983 under the auspices of CIE Division 1 - Vision and Colour.

The Terms of Reference of the Committee were as follows:

To derive methods of evaluating the colour rendering properties of illuminants based on colour appearance.

A Working Programme was established to provide guidelines for the work:

1. The acceptance of an appearance model that adequately predicts the appearance of simple coloured stimuli under a light source whose chromaticity is not far from the Planckian locus and with a colour temperature between those of typical daylight and tungsten light.
2. The application of the model to the assessment of the colour rendering capabilities of light sources.
3. To collect data from experimental determinations of colour appearance.  
(Item 3 of the working programme was added at the CIE Quadrennial Meeting in Venice in 1987.)

The Committee has been successful in achieving results that fulfil the first item in the working programme in as much that two models have been developed that enable colour appearance parameters to be predicted for coloured stimuli seen in defined viewing conditions. The models are from Dr Y Nayatani and his co-workers in Japan, and from Dr R W G Hunt in Great Britain. It has not, however, been possible for the Committee to make a single recommendation for a preference between these two models.

### 3. The Models

The two models have many similarities. They both require input in the form of the CIE tristimulus values for the coloured sample, together with information about the colour and absolute light level of the 'surround' adapting field; they both then use empirical equations to model the signal processing of the retina and the interpretation of these signals by the brain. Although empirical, the equations used are modelled according to physiological data where this is available. Thus the overall philosophy of the two models is very similar; the differences can be found in one or two parts of the models where their authors have chosen to model physiological functions in a different way.

The current formulation of the Hunt Model can be found in the June 1991 issue of *Color Research and Application* [3.1]. The paper deals with both related and unrelated colours and represents a revision of previous versions of the model [3.2-3.6]

The current formulation of the Nayatani Model for related colours can be found in the October 1987 and the August 1990 issues of *Color Research and Application* [3.7, 3.8]. The model is a considerable extension of the authors' earlier work on chromatic adaptation [3.9-3.14].

Both authors list the steps required to calculate the various parameters and Hunt [3.1] includes a worked example.

### 4. Field Trials

There has been a considerable amount of work carried out to evaluate these models. Both authors report results of predictions of the Swedish NCS colour order system. Nayatani and his co-workers have conducted several sets of field trials [3.8, 4.1-4.4] to substantiate their model. The largest set of available data that test both models has been derived by Luo and his co-workers working at Loughborough University in England [4.5, 4.6].

### 5. The Future

At the Division 1 meeting held during the 22nd CIE Quadrennial meeting in Melbourne, Australia in 1991 it was agreed that TC 1-13 should be disbanded following the publication of this report. The work will be continued by several new committees:

## CIE Technical Collection 1993/1

**TC 1-32 Prediction of Corresponding Colours**

Chairman: Y Nayatani (JPN)

Terms of Reference:

To write a technical report describing the chromatic adaptation transform previously proposed for study [5.1] together with subsequent modifications.

**TC 1-33 Colour Rendering**

Chairman: W Walter (USA)

Terms of Reference:

To study indices for evaluation of colour rendering properties of light sources based on a colour appearance model. To prepare a report on a proposed method that will replace CIE Publ. No. 13.2 (this report has the potential to become a standard).

**TC 1-34 Testing of Colour Appearance Models**

Chairman: M Fairchild (USA)

Terms of Reference:

To investigate the performance of models based on their ability to predict the colour appearance of surface colours in simple and complex scenes under various illumination conditions.

These are in addition to the following Committee which was established at a Division 1 meeting in Vienna in 1989:

**TC 1-27 Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparison**

Chairman: P J Alessi (USA)

Terms of Reference:

1. To study and make recommendations for the specification of a colour appearance match between a reflective image and a self-luminous display image.
2. To act as official liaison to ISO/IEC JTC1/ SC18 in the development of colour standards for text and office systems.

Working Programme:

1. Investigate whether the CIELUV and CIELAB colour spaces adequately specify a colour appearance match between a reflective image and a self-luminous display image.
2. Investigate whether modifications to the CIELUV and CIELAB equations (such as white object point colour stimulus specification) would be adequate to specify a colour appearance match between a reflective image and a self-luminous display image.
3. Investigate the use of the Hunt and Nayatani colour appearance models to specify a colour appearance between a reflective image and a self-luminous display image.

