ISBN 3 901 906 xx y

Deadline for BA and D6 votes:
22.12.2002

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

SPECTRAL WEIGHTING OF SUNLIGHT

CIE 14x:2002

UDC: 612.014.481-06 Descriptor: Optical radiation effects on human

THE INTERNATIONAL COMMISSION ON ILLUMINATION

The International Commission on Illumination (CIE) is an organisation devoted to international co-operation and exchange of information among its member countries on all matters relating to the art and science of lighting. Its membership consists of the National Committees in 37 countries and one geographical area and of 9 associate members.

The objectives of the CIE are :

1. To provide an international forum for the discussion of all matters relating to the science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries.
2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
5. To maintain liaison and technical interaction with other international organisations concerned with matters related to the science, technology, standardisation and art in the fields of light and lighting.

The work of the CIE is carried on by seven Divisions each with about 20 Technical Committees. This work covers subjects ranging from fundamental matters to all types of lighting applications. The standards and technical reports developed by these international Divisions of the CIE are accepted throughout the world.

A plenary session is held every four years at which the work of the Divisions and Technical Committees is reviewed, reported and plans are made for the future. The CIE is recognised as the authority on all aspects of light and lighting. As such it occupies an important position among international organisations.

LA COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE

La Commission Internationale de l'Éclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 37 pays plus un territoire géographique, et de 9 membres associés.

Les objectifs de la CIE sont :

1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
4. De préparer et publier des normes, rapports et autres textes, concernant toutes matières relatives à la science, la technologie et l'art dans les domaines de la lumière et de l'éclairage.
5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

DIE INTERNATIONALE BELEUCHTUNGSKOMMISSION

Die Internationale Beleuchtungskommission (CIE) ist eine Organisation, die sich der internationalen Zusammenarbeit und dem Austausch von Informationen zwischen ihren Mitgliedsländern bezüglich der Kunst und Wissenschaft der Lichttechnik widmet. Die Mitgliedschaft besteht aus den Nationalen Komitees in 37 Ländern und einem geographischen Gebiet und aus 9 assoziierten Mitgliedern.

Die Ziele der CIE sind :

1. Ein internationaler Mittelpunkt für Diskussionen aller Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik und für den Informationsaustausch auf diesen Gebieten zwischen den einzelnen Ländern zu sein.
2. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
5. Liaison und technische Zusammenarbeit mit anderen internationalen Organisationen zu unterhalten, die mit Fragen der Wissenschaft, Technik, Normung und Kunst auf dem Gebiet der Lichttechnik zu tun haben.

Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtanwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

Published by the

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
CIE Central Bureau
Kegelgasse 27, A-1030 Vienna, AUSTRIA
Tel: +43(01)714 31 87 0, Fax: +43(01)713 08 38 18
e-mail: ciecb@ping.at
WWW: http://www.cie.co.at/cie/

ISBN 3 901 906 xx y

CIE

COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

SPECTRAL WEIGHTING OF SUNLIGHT

CIE 14x:2002

UDC: 612.014.481-06 Descriptor: Optical radiation effects on human

This Technical Report has been prepared by CIE Technical Committee 6-25 of Division 6 “Photobiology and Photochemistry” and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document 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 le Comité Technique CIE 6-25 de la Division 6 “Photobiologie et Photochimie” et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le document 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 connaître d'éventuels amendements, consulter les plus récents comptes rendus de la CIE ou le CIE NEWS.

Dieser Technische Bericht ist vom CIE Technischen Komitee 6-25 der Division 6 “Photobiologie und Photochemie” ausgearbeitet und vom Vorstand der Commission Internationale de l'Eclairage gebilligt worden. Das Dokument berichtet über den derzeitigen Stand des Wissens und Erfahrung in dem behandelten Gebiet von Licht und Beleuchtung; es ist zur Verwendung durch CIE-Mitglieder und durch andere Interessierte bestimmt. Es sollte jedoch beachtet werden, daß das Dokument eine Empfehlung und keine Vorschrift ist. Die neuesten CIE-Tagungsberichte oder das CIE NEWS sollten im Hinblick auf mögliche spätere Änderungen zu Rate gezogen werden.

Any mention of organisations or products does not imply endorsement by the CIE. Whilst every care has been taken in the compilation of any lists, up to the time of going to press, these may not be comprehensive.

Toute mention d'organisme ou de produit n'implique pas une préférence de la CIE. Malgré le soin apporté à la compilation de tous les documents jusqu'à la mise sous presse, ce travail ne saurait être exhaustif.

Die Erwähnung von Organisationen oder Erzeugnissen bedeutet keine Billigung durch die CIE. Obgleich große Sorgfalt bei der Erstellung von Verzeichnissen bis zum Zeitpunkt der Drucklegung angewendet wurde, ist es möglich, daß diese nicht vollständig sind.

The following contributors took part in the preparation of technical report TC 6-25 "Spectral Weighting of Sunlight". The Technical Committee comes under CIE Division 6 "Photobiology and Photochemistry".

Chair:	Stephen Wengraitis	USA
Committee Members:	Mario Blumthaler	Austria
	Jean-Pierre Césarini	France
	Erin Chaney	USA
	Peter Koepke	Germany
	Sasha Madronich	USA
	János Schanda	Hungary
	David Sliney	USA
	Frederick Urbach	USA
	Ann Webb	United Kingdom
	Ulf Wester	Sweden

CONTENTS

SPECTRAL WEIGHTING OF SUNLIGHT

SUMMARY

Sunlight has long been correlated with many beneficial and harmful biological effects. Excessive ultraviolet radiation exposure has been identified as a contributor to several short- and long-term health problems, including erythema, photokeratitis, cataract, and skin cancer. The photobiological effectiveness of ultraviolet radiation at causing a biological effect varies with wavelength, and the variation of a given effectiveness function with wavelength is referred to as the "action spectrum" for that type of effect. When an action spectrum is spectrally weighted with the spectral distribution of sunlight or an artificial light source, the result is the "effective irradiance" of that light source for causing the biological effect. Comparison of the effective irradiances of light sources is a valuable tool for risk assessment. Outdoor sunlight is the most common source of chronic ultraviolet radiation exposure for the general public. This document lists the effective solar irradiances for various environmental conditions and types of photobiological effects. These effective irradiances at a horizontal ground surface (i.e. the global ultraviolet irradiance) were determined with the use of a multiple scattering model for ultraviolet radiation spectral irradiance.

FRENCH TITLE

RESUME

GERMAN TITLE

ZUSAMMENFASSUNG

1. REPORT OBJECTIVE AND SCOPE

This document is intended to provide health research scientists with a simple reference for estimating the risk associated with exposure to various levels of sunlight. This was accomplished by creating tables of the effective irradiances, for several photobiological effects, that would be received from clear-atmosphere solar UVR exposure under various environmental conditions. It must be emphasized that this report is not intended to include the effects from all possible environmental conditions. The effects of variable factors like pollutants and cloud cover are not included in the data tables, but their possible effects are discussed in Section 5. Attenuation of UVR from Pollutants and Clouds.

2. BACKGROUND – BENEFITS AND HAZARDS OF SOLAR ULTRAVIOLET RADIATION (UVR), AND ENVIRONMENTAL FACTORS AFFECTING SOLAR ULTRAVIOLET (UV) IRRADIANCE

Throughout history, solar UVR exposure has been correlated to a variety of beneficial and harmful biological effects. It has played a beneficial role in treating vitamin D deficiency in humans (Webb and Holick, 1988; Holick, 1992), was one of the first methods used for treatment of seasonal affective disorder (Lewy et al., 1987; Rosenthal et al., 1989), and to a lesser extent has shown capability as a germicidal agent (Finsen, 1899; Buttolph and Haynes, 1953; Buttolph, 1955; CIE, 1998a). However, experimental evidence also indicates that excessive solar UVR exposure causes short-term injuries to the skin and eyes like erythema and photokeratitis (Home, 1820; Davy, 1829; Charcot, 1858; Widmark, 1889; Finsen, 1900; Blumthaler et al., 1987; McKinlay and Diffey, 1987; Zuclich, 1989; Urbach, 1998). Excessive chronic exposure to UVR has been identified as a contributor to skin cancer development (Roffo, 1933; Blum, 1959; Césarini, 1987; CIE, 2000), cataract formation (Bachem, 1956; Pitts and Cullen, 1977; Pitts et al., 1977), immune system damage (Kripke, 1976; Fisher and Kripke, 1977; Kripke et al., 1977; de Fabo and Noonan, 1983), and DNA damage (Setlow, 1974; Peak and Peak, 1982).

The most common source of chronic UVR exposure to general populations is outdoor sunlight. Besides variable factors like local pollutants and clouds, the terrestrial solar spectral irradiance distribution in the ultraviolet spectral region depends strongly on the solar zenith angle (SZA), the total column ozone, and to a lesser extent on the ground albedo and the altitude above sea level (for example, see recent review by Koepke et al., 2002). The altitude above sea level is a fairly self-evident term, and the other terms may be described as follows:

The *solar zenith angle* (SZA) is equal to 90° minus the elevation angle of the sun above the horizon. For example, 0° SZA indicates that the sun is directly overhead, 45° SZA indicates that the sun is halfway between overhead and the horizon, and 90° SZA indicates that the sun is on the horizon. The SZA depends on the time of day, the day of

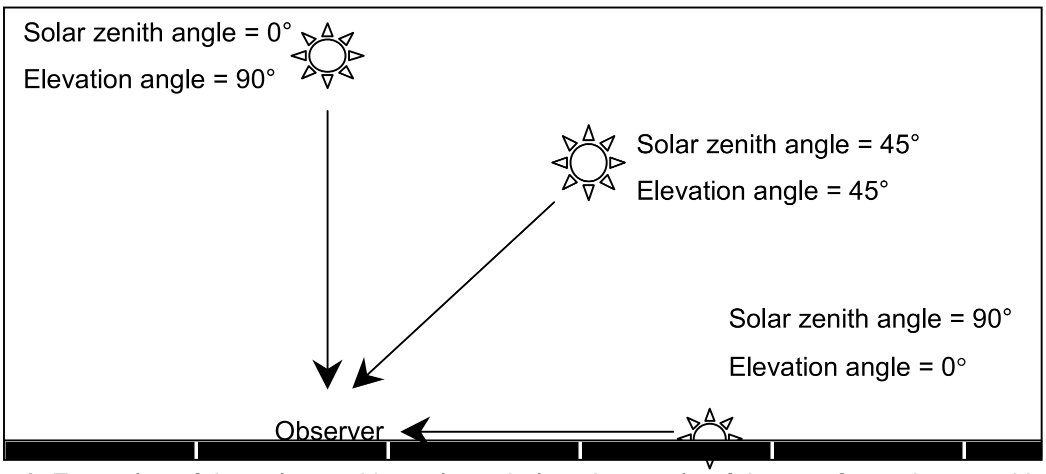


Fig. 1. Examples of the solar zenith angle and elevation angle of the sun for various positions of the sun in the sky. The illustration of the half-exposed sun for solar zenith angle = 90° / Elevation angle = 0° is intended to show that the sun is located at the horizon at that solar zenith angle/elevation angle.

the year, and geographical location of the sun's observer. Three examples of the position of the sun in the sky, and the corresponding SZA's and elevation angles, are illustrated in Figure 1.

- The *total column ozone* is a measure of the thickness of all the ozone located in a vertical column between a given area on the Earth's surface and outer space. An instrument designed to measure this quantity was presented by Dobson (Dobson, 1931), and the units for this quantity are "Dobson Units" (DU = 2,69 x 10^{21} molecule m^{-2}). A Dobson Unit may be described as follows: if all the ozone in the atmosphere above a given location were compressed into a slab at temperature = 0°C and pressure = 1013,25 hPa, a 3 mm thick ozone slab would be defined as 300 DU. A 4 mm thick ozone slab would be defined as 400 DU, etc. Variations in the total column ozone have been reported at several locations by as much as 100 DU or more within a one-month timeframe (Slusser et al., 1999; Wester, 2000a).
- The *ground albedo* is the ratio of light reflected by the ground to the light incident upon it. Radiation reflected by surfaces can reach the observer directly (e.g. from nearby roads and structures, vegetation, soils, water or snow) or indirectly if scattered in the atmosphere back towards the surface.