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## Industrial Lighting and Safety at Work

The following members of TC 3-05 "Industrial Lighting and Safety at Work" took part in the preparation of this Technical Report. The Committee comes under CIE Division 3 "Interior Environment and Lighting Design".

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### SUMMARY

#### INDUSTRIAL LIGHTING AND SAFETY AT WORK

The task of TC 3-05 "Industrial Lighting and Safety at Work" was to collect information about national rules and recommendations, to analyse the factors of lighting influencing safety at work and to give guidance on techniques for the achievement of those parameters.

As a first step TC 3-05 circulated a questionnaire in two parts, part A asking for national rules and part B for existing research work on industrial lighting and accidents caused by bad lighting.

Part A was responded to by 14 countries, but part B could not be answered because of lack of information. This report summarises the results of the questionnaire part A and gives guidelines to encourage national research into lighting and accidents.

### ZUSAMMENFASSUNG

#### INDUSTRIEBELEUCHTUNG UND SICHERHEIT BEI DER ARBEIT

Die Aufgabe von TC 3-05 "Industriebeleuchtung und Sicherheit bei der Arbeit" war es, Informationen über nationale Regeln und Empfehlungen zu sammeln, die Beleuchtungsfaktoren zu analysieren, die die Sicherheit bei der Arbeit beeinflussen, und Anleitungen zur Erfüllung dieser Parameter zu geben.

Als ersten Schritt gab TC 3-05 einen Fragebogen in zwei Teilen heraus, von denen Teil A nach nationalen Regeln und Teil B nach vorhandenen Forschungsergebnissen über Industriebeleuchtung und Unfälle als Folge schlechter Beleuchtung fragte.

Teil A wurde von 14 Ländern beantwortet, aber Teil B konnte wegen fehlender Informationen nicht beantwortet werden.

Dieser Bericht faßt die Ergebnisse des Fragebogens A zusammen und gibt Anregungen für nationale Forschungen über Beleuchtung und Unfälle.

### RESUME

#### ECLAIRAGE INDUSTRIEL ET SECURITE AU TRAVAIL

La tâche du TC 3-05 "Eclairage industriel et sécurité au travail" était de collecter des informations sur les règlements et recommandations nationales, d'analyser les facteurs d'éclairage, influençant la sécurité au travail et de donner un guide sur les techniques pour l'obtention de ces paramètres.

Dans un premier temps le TC 3-05 a fait circuler un questionnaire en deux parties, la partie A concernant les règlements nationaux, et la partie B les travaux de recherche existant sur l'éclairage industriel et les accidents causés par un mauvais éclairage.

A la partie A, 14 pays ont répondu, mais la partie B a été abandonnée par manque d'information.

Ce rapport résume les résultats de la partie A du questionnaire, donne des conseils et encourage les recherches nationales sur la relation entre éclairage et accidents.

## 1. Introduction

Industrial lighting has two main functions: to assist productivity and to improve safety. It is in the scope of CIE TC 3-05 "to analyse the influence of industrial lighting on safety at work and to define the relevant lighting parameters". The definition of safety at the workplace includes issues relevant not only to how safely the work is done, but also to the safe movement of personnel and goods. Emergency lighting is outside the scope of TC 3-05. Lighting for safety should not be confused with emergency lighting, which is dealt with in CIE Publ. No. 49. Industrial lighting is normally considered as that lighting required by workers to perform work efficiently throughout the working day without undue fatigue. This means lighting for productivity. Thus recommendations for industrial lighting are based on the ergonomics of visual performance and are related to specific tasks. These recommendations usually include aspects of safety at work. Nevertheless it cannot be guaranteed that specific aspects of lighting for safety at work are automatically complied with. Lighting for safety at work means that people are able to move around and to carry out their work safely over a normal working period. There is a need to define the lighting parameters for safety as well as for productivity.

As a first step TC 3-05 circulated a questionnaire in two parts, part A asking for national rules and Part B for existing research work on industrial lighting and accidents caused by bad lighting.

The analysis of questionnaire A has given information on the present state of rules and codes in 14 countries. Therefore this report starts with a review of this state of the art.

It then attempts to give guidance on how to perform national research work on accidents caused by bad lighting, and to encourage research in this area.

## 2. The Questionnaire Part A - General Information

- 1) Current national laws and statutory regulations on occupational health, safety at work etc., applied in a country referring to environmental conditions particularly dealing with lighting, and
- 2) current national Standards, Codes and Guides, that are in use in a country referring to lighting of work places, and
- 3) further questions - with yes-no-answers - for additional information related to the above.

### 2.1 Responses to the questionnaire Part A

Fourteen countries provided answers to the questionnaire and the summary is indicated in Table 1.

From the responses received it should be mentioned that only illuminance is used as a specified quantifiable measure by inspectors (see Table 2), whereas limiting glare, avoidance of stroboscopic effects, availability of sufficient daylight are only addressed as qualitative aspects. Special recommendations applying to safety are not found or are mentioned only in a general manner. Therefore guidance for specific features of lighting for safety at work cannot be derived from them.

Nearly all responses indicate that there are no statistics on accidents caused by bad lighting.

### 2.2 Analysis of the existing practice, Codes and Rules for safety at work in different countries

Twelve of the fourteen countries that responded to the questionnaire have laws and/or statutory regulations for the safety and accident prevention of workers with regard to lighting. In three countries the recommended illuminances are identical with the recommendations for lighting work-places. In eight countries the maintenance of minimum levels may be controlled by inspectors of the bodies involved in occupational health for the Ministry of Labour. In four countries there are only minimum levels for safety. These are lower than the levels recommended for normal work. Only the minimum levels are enforced.

### **3. The Questionnaire-Part B Statistics of Accidents and Causes of Accidents Particularly Due to Bad Lighting**

Most countries indicated that they could not respond to questionnaire B, because the data on accident statistics were not readily available. Therefore it is necessary for CIE Division 3 to encourage national research work on bad lighting as a cause of accidents.

### **4. Relevant Lighting Parameters for Safety and Productivity**

Lighting parameters for industrial lighting as well as for general interior lighting, especially with emphasis on electric lighting, are part of the scope of CIE Publ. No. 29/2 1986. In the introduction to the Guide it is stated that "the lighting standards are well established and promote efficient work, safety and welfare". Furthermore, in relation to visibility it is stated that "in order to be able to move around and to perform intended activities easily, safely and efficiently, it is essential for people to be informed about their environment". From these general statements it is obvious that by following the guidelines and similar National Guides or Codes of Good Practice, lighting for safety at work will be achieved.

### **5. Bad Lighting as a Cause of Accidents**

In most instances the data gathering technique of occupational safety and health officials is not designed to extract this information, because lighting is perceived as playing a minor role. In many cases the reporting of accidents does not even address the question of bad lighting as being a possible cause. Therefore bad lighting often is not recognized as a cause for an accident, even if in fact it may very well be.

However, there are some indirect influences of both daylighting and electrical lighting on the causes of accidents, especially those involving fatigue, lack of concentration and attention. In order to get more information on accidents due to poor lighting, a check list is proposed which will be evaluated at a later date by bodies concerned with occupational health and safety or by research institutes.

#### **5.1 Checklist**

The checklist shown on page 10 should be used by inspectors of occupational health and safety to assess the causes of industrial accidents as they may relate to lighting. This can be added to existing accident report forms. This would facilitate the determination of accidents which may be caused by or affected by lighting. It is felt that evaluation of such additional questions would allow more information to be collected to improve lighting for safety.

### **6. Conclusions**

Finally it is necessary to assess the extent to which the purpose of this study has been achieved. The terms of reference were "to analyse the influence of industrial lighting on safety at work and to define the relevant lighting parameters".

Although the missing responses to the questionnaire Part B (see Section 3) result in little information about accidents caused directly by bad lighting, this does not mean that "relevant lighting parameters" cannot be defined.

Thus just the statement that the CIE Guide on Interior Lighting and the National Codes present rules for good lighting for safety at work confirms this claim and suggests an approach to the problem. On the other hand there are a lot of existing bad installations or installations which are badly maintained. A separate report about Lighting for Safety at Work therefore may be helpful for inspectors of occupational health who have to investigate bad lighting. It should not be overlooked that the reason for missing responses on statistics about accidents caused by bad lighting is not only the lack of awareness of the problem, but also the assumption that there are more serious causes of accidents than bad lighting. Nevertheless, it should not be assumed that bad lighting is not a cause for accidents even if it is not as obvious as more common causes. In order to investigate the different influences of bad lighting on accidents this report recommends that national institutions of occupational health encourage the use of checklist given here to assess the role of lighting in industrial accidents.