It is useful to distinguish between the "local" albedo in the direct proximity of the observer, and the "regional" albedo averaged over several km^2 around the observer. Locally reflected radiation can reach the observer directly from below or the sides; although important, such local reflections depend entirely on the details of specific surfaces, their orientation relative to the sun, and the shape, position, and orientation of the observer. A high regional albedo effectively increases the brightness of the sky, and therefore increases the total or "global" solar UVR exposure incident on an upward-facing horizontal surface (equal to the direct solar UVR plus the scattered or "diffuse" solar UVR). Green grass is a poor reflector of UVR, with albedo ~ 0,02, while fresh snow reflects UVR strongly, with albedo ~ 0,8 or higher (Grenfell et al., 1994). Snow covered surfaces in human environments, however, usually have an albedo on the order of 0,4, due to plants, rocks, buildings or other such materials protruding through the snow (Doda and Green, 1981; Schwander et al., 1999). See Figure 2 for an illustration of this effect. Albedo properties of various surfaces are listed in Appendix D (Blumthaler and Ambach, 1988; Feister and Grewe, 1995). The tabulations presented in this report include the effects of average regional albedo but not those of local reflections.

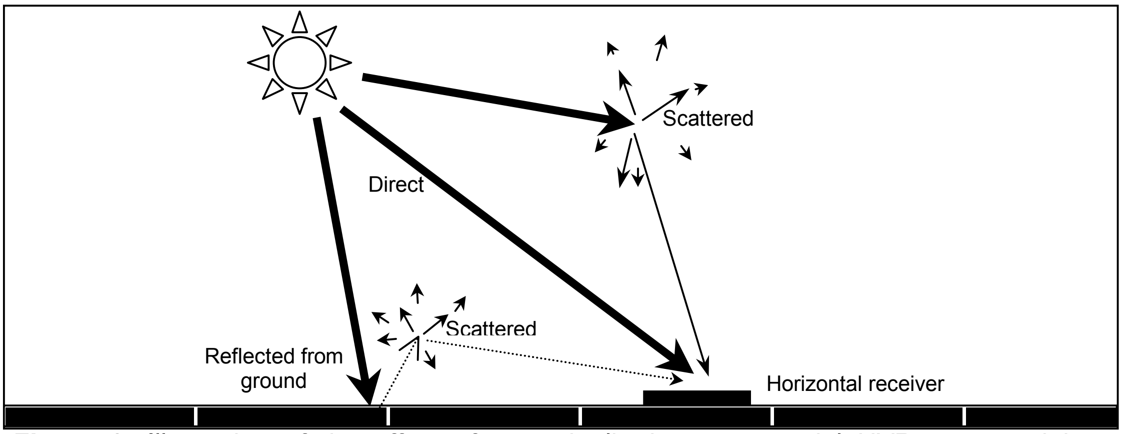


Figure 2. Illustration of the effect of ground albedo on terrestrial UVR measured by a horizontal receiver. The total or "global" solar UVR exposure reaching a flat horizontal surface on the ground is equal to the direct solar UVR plus the scattered or "diffuse" solar UVR (i.e. Global solar UVR = Direct solar UVR + Diffuse solar UVR). The global solar UVR is increased when the ground partially reflects the incident solar radiation, with higher albedo surfaces being more reflective. Some of the reflected radiation is then scattered by the atmosphere, some of which returns to the ground and increases the terrestrial UVR exposure. Albedo properties of various surfaces are listed in Appendix D.

3. DETERMINING THE PHOTOBIOLOGICAL EFFECTIVENESS OF SOLAR UVR EXPOSURE – "THE EFFECTIVE EXPOSURE DOSE RATE"

Assessing the effectiveness of solar UVR exposure at causing a given photobiological effect is a difficult problem, because not only does the solar spectral irradiance distribution vary significantly for different environmental conditions, but the photobiological effectiveness of UVR is typically a function of wavelength and exposure geometry (Sliney and Wolbarsht, 1980; Coohill, 1998; CIE, 1998a). This effectiveness function is also known as the "action spectrum" for the photobiological effect. When an action spectrum is used as a weighting function applied to the spectral irradiance of a light source, the result is the "effective irradiance" of that source for photobiological effect, and is "spectrally weighted" for photobiological effect. The equation for weighting of the spectral distribution of the solar irradiance $E_\lambda(\lambda)$ with an action spectrum takes the form of:

$$E_{\text{eff}} = \int_{\lambda_1}^{\lambda_2} E_\lambda(\lambda)\ s(\lambda)\ \mathrm{d}\lambda$$

where $s(\lambda)$ may be any action spectrum of interest, λ_1 and λ_2 are the lower and upper bounds of the spectral distribution in question, and E_{eff} is the photobiologically effective irradiance. Using this method, one can compare different sunlight exposure conditions (or artificial sources) to determine the relative effectiveness of each source for causing a given photobiological effect. Effective irradiances are used to determine safety limits for UVR exposure in occupational settings (American Conference of Governmental Industrial Hygienists (ACGIH), 2001; Wester, 2000b; International Non-Ionizing Radiation Committee of the International Radiation Protection Association (INIRC/IRPA), 1989; INIRC/IRPA, 1991; International Commission on Non-Ionizing Radiation Protection (ICNIRP), 1996). Action spectra have helped guide the development of radiometers that measure photobiological effects (Berger, 1976; CIE, 1998b).

4. BASIS OF THE DATA TABLES IN THIS REPORT

The spectral data from the CIE document "Solar Spectral Irradiance" (CIE, 1989) were first considered as the source of information for this study. It was eventually decided not to use these data, however, for the following reasons: (1) the lower wavelength limit of the data in the "Solar Spectral Irradiance" document was 300 nm. This was judged to include too few wavelengths in the UV-B range (280 nm - 315 nm) for our purpose; (2) the tables of that report included total column ozone conditions of approximately 0 DU, 300 DU, and 600 DU. This was judged to be too broad a variation in ozone levels for our purpose; (3) the data in the "Solar Spectral Irradiance" document are reported every 5 nm; however, our requirement to weigh the data with photobiological action spectra necessitated that the data be reported in 1 nm intervals.

The requirement to use a variety of clear-atmosphere environmental conditions led to the use of a model to generate the data for this report. There is no "official" model adopted by CIE, and the use of a particular model for this report does not constitute an official endorsement of that model by the CIE. The Green model, configured with its original analytical specifications (Green et al., 1980) was considered because its development was based on curve fittings to high-accuracy spectroradiometric measurements. Further, a recent intercomparison of 18 models against a reference result – the average calculation of six models designed to consider the effects of multiple scattering between atmospheric layers – indicated agreement between Green model calculations and the reference within approximately 10% for most clear-atmosphere environmental conditions (Koepke et al., 1998; intercomparison data available by internet download). The consensus of the committee, however, led instead to the choice of the more recently-developed STAR model (Schwander et al. 2001), for this report. The STAR model was one of the six models used to calculate the reference result from the Koepke et al. study, and agreed with the reference result within approximately 6% for the same conditions mentioned earlier. Further, the absolute average deviation between the STAR model and the reference result was 3,6% for the full range of environmental conditions. It must be emphasized again that the choice of this model for this report does not constitute an endorsement of this model by the CIE. Further, the choice of this model for this report does not suggest any advantage in using this model compared to other models. A brief list of models that have been used to calculate solar exposures from a variety of wavelengths is provided in Appendix C.

Using the STAR model, solar spectra in the UVR range were generated for the following environmental conditions: clear-skies modeled under realistic assumptions for aerosols, minimal ground albedo, altitudes at 0, 1,0 and 2,0 km, solar zenith angles at 0° (sun overhead), 15°, 30°, 45°, 60°, and 80° (sun near horizon), and total column ozone at 40 DU intervals from 220 DU to 420 DU. Additional model parameters are listed in Appendix F. These solar spectral data were then weighted with the action spectra for several photobiological effects. These action spectra were: the erythema action spectrum adopted by CIE (CIE, 1998b), which is represented by analytical functions over three spectral regions:

$s_{er}(\lambda) = 1{,}0$ for 250 nm $\leq \lambda \leq$ 298 nm

$s_{er}(\lambda) = 10^{0{,}094(298-\lambda)}$ for 298 nm $\leq \lambda \leq$ 328 nm

$s_{er}(\lambda) = 10^{0{,}015(140-\lambda)}$ for 328 nm $\leq \lambda \leq$ 400 nm

The other action spectra were: the high-resolution erythema action spectrum measured with lasers by Anders et al. (Anders et al., 1995), photocarcinogenesis of non-melanoma skin cancers (CIE, 2000), contact hypersensitivity (De Fabo and Noonan, 1983) and DNA lethality, mutagenesis and pyrimidine dimer formation (Peak et al., 1984). The UVR hazard action spectrum from ACGIH/ICNIRP (ACGIH, 2001; ICNIRP, 1996) follows the action spectrum for photokeratitis closely, and is included for that assessment. The action spectra for contact hypersensitivity, DNA damage and the Anders erythema action spectrum were generated from available data and close visual inspection of Figure graphics from the original technical reference. These action spectra are for harmful effects only. The beneficial photobiological effect of UVR irradiation causing vitamin D synthesis is not included in this report, as it is a complicated process involving an initial photoreaction dependent on radiation of wavelengths less than 316 nm (i.e. UV-B only), after which further photochemistry and heat isomerisation are involved in regulating vitamin D production (Webb and Holick, 1988; Holick, 1992).

For all action spectra, trendline fittings and data interpolations were also performed to generate the action spectra at 1 nm intervals. The action spectra used in this report are displayed graphically in Appendix A and are tabulated in Appendix B. For the contact hypersensitivity, DNA damage and Anders erythema action spectra, Appendix B distinguishes between the technical reference data and the data which were generated from close visual inspection of Figure graphics. The solar spectral irradiance reaching the ground becomes vanishingly small near 280 nm, and Appendix B includes action spectra data below 280 nm only for technical correctness.

It is also important to mention, regarding the features and boundaries of the action spectra in Appendix B:

- CIE erythema: this action spectrum is not defined below 250 nm.
- CIE photocarcinogenesis: this action spectrum is not defined below 250 nm. The flatness of the curve in the region from 340 nm - 400 nm is due to large margins of uncertainty in the action spectrum in this range.
- Anders erythema: prior studies measured the action spectrum from 250 nm - 320 nm using dye laser irradiation and visual observation of skin reactions (Anders et al., 1984). The study referenced for this paper, however, measured the action spectrum from 294 nm - 374 nm using dye laser irradiation and colorimetric measurement of skin reactions (Anders et al., 1995).
- DNA lethality, mutagenesis, and pyrimidine dimer formation: the lower wavelength limit of this action spectrum is based on measurements where the sample was irradiated by a Hg lamp source (254 nm).
- Contact hypersensitivity: no data points were provided outside the tabulated wavelength range. The action spectrum is based on the quanta/m^2 x 10^{20} for 50% suppression at the following wavelengths: 250 nm, 260 nm , 270 nm, 275 nm, 280 nm, 285 nm, 290 nm, 295 nm, 305 nm and 320 nm.

The average daily erythemal doses for various seasons and locations in the United States were calculated from data published in a 2001 population study and are listed in

Appendix E (Godar et al., 2001). These data, which included cloudy days as well as clear days, are included for comparison with doses that may be calculated by the reader based on the data tables from this report (which indicate only clear conditions). These data were measured from a network of Brewer MKIV spectrophotometers (SCI-TEC, Saskatoon, SK, Canada) used for ultraviolet radiation monitoring by the U.S. Environmental Protection Agency (USEPA, see references for internet hyperlink to "UV-net" database). These EPA Brewer spectrophotometer measurements were taken 20-30 times daily almost every day for over two years (January 1996-August 1998). The data listed in the Godar et al. report are three-month erythemally-weighted solar UVR seasonal doses. From these data, the average daily erythemally-weighted dose during each season is calculated in Appendix E as follows:

$$\frac{\textit{Seasonal erythemal dose}(J/m^2)}{92\ \textit{days}} = \textit{Erythemal dose per day}\ (J/m^2)\ \textit{during each season}$$

5. ATTENUATION OF UVR FROM POLLUTANTS AND CLOUDS

The spectral irradiance and geometrical distribution of solar UVR can be modified by many factors. While ozone molecules in the stratosphere (~10 km to 50 km above sea level) absorb all ultraviolet-C (<280 nm) and most UV-B (280-315 nm) radiation, highly variable factors such as air pollutants in the lower atmosphere like ozone, aerosol particles, nitrogen dioxide and sulfur dioxide can further attenuate solar UVR (Bais et al., 1993; Webb, 1997). Man-made pollutants tend to be distributed more locally, and amounts can vary in short time periods according to conditions like working hours and weather (Justus and Murphy, 1994; Webb, 1997). Low-level pollutants will also lead to the apparent increase in UVR with altitude to a greater degree than for clear atmosphere.