Further work of CIE Division 3 will be devoted to encouraging and supporting national investigations on bad lighting as a cause of accidents and as a rationale for applying the checklist. The second report of TC 3-05 therefore will provide additional relevant lighting parameters so that officers of occupational health bodies will become more conscious of the effects of lighting. The checklist will then become a useful tool to obtain statistics on the relationship between lighting and accidents.

## Checklist

to be used by inspectors of occupational health and safety to assess the role of lighting in industrial accidents.

The accident occurred during

- \* night-time/day-time (with or without daylight)
  - \* night-shift
  - \* normal-shift in winter-time, that is under specified daylight - night-time conditions
  - \* duration of hours of work
  - \* time of accident: beginning/end of shift
- occurred at
- \* work-place
  - \* circulation-area
  - \* zone with mixed traffic
  - \* stair-case, etc.

- \* reasons for excluding causes others than bad lighting, for example lack of adequate tools, poor machinery, etc.

Experts in the field of lighting safety-research could add the following items:

- \* illuminance (vertical plane, horizontal plane, working plane)
- \* uniformity of illuminance
- \* luminance- and colour-contrast
- \* glare-situations, especially unshielded bare lamps
- \* harsh shadows, especially those affecting the visibility of obstacles, etc.
- \* disturbing reflections, especially reflected glare
- \* poor colour rendering, especially related to safety-colours
- \* poor maintenance of lighting system.

| Question No.                  | A 1 *)                      | A 2 *)                      | A 3                            | A 4/5                                |
|-------------------------------|-----------------------------|-----------------------------|--------------------------------|--------------------------------------|
| Countries                     | Laws, Statutory<br>Regulat. | Standards,<br>Codes, Guides | Bodies enforcing<br>A 1 or A 2 | Statist. Records<br>Causes of Accid. |
| Austria                       | y 1)                        | y 2)                        | y                              | n                                    |
| Belgium                       | y 3)                        | y 4)                        | y: A 1                         | n                                    |
| Denmark                       | y 5)                        | y 6)                        | y 7)                           | y                                    |
| France                        | y 8)                        | y 9)                        | y: A 1                         | n                                    |
| Germany, F.R. +<br>former DDR | y 10)                       | y 11)12)14)                 | y: A 1 13)                     | n                                    |
| Hungary                       | n                           | y 15)                       | y: A 2                         | n                                    |
| Japan                         | y 16)                       | y 17)                       | n                              | n                                    |
| The Netherlands               | n                           | y 18)                       |                                |                                      |
| Norway                        | y 19)                       | y 20)                       | y 21)                          | y                                    |
| South Africa<br>(RSA)         | y 22)                       | y 23)                       | y: A 1                         | n                                    |
| Sweden                        | y 24)                       | y 25)                       | n                              | n                                    |
| Switzerland                   | y 26)                       | y 27)                       | y 28)                          | y                                    |
| United Kingdom                | y 29) 31)                   | y 30)                       | y: A 1                         | y                                    |
| USA                           | -                           | y 32)                       |                                |                                      |

\*) A1: Mandatory  
A2: Recommended

"y" = "yes", "n" = "no"; superscripted number refers to Reference number.