Clouds redistribute and generally reduce the total UVR reaching the earth's surface, although not to the same extent as infrared radiation (IR). Light clouds scattered over a blue sky make little difference to the global (direct plus diffuse) UV irradiance unless the sun is directly covered, while complete light cloud cover reduces terrestrial UVR to about one-half of that from a clear atmosphere. Even with heavy cloud cover the scattered ultraviolet component of sunlight (the skylight that is often called the "diffuse" component) is seldom less than 10% of that under clear sky (Paltridge and Barton, 1978). Only heavy storm clouds can virtually eliminate terrestrial UVR. More importantly, light overcast or the presence of partial cloudiness generally redistributes more UVR to the horizon sky, thus increasing UVR exposure to the eyes (Sliney, 1995).

Although it is desirable to include as many meteorological conditions as possible, it was decided that the highly-variable and localized nature of pollutants and cloud cover precludes their use in this report.

6. DISCUSSION OF UNCERTAINTIES

Variations in calculations from one model to another. The STAR and Green models are not the only models that can be used to estimate solar UVR exposure. It is re-emphasized that there is no "official" model adopted by CIE, and the consideration of these models for use in this report does not constitute an official endorsement of these models by the CIE. Solar UVR exposure models have been developed using various methods, including analytical functions, curve fits to high-precision solar spectra measurements, and using algorithms that account for radiative transfer between atmospheric layers. Various model input parameters have been used at several international agencies, hence many models and their variants are now used in the photobiology community (Koepke et al., 1998). A brief list of models is provided in Appendix C. Model intercomparisons can suggest advantages, improvements, and the ranges of uncertainty in model use.

A model intercomparison by Koepke et al. (1998) compared 18 models against a reference result for 106 combinations of environmental conditions. The reference result was defined as the average of the erythemal irradiances calculated by six models that considered the effects of multiple scattering in the atmosphere. The STAR model used in this report was one of these six models. The authors stated that the average "cannot be taken to be the truth, which is not really known. But, because the results of the multiple-scattering models are close together, these average values provide good expediency to compare all models." The study included solar zenith angles 15°, 30°, 60°, and 80°, and included total column ozone at 150, 190, 285, and 380 DU. Other varying meteorological factors were altitude, aerosol level, ground albedo, and cirrus optical depth. The STAR model consistently agreed with the reference result within approximately 6% for most clear-atmosphere conditions, and on average agreed with the reference within approximately 1% - 6% across the full range of widely-varying environmental conditions in the intercomparison. This was judged to lend support for its use in this report.

This model intercomparison also showed that model calculations could disagree substantially. For some conditions, other models differed from the reference result by as many as 12 UV Index levels, and that some models could provide accurate results, but only for the atmospheric conditions for which they had been developed. As stated earlier, for clear-atmosphere conditions, the Green model agreed with the reference result within approximately 10%. However, for less-clear atmosphere conditions indicating higher levels of pollutants, the Green model showed less agreement with the reference result, within approximately 10% - 25%. Qualitatively similar behavior was also seen for both Green and Lowtran models when compared to a model developed using the discrete ordinate method (DOM) (Stamnes et al., 1988). This intercomparison was done by Weihs and Webb (Weihs and Webb, 1996). Such varying degrees of differences across the range of environmental conditions show a cause for concern regarding the use of models in general. This emphasizes the need for awareness of the ranges of environmental conditions where models fail to agree, and a possible need for harmonization or cross-calibration between the models and their variants that are used within the photobiology community.

The “Altitude Effect” on UVR Exposure. Global UVR exposure tends to increase with altitude, due to less atmosphere being present between the sun and the receiver. However, this is strictly true only if the low and high elevation sites being compared have similar environmental conditions such as cloud cover, pollution, and surface albedo. In practice, the differences in environmental conditions can be more important than the thickness of the overhead atmosphere (stratospheric ozone, the main UVR absorber, is located well above any terrestrial surface). Strong increases in UVR with elevation may occur if the higher altitude site has higher surface albedo (e.g. rocks, or fresh snow) relative to the lower altitude site. Further, UVR may be directed to the higher altitude from albedo-dependent reflections from lower-altitude clouds, and the lower elevation site may experience decreased UVR due to higher pollution levels or more clouds. Orographic clouds, on the other hand, can preferentially obscure mountaintops relative to nearby sunlit valleys.

For clear sky low albedo conditions in pristine environments (no aerosols, background levels of tropospheric ozone), model calculations indicate a UVR increase of approximately 6% per km, with about equal contribution from Rayleigh scattering and absorption by ozone (at background levels) in the differential air column. Measurements at remote locations in Chile show increases of 4% - 10% per km, in approximate agreement with the models (Cabrera et al., 1995). However, measurements at less remote locations consistently indicate stronger increases with altitude, e.g. 15% to 25% per km in the Alps (Blumthaler and Ambach, 1987; Blumthaler et al., 1997) and up to 40% per km near Santiago, Chile (Cabrera et al., 1995). Model calculations generally agree with the measured values, if pollutants (esp. aerosols) are taken into account (Koepke et al., 1998).

The wide variations possible for the altitude effect on UVR exposure should be kept in mind when the data tables from this report are used, and when models are used in general. The data tables of this report assume mostly-clear atmosphere and minimal albedo conditions at low and high altitudes.

7. RECOMMENDATIONS

Moderate to large differences have been documented between UV irradiances calculated by a variety of models for some environmental conditions. Further, high- and low-altitude UVR measurements indicate that the effect of increasing altitude on UVR exposure can vary substantially with environmental conditions. This committee encourages that (1) harmonization or cross-calibration efforts of these models be performed to minimize the chance of these differences occurring, resulting in confusion or (at worst) misleading interpretations of data; (2) studies continue to be performed to establish the range of environmental conditions where agreement between models is best, or worst; and (3) model developers increase awareness of the variations in the altitude effect by briefly discussing it in the model's user documentation and/or model description.

8. DATA TABLES

The tables were developed from solar spectra calculated with the STAR Model. The columns represent irradiances integrated from 280-400 nm ($\mu W/cm^2$).

Multiply the data in these tables by 10 to convert to mW/m^2.

There is no "official" model adopted by CIE, and the use of the STAR model for this report does not constitute an endorsement of this model by CIE. See Appendix C for a brief list of models that have been used for calculating solar UVR exposure.

The action spectra for contact hypersensitivity, DNA damage and the Anders erythema action spectrum were generated from data from the technical reference, and close visual inspection of Figure graphics from the technical reference. For all action spectra, curve fittings and data interpolations were performed to provide the action spectra at 1 nm intervals. The action spectra used in this report are displayed graphically in Appendix A and are tabulated in Appendix B. For the contact hypersensitivity, DNA damage and Anders erythema action spectrum, Appendix B also distinguishes between the technical reference data and the data generated from close visual inspection of Figure graphics.

These data assume clear-atmosphere conditions. See Section 6 for discussion of uncertainties regarding this, and possible wide variations in the effects of altitude on increasing UVR exposure.

List of symbols

Z	Solar zenith angle (degrees)
E_{UVB}, E_{UVA}	Unweighted UV-B (280-315 nm) and unweighted UV-A (315-400 nm) solar irradiances
E_{solar}	Unweighted UV solar irradiance.
$E_{erythema}$	Solar irradiance weighted by CIE erythema action spectrum.
E_{anders}	Solar irradiance weighted by erythema action spectrum measured with lasers.
$E_{actinic\ UVR}$	Solar irradiance weighted by ACGIH/ICNIRP Actinic UVR action spectrum, similar to photokeratitis action spectrum.
$E_{photocarcino}$	Solar irradiance weighted by CIE photocarcinogenesis (Non-melanoma skin cancers) action spectrum.
$E_{DNA\ damage}$	Solar irradiance weighted by DNA lethality, mutagenesis, and pyrimidine dimer formation action spectrum.
E_{CHS}	Solar irradiance weighted by contact hypersensitivity action spectrum.

Table 1. Solar Spectral Irradiances Weighted to Photobiological Action Spectra Altitude 0 km, Clear atmosphere, minimal albedo, low aerosol turbidity.

Total Column Ozone 220 DU

Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6729	276	6453	43,29	53,77	12,58	93,29	1,20	31,08
15	6432	257	6175	39,59	48,83	11,39	85,76	1,06	28,90
30	5568	203	5365	29,87	35,85	8,31	65,58	0,71	22,92
45	4236	129	4107	17,69	19,84	4,64	39,40	0,34	14,75
60	2615	57	2558	7,36	7,06	1,77	16,24	0,10	6,79
80	623	5	618	0,82	0,58	0,18	1,55	0,01	0,73

Total Column Ozone 260 DU

Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6679	243	6436	35,51	42,42	9,83	78,21	0,83	27,53
15	6382	225	6157	32,47	38,37	8,89	71,75	0,73	25,56
30	5526	177	5349	24,48	27,84	6,48	54,50	0,49	20,18
45	4203	110	4093	14,50	15,11	3,62	32,37	0,24	12,85
60	2594	47	2547	6,06	5,29	1,40	13,14	0,07	5,79
80	617	4	613	0,70	0,49	0,16	1,24	< 0,01	0,58

Total Column Ozone 300 DU

Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6635	216	6419	29,93	34,10	7,93	66,68	0,61	24,67
15	6341	200	6141	27,36	30,75	7,18	61,06	0,54	22,87
30	5488	155	5333	20,63	22,11	5,24	46,13	0,36	17,96
45	4174	95	4079	12,25	11,85	2,95	27,15	0,18	11,32
60	2575	39	2536	5,15	4,14	1,16	10,90	0,05	5,00
80	612	3	609	0,61	0,43	0,14	1,04	< 0,01	0,47

Total Column Ozone 340 DU

Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6595	193	6402	25,76	27,88	6,58	57,64	0,46	22,28
15	6302	178	6124	23,55	25,08	5,96	52,70	0,41	20,63
30	5455	137	5318	17,77	17,91	4,36	39,64	0,28	16,13
45	4148	83	4065	10,58	9,53	2,47	23,17	0,13	10,07
60	2559	33	2526	4,49	3,37	0,99	9,24	0,04	4,37
80	607	2	605	0,55	0,39	0,13	0,89	< 0,01	0,39

Total Column Ozone 380 DU

Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6559	173	6386	22,55	23,14	5,58	50,40	0,36	20,27
15	6267	159	6108	20,62	20,78	5,06	46,03	0,32	18,74
30	5425	122	5303	15,58	14,78	3,71	34,50	0,22	14,58
45	4124	72	4052	9,30	7,85	2,12	20,06	0,11	9,02
60	2544	28	2516	3,98	2,84	0,88	7,97	0,03	3,84
80	604	2	602	0,50	0,37	0,12	0,78	< 0,01	0,32

Total Column Ozone 420 DU

Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6526	156	6370	20,01	19,48	4,82	44,52	0,29	18,54
15	6236	143	6093	18,31	17,47	4,37	40,62	0,26	17,12
30	5397	109	5288	13,85	12,40	3,22	30,36	0,18	13,26
45	4104	64	4040	8,31	6,61	1,86	17,59	0,09	8,13
60	2531	24	2507	3,59	2,47	0,79	6,98	0,03	3,40
80	599	1	598	0,47	0,35	0,11	0,69	< 0,01	0,27

See page 7 for explanation of column headers.

Table 2. Solar Spectral Irradiances Weighted to Photobiological Action Spectra Altitude 1 km, Clear atmosphere, minimal albedo, low aerosol turbidity.

Total Column Ozone 220 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7119	306	6813	48,21	60,17	14,09	103,77	1,36	34,38
15	6815	285	6530	44,19	54,78	12,78	95,63	1,20	32,04
30	5935	227	5708	33,56	40,54	9,39	73,68	0,81	25,61
45	4566	146	4420	20,10	22,72	5,30	44,83	0,40	16,71
60	2873	66	2807	8,46	8,18	2,04	18,75	0,12	7,82
80	695	6	689	0,93	0,66	0,21	1,75	0,01	0,83
Total Column Ozone 260 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7064	270	6794	39,49	47,46	10,98	86,96	0,94	30,45
15	6761	250	6511	36,18	43,03	9,95	79,96	0,83	28,34
30	5889	198	5691	27,46	31,46	7,31	61,20	0,56	22,54
45	4529	125	4404	16,44	17,28	4,13	36,80	0,28	14,55
60	2849	54	2795	6,95	6,11	1,61	15,14	0,09	6,67
80	688	4	684	0,79	0,55	0,18	1,41	< 0,01	0,66
Total Column Ozone 300 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7014	239	6775	33,23	38,14	8,85	74,10	0,69	27,27
15	6715	222	6493	30,44	34,47	8,02	68,01	0,61	25,35
30	5847	174	5673	23,10	24,97	5,89	51,77	0,41	20,06
45	4496	108	4388	13,86	13,53	3,34	30,84	0,20	12,82
60	2828	45	2783	5,90	4,77	1,33	12,55	0,06	5,76
80	682	3	679	0,69	0,48	0,16	1,17	< 0,01	0,54
Total Column Ozone 340 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6971	214	6757	28,56	31,16	7,33	64,02	0,52	24,64
15	6674	198	6476	26,16	28,10	6,65	58,67	0,46	22,86
30	5811	154	5657	19,87	20,21	4,89	44,45	0,32	18,01
45	4468	94	4374	11,95	10,86	2,80	26,30	0,16	11,40
60	2809	38	2771	5,13	3,87	1,14	10,63	0,05	5,03
80	677	2	675	0,62	0,44	0,14	1,00	< 0,01	0,44
Total Column Ozone 380 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6932	192	6740	24,96	25,85	6,21	55,96	0,41	22,41
15	6635	177	6458	22,88	23,26	5,63	51,22	0,36	20,77
30	5778	137	5641	17,39	16,65	4,16	38,67	0,25	16,29
45	4441	82	4359	10,49	8,92	2,40	22,75	0,12	10,22
60	2793	33	2760	4,54	3,25	1,00	9,16	0,04	4,43
80	673	2	671	0,57	0,41	0,13	0,88	< 0,01	0,36
Total Column Ozone 420 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	6896	173	6723	22,13	21,73	5,35	49,40	0,33	20,50
15	6602	160	6442	20,29	19,53	4,86	45,17	0,29	18,97
30	5747	122	5625	15,44	13,95	3,60	34,00	0,20	14,81
45	4419	73	4346	9,35	7,49	2,10	19,93	0,10	9,21
60	2778	28	2750	4,09	2,81	0,89	8,01	0,03	3,92
80	668	1	667	0,53	0,39	0,13	0,78	< 0,01	0,30

See page 7 for explanation of column headers.

Table 3. Solar Spectral Irradiances Weighted to Photobiological Action Spectra Altitude 2 km, Clear atmosphere, minimal albedo, low aerosol turbidity.

Total Column Ozone 220 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7424	331	7093	52,38	65,63	15,38	112,59	1,50	37,11
15	7116	309	6807	48,09	59,87	13,97	103,94	1,33	34,65
30	6221	247	5974	36,70	44,56	10,32	80,52	0,91	27,85
45	4826	161	4665	22,17	25,22	5,87	49,48	0,45	18,36
60	3081	73	3008	9,42	9,18	2,27	20,95	0,14	8,71
80	760	6	754	1,02	0,73	0,23	1,94	0,01	0,92
Total Column Ozone 260 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7364	291	7073	42,86	51,78	11,97	94,34	1,04	32,86
15	7059	271	6788	39,33	47,04	10,87	86,90	0,92	30,64
30	6170	215	5955	29,99	34,59	8,02	66,86	0,63	24,51
45	4786	138	4648	18,11	19,18	4,56	40,60	0,31	15,99
60	3055	61	2994	7,73	6,84	1,79	16,91	0,10	7,44
80	753	5	748	0,87	0,60	0,20	1,56	0,01	0,73
Total Column Ozone 300 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7312	259	7053	36,03	41,62	9,64	80,38	0,76	29,44
15	7008	240	6768	33,06	37,69	8,75	73,90	0,67	27,41
30	6126	189	5937	25,20	27,44	6,46	56,55	0,46	21,82
45	4751	119	4632	15,24	15,00	3,69	34,01	0,23	14,09
60	3032	51	2981	6,55	5,32	1,48	14,01	0,07	6,43
80	746	3	743	0,76	0,53	0,17	1,30	< 0,01	0,59
Total Column Ozone 340 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7265	231	7034	30,94	34,01	7,97	69,43	0,57	26,60
15	6964	214	6750	28,39	30,71	7,24	63,74	0,51	24,73
30	6087	168	5919	21,65	22,20	5,35	48,55	0,35	19,59
45	4720	104	4616	13,12	12,02	3,08	28,99	0,17	12,53
60	3012	43	2969	5,68	4,31	1,26	11,85	0,05	5,61
80	741	3	738	0,68	0,48	0,16	1,11	< 0,01	0,49
Total Column Ozone 380 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7224	208	7016	27,02	28,20	6,74	60,67	0,45	24,20
15	6924	192	6732	24,80	25,42	6,13	55,63	0,40	22,46
30	6051	149	5902	18,93	18,27	4,54	42,21	0,27	17,72
45	4692	91	4601	11,51	9,86	2,63	25,06	0,14	11,23
60	2993	36	2957	5,03	3,60	1,10	10,20	0,04	4,94
80	736	2	734	0,62	0,45	0,15	0,97	< 0,01	0,40
Total Column Ozone 420 DU									
Z	E_{solar}	E_{UVB}	E_{UVA}	$E_{erythema}$	E_{anders}	$E_{actinic\ UVR}$	$E_{photocarcino}$	$E_{DNA\ damage}$	E_{CHS}
0	7186	188	6998	23,93	23,69	5,81	53,55	0,36	22,13
15	6887	173	6714	21,97	21,33	5,28	49,05	0,32	20,52
30	6018	133	5885	16,79	15,29	3,93	37,10	0,22	16,11
45	4666	80	4586	10,24	8,27	2,30	21,94	0,11	10,13
60	2976	31	2945	4,52	3,11	0,99	8,91	0,03	4,37
80	732	2	730	0,58	0,43	0,14	0,86	< 0,01	0,34

See page 7 for explanation of column headers.

9. REFERENCES

ACGIH (2001). *Threshold Limit Values and Biological Exposure Indices*, Publication #0101, ACGIH, Cincinnati, OH, USA.

ANDERS, A., AUFMUTH, P., BÖTTGER, E.-M., TRONNIER, H. (1984). Investigation of the erythema effectiveness curve with tunable lasers. *Dermatosen,* **32,** 166-170.

ANDERS, A., ALTHEIDE, H.-J., KNÄLMANN, M., TRONNIER, H. (1995). Action spectrum for erythema in humans investigated with dye lasers. *Photochem. Photobiol.,* **61**, 200-205.

BACHEM, A. (1956). Ophthalmic ultraviolet action spectra. *Am. J. Ophthalmol.,* **41**, 969-975.

BAIS, A.F., ZEREFOS, C.S., MELETI, C., ZIOMASS, I.C., TOURPALI, K. (1993). Spectral measurements of solar UVB radiation and its relation to total ozone, SO_2, and cloud. *J. Geophys. Res.,* **98**, 5199-5204.

BERGER, D. (1976). The sunburning ultraviolet meter: Design and performance. *Photochem. Photobiol.,* **24**, 587-593.

BIRD, R.E., HULSTROM, R.L., LEWIS, L.J. (1983). Terrestrial solar spectral data sets. *Solar Energy,* **30**, 563-573.

BIRD, R.E., RIORDAN, C. (1986). Simple solar spectral model for direct and diffuse irradiance on horizontal and tilted planes at the Earth’s surface for cloudless atmosphere. *J. Climate Appl. Meteorol.,* **25**, 87-97.

BLUM, H. (1959). *Carcinogenesis by Ultraviolet Light.* Princeton University Press, Princeton, NJ, USA.

BLUMTHALER, M. (1987). On the threshold radiant exposure for keratitis solaris. *Invest. Ophthalmol. Vis. Sci.,* **28**, 1713-1716.

BLUMTHALER, M., AMBACH, W. (1987). Share of erythema dose of solar radiation in high mountains. In: *Human Exposure to Ultraviolet Radiation: Risks and Regulations* (edited by W.F. Passchier and B.F.M. Bosnjakovic), Elsevier Science Publishers Biomedical Division, Amsterdam, The Netherlands.

BLUMTHALER, M., AMBACH, W. (1988). Solar UVB-albedo of various surfaces. *Photochem. Photobiol.,* **48(1)**, 85-88.

BLUMTHALER, M., WEBB, A.R., SECKMEYER, G., BAIS, A.F., HUBER, M. MAYER, B. (1994). Simultaneous spectroradiometry: A study of solar UV irradiance at two altitudes. *Geophys. Res. Lett.,* **21(25)**, 2805 - 2808.

BLUMTHALER, M., AMBACH, W., ELLINGER, R. (1997). Increase in solar UV radiation with altitude. *J. Photochem. Photobiol.,* **39(2)**, 130-134.

BURROWS, W.R., VALLEE, M., WARDLE, D.I., KERR, J.B., WILSON, L.J., TARASICK, D.W. (1994). The Canadian operational procedure for forecasting total ozone and UV radiation. *Met. Apps.,* **1**, 247-265.

BUTTOLPH, L.J. (1955). Practical application and sources of ultraviolet energy, Chapter 2. In: *Radiation Biology, Vol. II, Ultraviolet and Related Radiations* (edited by A. Hollaender), McGraw-Hill, New York, 41-93.

BUTTOLPH, L.J., HAYNES, H. (1953). *Ultraviolet Air Sanitation.* General Electric Lamp Division, Cleveland, Ohio.

CABRERA, S., BOZZO, S. FUNEZALIDA, H. (1995). Variations in UV radiation in Chile. *Journal of Photochemistry and Photobiology.* **28**, 137-142.

CESARINI, J.-P. (1987). Effects of ultraviolet radiations on the human skin: With emphasis on skin cancer. In: *Human Exposure to Ultraviolet Radiation: Risks and Regulations* (edited by W.F. Passchier and B.F.M. Bosnjakovic), Elsevier Science Publishers Biomedical Division, Amsterdam, The Netherlands.

CHARCOT, J.M. (1858). Erythéme produit par l’action de la lumière électrique. *Comptes Rendus Soc. Biol.,* **5**, 63-65.

CIE (1989). *Solar spectral irradiance*, CIE 85-1989.

CIE (1998a). *Measurements of Optical Radiation Hazards*. (edited by R. Matthes, D. Sliney, S. DiDomenico, P. Murray, R. Phillips, S. Wengraitis), CIE x016-1998 / ICNIRP 6/98.

CIE (1998b). *Erythema reference action spectrum and standard erythema dose*, CIE S007/E-1998.

CIE (1999). *Standardization of the terms UV-A1, UV-A2 and UV-B*, CIE 134/1-1999.

CIE (2000). *Action spectrum for photocarcinogenesis (non-melanoma skin cancers)*, CIE 138/2-2000.

COOHILL, T.P. (1998). Photobiological action spectra – what do they mean? In: *Measurements of Optical Radiation Hazards* (edited by R. Matthes, D. Sliney, S. DiDomenico, P. Murray, R. Phillips, S. Wengraitis), CIE x016-1998 / ICNIRP 6/98, 27-39.