*Table 1: Summary of responses to the questionnaire part A.*

## CIE Technical Collection 1993/2

| Countries                     | Code of Practice 1)<br>Ill.task /<br>$E_n/l_x$ 5) | Modifying<br>factor<br>$f_{min}$ 2) 6) | Code of<br>Practice<br>applied by<br>labour<br>authority | Code of<br>Practice<br>enforced<br>by law for<br>safety | specified<br>min. level<br>for safety<br>3) | level for<br>safety<br>enforced<br>by law |
|-------------------------------|---------------------------------------------------|----------------------------------------|----------------------------------------------------------|---------------------------------------------------------|---------------------------------------------|-------------------------------------------|
| Austria                       | 200/1000                                          | 0,8                                    | yes                                                      | no                                                      | -                                           | -                                         |
| Belgium                       | 200/1000                                          | 1,0                                    | yes                                                      | no                                                      | 200                                         | yes                                       |
| Denmark                       | 200/1000                                          |                                        | yes                                                      | yes                                                     | 4)                                          | yes                                       |
| France                        | 200/1000                                          | 0,8                                    |                                                          | no                                                      | 40/200                                      | yes                                       |
| Germany, F.R.<br>+ former DDR | 200/1000                                          | 0,8                                    | yes                                                      | no                                                      | -                                           | -                                         |
| Hungary                       | Draft                                             | Draft                                  | no                                                       | no                                                      | -                                           | -                                         |
| Japan                         | 200/1000                                          | 0,8                                    | no                                                       | no                                                      | 70/300                                      | yes                                       |
| The Netherlands               | 200/1000                                          | 0,8                                    |                                                          |                                                         |                                             |                                           |
| Norway                        | 150/1500                                          | 0,8                                    | yes                                                      | no                                                      | 4)                                          |                                           |
| South Africa<br>(RSA)         | 100/1000                                          | 1,0                                    | yes                                                      | no                                                      | 4)                                          | yes                                       |
| Sweden                        | 200/1000                                          |                                        | no                                                       | no                                                      | no                                          | no                                        |
| Switzerland                   | 200/1000                                          | 0,8                                    | yes                                                      | no                                                      | -                                           | -                                         |
| United Kingdom                | 200/1000                                          |                                        | yes                                                      |                                                         |                                             | no                                        |
| USA                           | 100/2000 <sup>32)</sup>                           | 1                                      |                                                          |                                                         | 5/54 <sup>32)</sup>                         |                                           |

1) continued work/general illumination, indoors

3) not emergency

5)  $E_n$  nominal illuminance

2) min. value on task throughout time

4) identical with Code of Practice

6) factor due to depreciation

Table 2: Summary of lighting levels.

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## CIE RESEARCH NOTE

## Reference Action Spectra for Ultraviolet Induced Erythema and Pigmentation of Different Human Skin Types

The following members of TC 6-10 "Photobiological Effects in Human Skin" took part in the preparation of this Research Note. The Committee was constituted within CIE Division 6: Photobiology and Photochemistry.

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## SUMMARY

### REFERENCE ACTION SPECTRA FOR ULTRAVIOLET INDUCED ERYTHEMA AND PIGMENTATION FOR DIFFERENT HUMAN SKIN TYPES

Increasing public awareness of acute cutaneous UV reactions created the need to evaluate UV induced erythema and pigmentation for any UV sources without carrying out time consuming and expensive experiments. A practical method is to convolute the spectral power distribution of the UV source with an action spectrum.

For white people with sensitive skin as well as for people with normal skin reactions action spectra for erythema and pigmentation are expressed as sets of exponential equations. When displayed on a log-linear scale each of the four action spectra consists of three straight lines.

These action spectra together with their threshold doses can be used easily to evaluate mathematically the photobiological effects of erythema and pigmentation for different skin types. This can save time and money if natural respectively artificial UV emitting sources have to be compared.

## ZUSAMMENFASSUNG

### SPKTRALE WIRKUNGSFUNKTIONEN ALS BEZUGSWERTE FÜR DURCH ULTRAVIOLETT AUSGELOSTES ERYTHEM UND PIGMENTIERUNG FÜR VERSCHIEDENE MENSCHLICHE HAUTTYPEN

Seit die Öffentlichkeit in verstärktem Maße akute, durch UV hervorgerufene Hautreaktionen bewußt wahrnimmt, besteht die Notwendigkeit, durch beliebige UV-Strahlungsquellen induziertes Erythem und Pigmentierung abzuschätzen, ohne dafür zeit- und kostenaufwendige Versuche durchführen zu müssen. Ein praktisches Verfahren hierfür ist, die spektrale Bestrahlungsstärke der UV-Strahlungsquelle mit einer spektralen Wirkungsfunktion zu bewerten.

Sowohl für die weißhäutige Bevölkerung mit empfindlicher Haut als auch für die mit normalen Hautreaktionen wurden spektrale Wirkungsfunktionen für Erythem und Pigmentierung als Gruppen von Exponentialgleichungen ausgedrückt. Wenn diese in einem einfach-logarithmischen System dargestellt werden, setzen sie sich aus jeweils drei Geraden zusammen.

Mit Hilfe dieser spektralen Wirkungsfunktionen und den dazu gehörenden Schwellenwerten können die photobiologischen Wirkungen von Erythem und Pigmentierung für die verschiedenen Hauttypen auf einfache Art mathematisch ermittelt werden. Damit lassen sich Zeit und Geld einsparen, wenn natürliche bzw. künstliche UV-Strahlungsquellen miteinander verglichen werden müssen.

## RESUME

### SPECTRE D'EFFICACITE DE REFERENCE POUR L'ERYTHEME ET LA PIGMENTATION INDUITS PAR LES ULTRAVIOLETS POUR DIFFERENTS PHOTOTYPES CUTANES HUMAINS

Avec la prise de conscience de plus en plus large des réactions cutanées aiguës aux UV, il a été nécessaire d'évaluer l'érythème actinique et la pigmentation induite par chaque source UV sans procéder à des expériences coûteuses en temps et en argent. Une méthode élégante consiste à convoluer la distribution spectrale de la puissance d'émission de la source UV avec un spectre d'action.

Pour les sujets blancs avec une peau particulièrement sensible, aussi bien que pour les sujets avec des réactions normales, les spectres d'action pour l'érythème et la pigmentation sont exprimés par des séries d'équations exponentielles. Quand ils sont tracés sur une échelle linéaire logarithmique, les 4 spectres d'efficacité forment alors chacun 3 lignes droites.

Ces spectres d'efficacité associés aux doses seuils de déclenchement peuvent être utilisés facilement pour évaluer mathématiquement les effets photobiologiques érythémaux et pigmentaires pour différents phototypes cutanés. Ce procédé économise temps et argent si les comparaisons entre sources naturelles et/ou artificielles doivent être effectuées.

## 1. Introduction

The CIE Reference Action Spectrum for Ultraviolet Induced Erythema in Human Skin [1] can be displayed on a log-linear scale by three straight lines. It expresses to an acceptable extent experimental results for the 24 hour ultraviolet (UV) induced erythema in the range 250 - 400 nm. At Harvard Medical School a working group led by Parrish irradiated fair-skinned volunteers with monochromatic radiation and studied the effects of erythema and pigmentation [2]. These volunteers could be defined as skin types I and II according to Pathak et al. [3]. Skin type I are people most often with fair skin, blue eyes, freckles, their unexposed skin is white, and they always burn easily and severely, they tan little or not at all when exposed to UV. A little less sensitive is skin type II, who most often have fair skin, red or blond hair, blue, hazel or even brown eyes, while their unexposed skin is white, and they usually burn fairly easily but tan mildly [4]. If a threshold dose of  $250 \text{ J} \cdot \text{m}^{-2}$  (weighted) is used as the minimal erythema dose (MED), the CIE Reference Action Spectrum for Ultraviolet Induced Erythema in Human Skin  $s(\lambda)_{\text{ER},12}$  reflects the experimental results obtained with skin types I and II [2]. Therefore,  $s(\lambda)_{\text{ER},12}$  is now widely used as a measure for the erythema effectiveness of UV emitting sources [5, 6, 7], especially when radiation safety is concerned.

In white Caucasoids there are two more skin types, types III and IV. Skin type III are people that burn mildly and tan moderately, while their unexposed skin is white, representing the normal, average Caucasoid. The least sensitive Caucasoid skin type is IV, burning minimally tanning easily and above average, the unexposed skin being white or light brown, and has dark-brown hair and eyes [4].

Table 1 shows for the 4 Caucasoid skin types a brief description of erythema and pigmentation effects [8] as well as their statistical distribution in Central Europe [9]. For practical reasons it is necessary to assess the erythema and pigmentation effects in all these 4 skin types with regard to natural and artificial UV emitting sources.

**Table 1:** Skin reactions of the 4 Caucasoid skin types after UV-irradiation and their statistical distribution in the Central European population.

| SKIN TYPE | SKIN REACTIONS              | DISTRIBUTION |
|-----------|-----------------------------|--------------|
| I         | always burn, never tan      | 2 %          |
| II        | usually burn, sometimes tan | 12 %         |
| III       | sometimes burn, usually tan | 78 %         |
| IV        | never burn, always tan      | 8 %          |

Upon request from Division 6 of the CIE the members of Technical Committee 10 propose the following:

The reference action spectra for

|                                         |                               |
|-----------------------------------------|-------------------------------|
| erythema for skin types III and IV,     | $s(\lambda)_{\text{ER},34}$ , |
| pigmentation for skin types I and II,   | $s(\lambda)_{\text{PP},12}$ , |
| pigmentation for skin types III and IV, | $s(\lambda)_{\text{PP},34}$   |

should be those shown in Figure 1 (proposed action spectra).