DAVY, J. (1829). Observations on the effect of the sun's rays on the human body. *Trans. Med.-Chir. Soc. Edinburgh*, 256.

DE FABO, E.C., NOONAN, F.P. (1983). Mechanism of immune suppression by ultraviolet irradiation in vivo. Evidence for the existence of a unique photoreceptor in skin and its role in photoimmunology. *J. Exp. Med.,* **158**, 84-98.

DIFFEY, B.L. (1977). The calculation of the spectral distribution of natural ultraviolet radiation under clear day conditions. *Phys. Med. Biol.,* **22**, 309-316.

DOBSON, G.M.B. (1931). A photoelectric spectrophotometer for measuring the amount of atmospheric ozone. *Phys. Soc.,* **XLIII**(3), 324-339.

DODA, D.D., GREEN, A.E.S. (1981) Surface reflectance measurements in the ultraviolet from an airborne platform, Part 2. *Appl. Opt.,* **20**, 636-642.

FEISTER, U., GREWE, R. (1995). Spectral albedo measurements in the UV and visible region over different types of surfaces. *Photochem. Photobiol.,* **62(4)**, 736-744.

FINSEN, N.R. (1899). *Über die Bedeutung der Chemischen Strahlen des Lichtes für die Medizin und Biologie*. F.C.W. Vogel, Leipzig.

FINSEN, N.R. (1900). Neue Untersuchungen über die Einwirkung des Lichtes auf die Haut. *Mitt. Finsen. Institut.,* **1**, 8-12.

FISHER, M.S., KRIPKE, M.L. (1977). Systemic alteration induced in mice by ultraviolet light irradiation and its relationship to ultraviolet carcinogenesis. *Proc. Natl. Acad. Sci. USA,* **74**, 1688-1692.

FREDERICK, J. E., ERLICK, C. (1995). Trends and interannual variability in erythemal irradiance. *Photochem. Photobiol.*, **62**, 476-484.

GODAR, D.E., WENGRAITIS, S.P., SHREFFLER, J., SLINEY, D.H. (2001). UV doses of Americans. *Photochem. Photobiol.,* **73(6)**, 621-629.

GREEN, A.E.S., CROSS, K.R., SMITH, L.A. (1980). Improved analytic characterization of ultraviolet skylight. *Photochem. Photobiol.,* **31**, 59-65.

GRENFELL, T.C., WARREN, S.G., MULLEN, P.C. (1994). Reflection of solar radiation by the Antarctic snow surface at ultraviolet, visible, and near-infrared wavelengths. *J. Geophys. Res.,* **99(D9)**, 18669-18684.

GUEYMARD, C., (1995). *SMARTS2, a simple model of the atmospheric transfer of sunshine*. Florida Science Energy Center, Rep. FSEC-PF-270-95.

HOLICK, M.F. (1992). Vitamin D3 and sunlight: An intimate beneficial relationship. In: *The Biologic Effects of Light* (edited by M.F. Holick and A.M. Kligman), Walter de Gruyter, Berlin, 34-37.

HOME, E. (1820). On the black rete mucosum of the Negro, being a defense against the scorching effects of the sun's rays. *Philosophical Transactions of the Royal Society (London),* **111**, 1-7.

ICNIRP (1996). Guidelines on UV radiation exposure limits. *Health Phys.,* **71(6)**, 978.

INIRC/IRPA (1989). Proposed change to the IRPA 1985 guidelines on limits of exposure to ultraviolet radiation. *Health Phys.,* **56(6)**, 971-972.

INIRC/IRPA. (1991). Guidelines on limits of exposure to ultraviolet radiations of wavelengths between 180 nm and 400 nm. In: *IRPA guidelines on protection against non-ionizing radiations* (edited by A.S. Duchêne, J.R.A. Lakey, M.H. Repacholi). Oxford: Pergamon Press.

JUSTUS, C.G., MURPHY, B.B. (1994). Temporal trends in surface irradiance at ultraviolet wavelengths. *J. Geophys. Res.,* **99D1**, 1389-1394.

JUSTUS, C.G., PARIS, M.V. (1987). *Modeling solar spectral irradiance and radiance at the bottom and top of a cloudless atmosphere*. Internal Rep., School of Geophysical Science, Georgia Institute of Technology Atlanta, GA.

KOEPKE, P., BAIS, A., BALIS, D., BUCHWITZ, M., DE BACKER, H., DE CABO, X., ECKERT, P., ERIKSEN, P., GILLOTAY, D., HEIKKILÄ, A., KOSKELA, T., LAPETA, B., LITYNSKA, Z., LORENTE, J., MAYER, B., RENAUD, A., RUGGABER, A., SCHAUBERGER, G., SECKMEYER, G., SEIFERT, P., SCHMALWIESER, A., SCHWANDER, H., VANICEK, K., WEBER, M. (1998). Comparison of models used for UV Index calculations. *Photochem. Photobiol.,* **67(6)**, 657-662.

KOEPKE, P., REUDER, J., SCHWANDER, H. (2002) Review: Solar UV radiation and its variability due to atmospheric components. *Recent Res. Develop. Photochem. & Photobiol.*, in press.

KRIPKE, M.L. (1976). Target organ for a systemic effect of ultraviolet radiation. *Photochem. Photobiol.,* **24**, 599-600.

KRIPKE, M.L., LOFGREEN, J.S., BEARD, J., JESSUP, J.M., FISHER, M.S. (1977). In vivo immune responses of mice during carcinogenesis by ultraviolet irradiation. *J. Natl. Cancer Inst.,* **59**, 1227-1230.

KYLLING, A. (1994). UVSPEC, a program for calculation of diffuse and direct UV and visible fluxes and intensities at any altitude. Available by anonymous ftp to pluto.itek.norut.no, cd/pub/arve.

LEWY, A.J., SACK, R.L., MILLER, S., HOBAN, T.M. (1987). Antidepressant and circadian phase-shifting effects of light. *Science,* **235,** 352-354.

MADRONICH, S. (1993) UV radiation in the natural and perturbed atmosphere, In: *Environmental Effects of Ultraviolet Radiation* (edited by M. Tevini), Lewis Publishers, Boca Raton, FL, 17-69.

MCKINLAY, A.F., DIFFEY, B.L. (1987). A reference action spectrum for ultraviolet induced erythema in human skin. *CIE Journal* **6(1)**, 17-22.

PALTRIDGE G.W., BARTON, I.J. *Erythemal ultraviolet radiation distribution over Australia – the calculations, detailed results and input data*. Division of Atmospheric Physics Technical Paper 33, Australia: Commonwealth Scientific and Industrial Research Organisation, 1978.

PARIS, M.V., JUSTUS, C.G. (1988). A cloudy-sky radiative transfer model suitable for calibration of satellite sensors. *Remote Sensing of Environment,* **24**, 269-285.

PEAK, M.J., PEAK, J.G. (1982). Single strand breaks induced in Bacillus subtilis DNA by ultraviolet light: Action spectrum and properties. *Photochem. Photobiol.,* **35**, 675-680.

PEAK, M.J., PEAK, J.G., MOEHRING, M.P., WEBB, R.B. (1984). Ultraviolet action spectra for DNA dimer induction, lethality, and mutagenesis in Escherichia coli with emphasis on the UVB region. *Photochem. Photobiol.,* **40**, 613-620.

PITTS, D.G., CULLEN, A.P. (1977). *Ocular effects of ultraviolet radiation from 295 nm to 400 nm in the rabbit eye*. DHEW (NIOSH) Publication No. 77-175, Washington, DC, Department of Health Education and Welfare.

PITTS, D.G., CULLEN, A.P., HACKER, P.D. (1977). Ocular effects of ultraviolet radiation from 295 to 365 nm. *Invest. Ophthalmol. Vis. Sci.,* **16**, 932-939.

RENAUD, A., STAEHELIN, J., PHILIPONA, R., HEIMO, A. (1997). The influence of a cloud cover on erythemal UV radiation for low and high surface albedos. *Int. Summer School on Trop. Chem. a Space Obs.,* Riom, 17-27 July 1997.

ROFFO, A.H. (1933). Cáncer y sol. El desarrollo experimental de tumores espontáneos por las irradiaciones ultravioletas en relación con el heliotropismo de la colesterina. *Boll. Inst. de Med. Exe.r para el Estudio del Cáncer,* **10**, 417-439.

ROSENTHAL, N.E., SACK, D.A., SKWERER, R.G., JACOBSEN, F.M., WEHR, T.A., (1989) Phototherapy for seasonal affective disorder. In: *Seasonal Affective Disorders and Phototherapy* (edited by N.E. Rosenthal and M.C. Blehar), Guilford Press, New York, 273-294.

ROZANOV, V.V., DIEBEL, D., SPURR, R.J.D., BURROWS, J.P. (1997). GOMETRAN: a radiative transfer model for the satellite project GOME – the plane parallel version. *J. Geophys. Res.,* **102 (D14)**, 16683-16695.

SCHWANDER, H., MAYER, B., RUGGABER, A., ALBOLD, A., SECKMEYER, G., KOEPKE, P. (1999). Method to determine snow albedo values in the ultraviolet for radiative transfer modeling. *Appl. Opt.,* **38**, 3869-3875.

SCHWANDER, H., KAIFEL, A., RUGGABER, A., KOEPKE, P. (2001). Spectral radiative-transfer modeling with minimized computation time by use of a neural-network technique. *Appl. Opt.,* **40**, 331-335.

SETLOW, R.B. (1974). The wavelengths in sunlight effective in producing skin cancer: a theoretical analysis. *Proc. Nat. Acad. Sci.,* **71**, 3363-3366.

SLINEY, D.H. (1995). UV radiation ocular exposure dosimetry. *J. Photochem. Photobiol. B:Biology*, **31**, 69-77.

SLINEY, D.H., WOLBARSHT, M.L. (1980). *Safety of Lasers and Other Optical Radiation Sources*, Plenum Publishers, New York.

SLUSSER, J., GIBSON, J., BIGELOW, D., KOLINSKI, D., MOU, W., KOENIG, G., BEAUBIEN, A. (1999). Comparison of column ozone retrievals by use of an UV multifilter rotating shadow-band radiometer with those from Brewer and Dobson spectrophotometers. *Appl. Opt.,* **38(9)**, 1543-1551.

STAMNES, K.S., TSAY, S.C., WISCOMBE, W., JAYAWEERA, K. (1988). Numerically stable algorithm for discrete ordinate method radiative transfer in multiple scattering and emitting layered media. *Appl. Opt.,* **27**, 2502-2509.

URBACH, F. (1998). Ultraviolet action spectrum for erythema – history. In: *Measurements of Optical Radiation Hazards*. (edited by R. Matthes, D. Sliney, S. DiDomenico, P. Murray, R. Phillips, S. Wengraitis), CIE x016-1998 / ICNIRP 6/98, 51-62.

USEPA Brewer spectrophotometer UV monitoring network, http://www.epa.gov/uv-net/.

WEBB, A.R. (1997). Changes in stratospheric ozone concentrations and solar UV levels. *Radiation Protection Dosimetry,* **72(3-4)**, 207-216.

WEBB, A.R. AND HOLICK, M. F., (1988). The role of sunlight in the cutaneous production of vitamin D. Chapter 18 in *Annual Review of Nutrition* (edited by R.E. Olson), Annual Reviews Inc., 375-460.

WEIHS, P., WEBB, A.R. (1996). Comparison of Green and Lowtran radiation schemes with a discrete ordinate method UV model. *Photochem. Photobiol.,* **64(4)**, 642-648.