The threshold doses for

erythema for skin types I and II and skin types III and IV shall be defined as

$250 \text{ J} \cdot \text{m}^{-2}$  (weighted) (= 1 MED)

pigmentation for skin types I and II and skin types III and IV shall be defined as

$450 \text{ J} \cdot \text{m}^{-2}$  (weighted)

this is 1 minimal tanning dose (= 1 MTD).

The data contained in the action spectra and threshold doses should be used only as measures to compare the approximate efficacy of UV emitting sources (between 250 and 400 nm).

## 2. Proposed Action Spectra

The proposed action spectra are based on experimental results carried out by Parrish [2] for skin types I and II and Gange [10] for skin types III and IV. These action spectra should be displayed similar to the  $s(\lambda)_{ER,12}$  that is also shown in the figure.

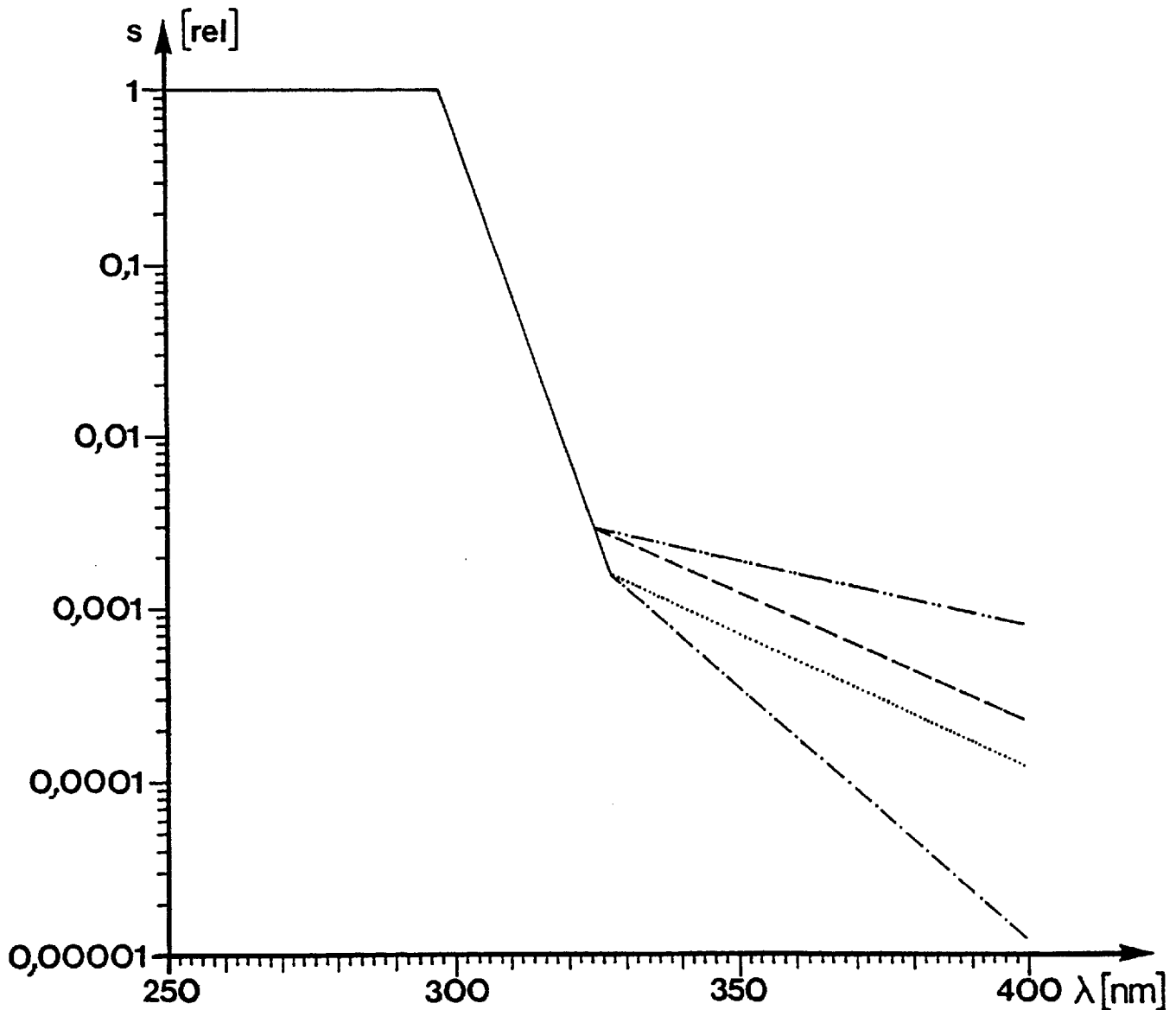


Figure 1: CIE Action Spectrum for Ultraviolet Induced Erythema in Human Skin  
 $s(\lambda)_{ER,12}$  (.....), and proposed action spectra  $s(\lambda)_{ER,34}$  (- · · · · ·),  $s(\lambda)_{PP,12}$  (- - - - -),  
 and  $s(\lambda)_{PP,34}$  ( · · - - - · · - - )

In the log-linear system used for the  $s(\lambda)_{ER,12}$  the abscissa, the wavelength  $\lambda$  has a linear scale, the ordinate, the relative erythema effect  $s(\lambda)$  has a logarithmic scale.

In such a system a function displayed as a straight line can be described mathematically in general as

$$s(\lambda) = 10^x \quad (1)$$

respectively

$$x = \log s(\lambda) \quad (2)$$

with  $x$  as a function of the wavelength

$$x = a(b - \lambda) \quad (3)$$

The equation reads

$$s(\lambda) = 10^{a(b - \lambda)} \quad (4)$$

If two points,  $P_1$ , with the coordinates  $\lambda_1$  and  $s_1$ , and  $P_2$  with  $\lambda_2$  and  $s_2$ , of the straight line are known, the constants  $a$  and  $b$  can be determined.