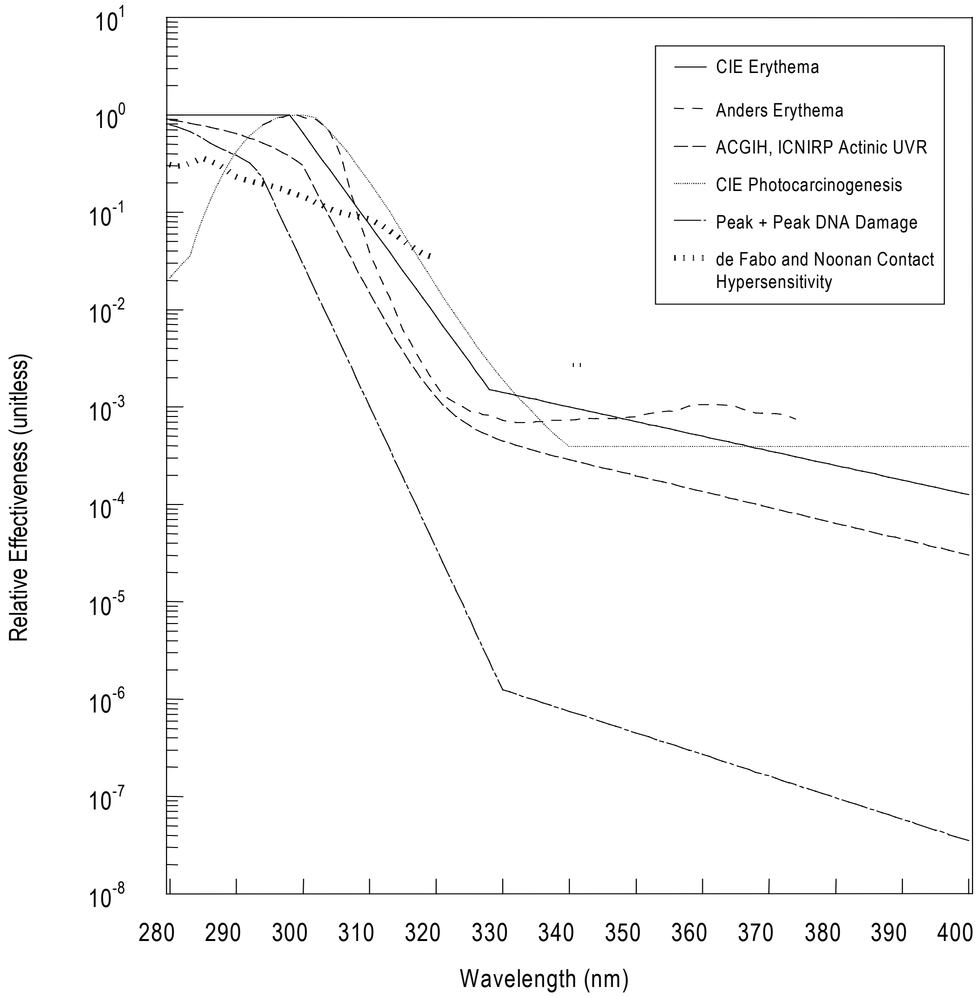
WESTER, U. (2000a). Analytic expressions to represent the ultraviolet action spectrum of ICNIRP and ACGIH. *Radiation Protection Dosimetry,* **91(1-3)**, 231-232.

WESTER, U. (2000b). Measurements of solar UVA, UVB, and of ozone: Estimates of population ultraviolet doses. *Radiation Protection Dosimetry,* **91(1-3)**, 115-118.

WIDMARK, E.J. (1889). Über den Einfluss des Lichtes auf die Haut. *Hygiena-Festband* **3**, 1-23.

ZUCLICH, J.A. (1989). Ultraviolet-induced photochemical damage in ocular tissues. *Health Physics,* **56(5)**, 671-682.

APPENDIX A – GRAPHICAL REPRESENTATION OF THE ACTION SPECTRA USED IN THIS REPORT FROM 280-400 NM.



Note: The action spectra for contact hypersensitivity, DNA damage and the Anders erythema action spectrum were generated from data and close visual inspection of Figure graphics from the technical reference.

For all action spectra, curve fittings and data interpolations were performed to provide the action spectra at 1 nm intervals.

APPENDIX B – ACTION SPECTRA USED IN THIS REPORT

The action spectra for contact hypersensitivity, DNA damage and the Anders erythema action spectrum were generated from data and close visual inspection of Figure graphics from the technical reference. For all action spectra, curve fittings and data interpolations were performed to provide the action spectra at 1 nm intervals.

The solar spectral irradiance reaching the ground approaches zero near 280 nm. The shorter-wavelength data are included for technical correctness only.

Important comments regarding the boundaries and features of these action spectra are included at the end of Section 4, “Basis of the Data Tables In This Report.”

Wavelength nm	Action Spectrum (unitless)					
	CIE Erythema[1]	Erythema Measured with Lasers[2]	ACGIH, ICNIRP Actinic UVR[3]	CIE Photocarci nogenesis[4]	DNA Lethality, Mutagenesis, and Pyrmidine Dimer Formation[5]	Contact Hypersensi-tivity[6]
1. CIE, 1998b., 2. Anders et. al., 1995., 3. ACGIH, 2001; Wester, 2000; ICNIRP, 1996., 4. CIE, 2000., 5. Peak et. al., 1984., 6. De Fabo and Noonan, 1983.						
180			0,012			
190			0,019			
200			0,03			
205			0,051			
210			0,075			
215			0,095			
220			0,12			
225			0,15			
230			0,19			
235			0,24			
240			0,3			
245			0,36			
250	1		0,432884607	0,0190		0,5864198
251	1		0,451391666	0,011139		0,6111571
252	1		0,470689954	0,011383		0,6383916
253	1		0,490813299	0,011633		0,6674991
254	1		0,511796975	0,011888	1	0,6978554
255	1		0,533677763	0,012158	1	0,728836
256	1		0,556494018	0,012435	1	0,7598165
257	1		0,580285733	0,012718	1	0,7901728
258	1		0,605094612	0,013007	1	0,8192803
259	1		0,630964142	0,013303	1	0,8465149
260	1		0,657939669	0,013605	1	0,8712522
261	1		0,686068476	0,013915	1	0,887873
262	1		0,715399871	0,014231	1	0,9019964
263	1		0,745985267	0,014555	1	0,9142469
264	1		0,777878276	0,014886	1	0,9252486
265	1		0,811134803	0,015225	1	0,9356261
266	1		0,845813142	0,015571	1	0,9556366
267	1		0,881974079	0,015925	1	0,9738631
268	1		0,919681	0,016287	1	0,9885218
269	1		0,959	0,016658	1	0,9978287
270	1		1	0,017037	1	1
271	1		0,997353857	0,017424	1	0,9908735
272	1		0,991752876	0,017821	0,9859374	0,9716381
273	1		0,983964143	0,018226	0,96128	0,9411045
274	1		0,974296534	0,018641	0,9356186	0,8980832
275	1		0,962938404	0,019065	0,915625	0,8413848
276	1		0,950021714	0,019498	0,8968442	0,7345581
277	1		0,935646215	0,019942	0,87679	0,6204913
278	1		0,919891078	0,020395	0,8503125	0,5068103
279	1		0,902821314	0,020859	0,8219157	0,4011416
280	1		0,884491669	0,021334	0,7903249	0,3111111
281	1		0,864949153	0,025368	0,7559654	0,2992536
282	1		0,844234759	0,030166	0,7183519	0,3045597
283	1		0,822384687	0,035871	0,67391	0,3209283
284	1		0,799431241	0,057388	0,6239982	0,3422587
285	1		0,775403506	0,088044	0,5705563	0,3624498
286	1		0,750327862	0,12967	0,5183789	0,3424472
287	1		0,7242284	0,183618	0,47692	0,317342
288	1		0,697127239	0,250586	0,4414112	0,2892714

Wavelength nm	Action Spectrum (unitless)					
	CIE Erythema[1]	Erythema Measured with Lasers[2]	ACGIH, ICNIRP Actinic UVR[3]	CIE Photocarci nogenesis[4]	DNA Lethality, Mutagenesis, and Pyrmidine Dimer Formation[5]	Contact Hypersensi-tivity[6]
1. CIE, 1998b., 2. Anders et. al., 1995., 3. ACGIH, 2001; Wester, 2000; ICNIRP, 1996., 4. CIE, 2000., 5. Peak et. al., 1984., 6. De Fabo and Noonan, 1983.						
289	1		0,669044797	0,330048	0,4112256	0,2603729
290	1		0,64	0,420338	0,3824735	0,2327841
291	1		0,610010467	0,514138	0,3524439	0,2199488
292	1		0,579092655	0,609954	0,3180664	0,2098714
293	1		0,547261989	0,70314	0,273136	0,2018626
294	1	0,7984314	0,514532966	0,788659	0,2212195	0,1952333
295	1	0,8495844	0,480919252	0,861948	0,1567389	0,1892942
296	1	0,9501582	0,446433757	0,91965	0,11215875	0,1806002
297	1	0,9472074	0,411088709	0,958965	0,080204152	0,1719071
298	1	0,9967346	0,37489571	0,988917	0,057353581	0,1632146
299	0,8053784	0,9967346	0,337865794	1	0,041013254	0,1545225
300	0,6486344	0,9501582	0,300009468	0,991996	0,029328369	0,1458306
301	0,5223962	0,9023692	0,222040795	0,96766	0,020972568	0,1362825
302	0,4207266	0,9023692	0,163703888	0,929095	0,014997376	0,1269462
303	0,3388442	0,7870458	0,120757542	0,79841	0,010724548	0,1180416
304	0,2728978	0,659	0,089139031	0,677339	0,007669069	0,1097766
305	0,219786	0,5041335	0,065858175	0,567466	0,005484113	0,1023671
306	0,1770109	0,32	0,048714187	0,470257	0,003921661	0,09827311
307	0,1425608	0,18	0,036087277	0,385911	0,00280436	0,09490076
308	0,1148154	0,1047129	0,026785265	0,313889	0,002005383	0,09190231
309	0,0924698	0,0645654	0,019930695	0,253391	0,001434039	0,08893002
310	0,0744732	0,0391027	0,014877747	0,203182	0,001025474	0,08563622
311	0,0599791	0,0269153	0,011151088	0,162032	0,000733311	0,07921156
312	0,0483059	0,0186209	0,00840086	0,128671	0,000524387	0,07238538
313	0,0389045	0,0134896	0,006369559	0,101794	0,000374987	0,06542534
314	0,0313329	0,0093541	0,00486765	0,079247	0,000268151	0,05859914
315	0,0252348	0,0062373	0,003755627	0,061659	0,000191753	0,05217449
316	0,0203236	0,0047863	0,002930804	0,047902	0,000137122	0,04641907
317	0,0163682	0,0035727	0,002317595	0,037223	9,80552E-05	0,04160059
318	0,0131826	0,0027797	0,001860361	0,028934	7,01188E-05	0,03798672
319	0,010617	0,0021184	0,00151814	0,022529	5,01416E-05	0,03584517
320	0,0085507	0,0016758	0,001260781	0,017584	0,000035856	0,03544363
321	0,0068865	0,001349	0,001066081	0,013758	2,56404E-05	
322	0,0055463	0,0012023	0,000917693	0,010804	1,83353E-05	
323	0,0044668	0,0010965	0,000803578	0,008525	1,31115E-05	
324	0,0035975	0,001	0,000714868	0,006756	9,37597E-06	
325	0,0028973	0,000912	0,000645031	0,005385	6,70471E-06	
326	0,0023335	0,0008913	0,000589252	0,004316	4,79451E-06	
327	0,0018793	0,0008318	0,00054398	0,003483	3,42853E-06	
328	0,0015136	0,0008128	0,000506597	0,00283	2,45172E-06	
329	0,0014622	0,0007816	0,00047517	0,002316	1,75321E-06	
330	0,0014125	0,0007297	0,000448271	0,001911	1,25371E-06	
331	0,0013646	0,0007079	0,000424843	0,00159	1,18748E-06	
332	0,0013183	0,0006918	0,000404104	0,001333	1,12834E-06	
333	0,0012735	0,0006918	0,000385472	0,001129	1,07216E-06	
334	0,0012303	0,0006918	0,000368516	0,000964	1,01877E-06	
335	0,0011885	0,0007079	0,000352912	0,00081	9,68034E-07	
336	0,0011482	0,0007079	0,000338419	0,000688	9,19826E-07	
337	0,0011092	0,0007262	0,000324853	0,000589	8,74023E-07	
338	0,0010715	0,0007262	0,000312078	0,00051	8,30499E-07	
339	0,0010351	0,0007297	0,000299987	0,000446	9,89142E-07	