$$\log s_1 = a(b - \lambda_1) \quad (5)$$

$$\log s_2 = a(b - \lambda_2) \quad (6)$$

$$b = \frac{\lambda_2 \cdot \log s_1 - \lambda_1 \cdot \log s_2}{\log s_1 - \log s_2} \quad (7)$$

$$a = \frac{\log s_1}{b - \lambda_1} \quad (8)$$

or

$$a = \frac{\log s_2}{b - \lambda_2} \quad (9)$$

For  $s(\lambda)_{ER,12}$  the values of the relative erythema effectiveness for skin types I and II, 24 hours after irradiation can be represented by:

$$s(\lambda)_{ER,12} = 10^0 \quad (250 \leq \lambda \leq 298 \text{ nm})$$

$$s(\lambda)_{ER,12} = 10^{0,094(298 - \lambda)} \quad (298 \leq \lambda \leq 328 \text{ nm})$$

$$s(\lambda)_{ER,12} = 10^{0,015(139 - \lambda)} \quad (328 \leq \lambda \leq 400 \text{ nm})$$

For  $s(\lambda)_{ER,34}$  the values of the relative erythema effectiveness for skin types III and IV, 24 hours after irradiation can be represented by:

$$s(\lambda)_{ER,34} = 10^0 \quad (250 \leq \lambda \leq 298 \text{ nm})$$

$$s(\lambda)_{ER,34} = 10^{0,094(298 - \lambda)} \quad (298 \leq \lambda \leq 328 \text{ nm})$$

$$s(\lambda)_{ER,34} = 10^{0,029(230 - \lambda)} \quad (328 \leq \lambda \leq 400 \text{ nm})$$

From 250 to 328 nm  $s(\lambda)_{ER,34}$  is identical to  $s(\lambda)_{ER,12}$ , while from 328 to 400 nm the values for  $s(\lambda)_{ER,34}$  are lower. In this range skin type III and IV people are less sensitive to erythema reactions than skin type I and II people.

The tabulated values of  $s(\lambda)_{ER,12}$  and  $s(\lambda)_{ER,34}$  are presented in Table 2.

In contrast to the erythema effect (24 hours after irradiation) the pigmentation was judged in the experiments [2, 10] 7 to 14 days after irradiation. Therefore, this pigmentation is not the immediate pigment darkening effect (IPD) that occurs immediately after irradiation and fades within hours, but is true melanogenesis or delayed, persistent pigmentation (PP) [11].