Wavelength nm	Action Spectrum (unitless)					
	CIE Erythema[1]	Erythema Measured with Lasers[2]	ACGIH, ICNIRP Actinic UVR[3]	CIE Photocarci nogenesis[4]	DNA Lethality, Mutagenesis, and Pyrmidine Dimer Formation[5]	Contact Hypersensi-tivity[6]
1. CIE, 1998b., 2. Anders et. al., 1995., 3. ACGIH, 2001; Wester, 2000; ICNIRP, 1996., 4. CIE, 2000., 5. Peak et. al., 1984., 6. De Fabo and Noonan, 1983.						
340	0,001	0,000735	0,000288498	0,000394	7,49845E-07	
341	0,0009661	0,0007439	0,000277548	0,000394	7,12505E-07	
342	0,0009333	0,000752	0,000267087	0,000394	6,77024E-07	
343	0,0009016	0,0007594	0,000257074	0,000394	6,4331E-07	
344	0,000871	0,0007663	0,000247475	0,000394	6,11275E-07	
345	0,0008414	0,0007643	0,000238264	0,000394	5,80835E-07	
346	0,0008128	0,0007634	0,000229418	0,000394	5,51911E-07	
347	0,0007852	0,0007625	0,000220916	0,000394	5,24427E-07	
348	0,0007586	0,0007692	0,00021274	0,000394	4,98312E-07	
349	0,0007328	0,000785	0,000204876	0,000394	4,73498E-07	
350	0,0007079	0,0008005	0,000197308	0,000394	4,49919E-07	
351	0,0006839	0,000831	0,000190025	0,000394	4,27514E-07	
352	0,0006607	0,000857	0,000183014	0,000394	4,06225E-07	
353	0,0006383	0,0008764	0,000176265	0,000394	3,85996E-07	
354	0,0006166	0,00089	0,000169766	0,000394	3,66774E-07	
355	0,0005957	0,000906	0,000163508	0,000394	3,4851E-07	
356	0,0005754	0,0009299	0,000157481	0,000394	3,31156E-07	
357	0,0005559	0,0009683	0,000151678	0,000394	3,14664E-07	
358	0,000537	0,0010179	0,000146089	0,000394	2,98995E-07	
359	0,0005188	0,0010627	0,000140706	0,000394	2,84106E-07	
360	0,0005012	0,0010637	0,000135522	0,000394	2,69958E-07	
361	0,0004842	0,001064	0,000130529	0,000394	2,56515E-07	
362	0,0004677	0,0010627	0,00012572	0,000394	2,43741E-07	
363	0,0004519	0,001052	0,000121089	0,000394	2,31603E-07	
364	0,0004365	0,001033	0,000116628	0,000394	2,2007E-07	
365	0,0004217	0,0010133	0,000112332	0,000394	2,09111E-07	
366	0,0004074	0,000957	0,000108194	0,000394	1,98698E-07	
367	0,0003936	0,0009	0,000104208	0,000394	1,88804E-07	
368	0,0003802	0,000864	0,000100369	0,000394	1,79402E-07	
369	0,0003673	0,0008622	9,6672E-05	0,000394	1,70468E-07	
370	0,0003548	0,0008608	9,31109E-05	0,000394	1,61979E-07	
371	0,0003428	0,0008592	8,9681E-05	0,000394	1,53913E-07	
372	0,0003311	0,000833	8,63775E-05	0,000394	1,46248E-07	
373	0,0003199	0,0007925	8,31956E-05	0,000394	1,38966E-07	
374	0,000309	0,0007494	8,01309E-05	0,000394	1,32046E-07	
375	0,0002985		7,71792E-05	0,000394	1,2547E-07	
376	0,0002884		7,43362E-05	0,000394	1,19222E-07	
377	0,0002786		7,15979E-05	0,000394	1,13285E-07	
378	0,0002692		6,89604E-05	0,000394	1,07644E-07	
379	0,00026		6,64202E-05	0,000394	1,02283E-07	
380	0,0002512		6,39735E-05	0,000394	9,71899E-08	
381	0,0002427		6,16169E-05	0,000394	9,23501E-08	
382	0,0002344		5,93472E-05	0,000394	8,77513E-08	
383	0,0002265		5,7161E-05	0,000394	8,33815E-08	
384	0,0002188		5,50554E-05	0,000394	7,92294E-08	
385	0,0002113		5,30274E-05	0,000394	7,52839E-08	
386	0,0002042		5,1074E-05	0,000394	7,1535E-08	
387	0,0001972		4,91926E-05	0,000394	6,79727E-08	
388	0,0001905		4,73805E-05	0,000394	6,45879E-08	
389	0,0001841		4,56352E-05	0,000394	6,13716E-08	
390	0,0001778		4,39542E-05	0,000394	5,83154E-08	

Wavelength nm	Action Spectrum (unitless)					
	CIE Erythema[1]	Erythema Measured with Lasers[2]	ACGIH, ICNIRP Actinic UVR[3]	CIE Photocarci nogenesis[4]	DNA Lethality, Mutagenesis, and Pyrmidine Dimer Formation[5]	Contact Hypersensi-tivity[6]
1. CIE, 1998b., 2. Anders et. al., 1995., 3. ACGIH, 2001; Wester, 2000; ICNIRP, 1996., 4. CIE, 2000., 5. Peak et. al., 1984., 6. De Fabo and Noonan, 1983.						
391	0,0001718		4,2335E-05	0,000394	5,54115E-08	
392	0,000166		4,07756E-05	0,000394	5,26521E-08	
393	0,0001603		3,92735E-05	0,000394	5,00302E-08	
394	0,0001549		3,78268E-05	0,000394	4,75388E-08	
395	0,0001496		3,64334E-05	0,000394	4,51715E-08	
396	0,0001445		3,50913E-05	0,000394	4,29221E-08	
397	0,0001396		3,37987E-05	0,000394	4,07847E-08	
398	0,0001349		3,25537E-05	0,000394	3,87537E-08	
399	0,0001303		3,13545E-05	0,000394	3,68239E-08	
400	0,0001259		3,01995E-05	0,000394	3,49902E-08	

1. CIE, 1998b., 2. Anders et. al., 1995., 3. ACGIH, 2001; Wester, 2000; ICNIRP, 1996., 4. CIE, 2000., 5. Peak et. al., 1984., 6. De Fabo and Noonan, 1983.

APPENDIX C – BRIEF LIST OF MODELS THAT HAVE BEEN USED FOR CALCULATING SOLAR UVR EXPOSURE.

Note: This is not an all-inclusive list, and many of these models have been modified by the use of a variety of meteorological input parameters (Koepke et al., 1998).

Bird's Model: BIRD, R.E., HULSTROM, R.L., LEWIS, L.J. (1983). Terrestrial solar spectral data sets. *Solar Energy,* **30**, 563-573.

Canadian Empirical Model: BURROWS, W.R., VALLEE, M., WARDLE, D.I., KERR, J.B., WILSON, L.J., TARASICK, D.W. (1994). The Canadian operational procedure for forecasting total ozone and UV radiation. *Met. Apps.,* **1**, 247-265.

Diffey's Model: DIFFEY, B.L. (1977). The calculation of the spectral distribution of natural ultraviolet radiation under clear day conditions. *Phys. Med. Biol.,* **22**, 309-316.

DISORT: STAMNES, K., TSAY, S.-C., WISCOMBE, W., JAYAWEERA, K. (1988). Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media. *Appl. Opt.,* **27**, 2502-2509.

Eddington Approximation Model: FREDERICK, J. E., ERLICK, C. (1995). Trends and interannual variability in erythemal irradiance. *Photochem. Photobiol.*, **62**, 476-484.

GOMETRAN: ROZANOV, V.V., DIEBEL, D., SPURR, R.J.D., BURROWS, J.P. (1997). GOMETRAN: a radiative transfer model for the satellite project GOME – the plane parallel version. *J. Geophys. Res.,* **102 (D14)**, 16683-16695.

Green's Model: GREEN, A.E.S., CROSS, K.R., SMITH, L.A. (1980). Improved analytic characterization of ultraviolet skylight. *Photochem. Photobiol.,* **31**, 59-65.

Justus' and Paris' Model: JUSTUS, C.G., PARIS, M.V. (1987). *Modeling solar spectral irradiance and radiance at the bottom and top of a cloudless atmosphere*. Internal. Rep., School of Geophysical Science, Georgia Institute of Technology, Atlanta, GA.

SMARTS2: GUEYMARD, C., (1995). *SMARTS2, a simple model of the atmospheric transfer of sunshine*. Florida Science Energy Center, Rep. FSEC-PF-270-95.

SPCTRAL2: BIRD, R.E., RIORDAN, C. (1986). Simple solar spectral model for direct and diffuse irradiance on horizontal and tilted planes at the Earth's surface for cloudless atmosphere. *J. Climate Appl. Meteorol.,* **25**, 87-97.

STAR: SCHWANDER, H., KAIFEL, A., RUGGABER, A., KOEPKE, P. (2001). Spectral radiative-transfer modeling with minimized computation time by use of a neural-network technique. *Appl. Opt.,* **40**, 331-335.

Swiss Empirical Model: RENAUD, A., STAEHELIN, J., PHILIPONA, R., HEIMO, A. (1997). The influence of a cloud cover on erythemal UV radiation for low and high surface albedos. *Int. Summer School on Trop. Chem. a Space Obs.,* Riom, Switzerland, 17-27 July 1997.

TUV: MADRONICH, S. (1993) UV radiation in the natural and perturbed atmosphere In: *Environmental Effects of Ultraviolet Radiation* (edited by M. Tevini), Lewis Publishers, Boca Raton, FL, 17-69.

UVSPEC: KYLLING, A. (1994). UVSPEC, a program for calculation of diffuse and direct UV and visible fluxes and intensities at any altitude. Available by anonymous ftp to pluto.itek.norut.no, cd/pub/arve.

APPENDIX D. ALBEDO PROPERTIES OF VARIOUS SURFACES

Partial listing of data from Table 3 “Spectral albedo measured over different surfaces” from the following reference: Feister, U., Grewe, R. (1995). Spectral albedo measurements in the UV and visible region over different types of surfaces. *Photochem Photobiol* 62(4), 736-744. (Reproduced with the kind permission of Photochemistry & Photobiology.)

Wave-length (nm)	Dry loamy soil, incl. clay, silt, sand	Short-cut lawn (dry soil visible)	Green pasture grass (0,2 m)	Wet concrete	Dry concrete	Sand	Snow, 2 cm	Snow, 5 cm
290	0,039	0,021	0,016	0,072	0,095	0,126	0,615	0,755
300	0,041	0,023	0,016	0,077	0,096	0,138	0,623	0,764
310	0,044	0,024	0,017	0,078	0,098	0,148	0,629	0,765
320	0,048	0,026	0,017	0,083	0,105	0,160	0,632	0,769
330	0,052	0,027	0,017	0,087	0,110	0,171	0,640	0,775
340	0,055	0,029	0,018	0,092	0,118	0,182	0,645	0,785
350	0,058	0,031	0,018	0,097	0,123	0,193	0,656	0,791
360	0,062	0,032	0,018	0,101	0,131	0,200	0,661	0,796
370	0,066	0,033	0,019	0,105	0,136	0,209	0,665	0,802
380	0,070	0,035	0,019	0,110	0,141	0,221	0,669	0,807
390	0,075	0,037	0,020	0,117	0,150	0,229	0,670	0,810
400	0,080	0,039	0,022	0,127	0,161	0,239	0,672	0,818

Table 1 “Mean values of the albedo for total solar radiation and erythemic range of solar radiation and number of sites of measurement for different types of surfaces” from the following reference: Blumthaler, M., Ambach, W. (1988). Solar UVB-albedo of various surfaces. *Photochem Photobiol* 48(1), 85-88. (Reproduced with the kind permission of Photochemistry & Photobiology.)

	Number of sites of measurement	Mean values (%)		Remarks
		a_T	a_{er}	
Glacier Ice	4	10,5	7,8	Very dirty
Water	15	9,1	4,8	Clear waters, bog-lake, river
Field, land	5	11,5	2,2	Varying moisture
Asphalt	12	10,6	5,5	Differently worn
Primitive rock	7	14,4	3,7	Different size, partly overgrown by lichens
Tennis court	3	17,6	2,9	Polyuretan, differently worn
Stream sand	8	23,8	9,1	Sedimentation on embankment
Alpine pasture	5	22,5	4,9	Transversed by limestone
Grassland, corn	40	20,7	1,3	Varying heights
Limestone	15	26,2	11,2	Rock debris of different size
New dry snow	7	87,0	94,4	High mountain area
New wet snow	21	74,5	79,2	High mountain area, varyingly dirty
Old dry snow	9	79,2	82,2	High mountain area, varyingly dirty
Old wet snow	40	72,4	74,4	High mountain area, varyingly dirty

APPENDIX E – AVERAGE DAILY ERYTHEMAL DOSES, CALCULATED FROM SEASONAL ERYTHEMAL DOSES MEASURED AT VARIOUS LOCATIONS IN THE UNITED STATES

Partial listing of Table 3 "Terrestrial, erythemally-weighted solar UV seasonal doses (J/m^2) for the continental United States" from the following reference:
Godar, D.E., Wengraitis, S.P., Shreffler, J., Sliney, D.H. (2001). UV doses of Americans. *Photochem Photobiol,* **73(6)**, 621-629. (Reproduced with the kind permission of Photochemistry & Photobiology.)

		Monitoring Site			
		Boston, MA[1]	Bozeman, MT[2]	Atlanta, GA[3]	Riverside, CA[4]
Season	Fall	103,602	90,736	148,961	191,736
	Winter	44,240	46,159	84,160	102,204
	Spring	170,559	188,554	244,546	281,161
	Summer	272,113	322,567	296,436	392,825

Average Daily Erythemal Doses (J/m^2) During Each Season, Calculated From Data in the Above Table (assumes 1 season = 92 days):

		Monitoring Site			
		Boston, MA[1]	Bozeman, MT[2]	Atlanta, GA[3]	Riverside, CA[4]
Season	Fall	1,126	986	1,619	2,084
	Winter	481	502	915	1,111
	Spring	1,854	2,050	2,658	3,056
	Summer	2,958	3,506	3,222	4,270

1. Latitude 42,37°, longitude 71,03°, altitude 9 m.
2. Latitude 45,78°, longitude 111,15°, altitude 1360 m.
3. Latitude 33,65°, longitude 84,43°, altitude 315 m.
4. Latitude 33,93°, longitude 118,4°, altitude 32 m.

APPENDIX F – ADDITIONAL PARAMETERS FOR THE STAR MODEL USED IN THIS REPORT

Extraterrestrial solar irradiance: Atlas 3 (Van Hoosier, 1996).
Earth – Sun distance: 1,0 astronomical unit.
Vertical profiles of ozone, temperature, air density: mid latitude summer (U.S. Standard Atmosphere, 1976).
Vertical profile of humidity: mid latitude summer, with relative humidity fixed to 70 % in the boundary layer (U.S. Standard Atmosphere, 1976).
Absorption cross sections of O_3: interpolated for pressure and temperature after Burrows et al., 1999.
Aerosols:
Optical depth (AOD) : 0,1 at 550 nm. (clear-atmosphere conditions)
Vertical profile:
- above 12 km: stratospheric background (Shettle, 1989)
- 3 km to 12 km: tropospheric background (Hess et al., 1998)
- 0 km to 3 km: continental average (Hess et al., 1998)

Spectral behaviour: The spectral dependency of all aerosol properties relevant for radiation processes is taken into account, based on the aerosol types and the relative humidity, after Hess et al., (1998)

Example extinction coefficients σ_e at different altitudes in the boundary layer for two wavelengths are given below:

altitude	σ_e km^{-1} at 300 nm	σ_e km^{-1} at 400 nm
0 km	0,079	0,059
1 km	0,049	0,037
2 km	0,014	0,010

The absorption properties of the aerosol in the boundary layer does not change with altitude, if it is described with help of the single scattering albedo SSA. Examples for the spectral behaviour are: SSA at 300 nm: 0,913; SSA at 400 nm: 0,919

Surface albedo: 0,02, independent of wavelength (low albedo representing vegetated surfaces)

References

BURROWS, J.P., A. RICHTER, A. DEHN, B. DETERS, S. HIMMELMANN, S. VOIGT, J. Orphal, Atmospheric remote-sensing reference data from GOME – 2. Temperature-dependent absorption cross sections of O_3 in the 231-794 nm range. *J. Quant. Spectrosc. Radiat. Trans.,* 61(4), 509-517, 1999.

HESS, M., P. KOEPKE, I. SCHULT, Optical properties of aerosols and clouds: The software package OPAC. *Bull. Am. Meteorol. Soc.*, 79(5), 831-844, 1998.

SHETTLE, E.P., Model of aerosols, clouds and precipitation for atmospheric propagation studies. *NATO Conf. Proc. No., 454*, 1989.

U.S. Standard Atmosphere, National Oceanic and Atmospheric Association (NOAA), Available from National Technical Information Office, Springfield, Virginia, Product Number: ADA-035-6000, 1976.

VAN HOOSIER M.E., The ATLASSD-3 solar spectrum, available via anonymous ftp (ftp://susim.nrl.navy.mil/pub/atlas3), 1996.

CIE PUBLICATIONS

Recommendations

17.4 International lighting vocabulary, 4th ed. (Joint publication IEC/CIE), 1987.
23 International recommendations for motorway lighting, 1973.
39.2 Recommendations for surface colours for visual signalling, 2nd ed., 1983.

Standards

ISO 10526/CIE S005 CIE standard illuminants for colorimetry, 1999.
ISO/CIE 10527 Colorimetric observers, 1991 (S002, 1986).
CIE S003-1996 Spatial distribution of Daylight — CIE standard overcast sky and clear sky, 1996.
CIE S004-2001 Colours of light signals, 2001.
ISO 16508/CIE S006 Road traffic light — 200 mm roundel signals photometric properties, 1999.
ISO 17166/CIE S007 Erythema reference action spectrum and standard erythema dose, 1998.
CIE S008-2001 Lighting of indoor work places, 2001.
S009:2002 Photobiological safety of lamps and lamp systems, 2002.
DS010.2-2001 Photometry – The CIE system of physical photometry, 2001.
DS011.2:2002 Spatial distribution of daylight – CIE standard general sky. 2002.
DS013.2:2002 International standard global UV index, 2002.

Technical Committee Reports

1 Guide lines for minimising urban sky glow near astronomical observatories (Joint publication IAU/CIE), 1980.
13.3 Method of measuring and specifying colour rendering of light sources, 1995.
15.2 Colorimetry, 2nd ed., 1986.
16 Daylight, 1970.
18.2 The basis of physical photometry, 2nd ed., 1983.
19.21 An analytic model for describing the influence of lighting parameters upon visual performance, 2nd ed., Vol.1.: Technical foundations, 1981.
19.22 An analytic model for describing the influence of lighting parameters upon visual performance, 2nd ed., Vol.2.: Summary and application guidelines, 1981.
23 International recommendations for motorway lighting, 1973.
31 Glare and uniformity in road lighting installations, 1976.
32 Lighting in situations requiring special treatment (in road lighting), 1977.
33 Depreciation of installation and their maintenance (in road lighting), 1977.
34 Road lighting lantern and installation data: photometrics, classification and performance, 1977.
38 Radiometric and photometric characteristics of materials and their measurement, 1977.
39.2 Recommendations for surface colours for visual signalling, 1983.
40 Calculations for interior lighting: Basic method, 1978.
41 Light as a true visual quantity: Principles of measurement, 1978.
42 Lighting for tennis, 1978.
43 Photometry of floodlights, 1979.
44 Absolute methods for reflection measurements, 1979.
45 Lighting for ice sports, 1979.
46 A review of publications on properties and reflection values of material reflection standards, 1979.
47 Road lighting for wet conditions, 1979.
48 Light signals for road traffic control, 1980.
49 Guide on the emergency lighting of building interiors, 1981.
51.2 A method for assessing the quality of daylight simulators for colorimetry, 1999.
52 Calculations for interior lighting: Applied method, 1982.
53 Methods of characterising the performance of radiometers and photometers, 1982.
54.2 Retroreflection: Definition and measurement, 2001.
55 Discomfort glare in the interior working environment, 1983.
57 Lighting for football, 1983.
58 Lighting for sports halls, 1983.
59 Polarisation: Definitions and nomenclature, instrument polarisation, 1984.
60 Vision and the visual display unit work station, 1984.
61 Tunnel entrance lighting: A survey of fundamentals for determining the luminance in the threshold zone, 1984.
62 Lighting for swimming pools, 1984.
63 The spectroradiometric measurement of light sources, 1984.
64 Determination of the spectral responsivity of optical radiation detectors, 1984.
65 Electrically calibrated thermal detectors of optical radiation (absolute radiometers), 1985.
66 Road surfaces and lighting (joint technical report CIE/PIARC), 1984.
67 Guide for the photometric specification and measurement of sports lighting installations, 1986.
69 Methods of characterising illuminance meters and luminance meters: Performance, characteristics and specifications, 1987.
70 The measurement of absolute luminous intensity distributions, 1987.
72 Guide to the properties and uses of retroreflectors at night, 1987.
73 Visual aspects of road markings (joint technical report CIE/PIARC; French translation: Aspects visuels des marquages routiers is available from PIARC), 1988.
74 Roadsigns, 1988.
75 Spectral luminous efficiency functions based upon brightness matching for monochromatic point sources, 2° and 10° fields, 1988.
76 Intercomparison on measurement of (total) spectral radiance factor of luminescent specimens, 1988.
77 Electric light sources: State of the art - 1987, 1988.
78 Brightness-luminance relations: Classified bibliography, 1988.

79 A guide for the design of road traffic lights, 1988.
80 Special metamerism index: Change in observer, 1989.
81 Mesopic photometry: History, special problems and practical solutions, 1989.
82 CIE History 1913 - 1988, 1990.
83 Guide for the lighting of sports events for colour television and film systems, 1989.
84 Measurement of luminous flux, 1989.
85 Solar spectral irradiance, 1989.
86 CIE 1988 2° spectral luminous efficiency function for photopic vision, 1990.
87 Colorimetry of self-luminous displays - A bibliography, 1990.
88 Guide for the lighting of road tunnels and underpasses, 1990.
89 Technical Collection 1990:
  89/1 Results of a CIE detector response intercomparison
  89/2 Photobiological effects of sunlamps
  89/3 On the deterioration of exhibited museum objects by optical radiation
  89/4 Guide for the measurement of underground mine lighting.
90 Sunscreen testing (UV.B), 1991.
93 Road lighting as an accident countermeasure, 1992.
94 Guide for floodlighting, 1993.
95 Contrast and visibility, 1992.
96 Electric light sources - State of the art, 1992.
97 Maintenance of indoor electric lighting systems, 1992.
98 Personal dosimetry of UV radiation, 1992.
99 Lighting education (1983-1989), 1992.
100 Fundamentals of the visual task of night driving, 1992.
101 Parametric effects in colour-difference evaluation, 1993.
102 Recommended file format for electronic transfer of luminaire photometric data, 1993.
103 Technical Collection 1993:
  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.
104 Daytime running lights (DRL), 1993.
105 Spectroradiometry of pulsed optical radiation sources, 1993.
106 CIE Collection in Photobiology and Photochemistry, 1993:
  106/1 Determining ultraviolet action spectra
  106/2 Photokeratitis
  106/3 Photoconjunctivitis
  106/4 A reference action spectrum for ultraviolet induced erythema in human skin
  106/5 Photobiological effects in plant growth
  106/6 Malignant melanoma and fluorescent lighting
  106/7 On the quantification of environmental exposures: limitations of the concept of risk-to-benefit ratio
  106/8 Terminology for photosynthetically active radiation for plants.
107 Review of the official recommendations of the CIE for the colours of signal lights, 1994.
108 Guide to recommended practice of daylight measurement, 1994.
109 A method of predicting corresponding colours under different chromatic and illuminance adaptation, 1994.
110 Spatial distribution of daylight - Luminance distributions of various reference skies, 1994.
111 Variable message signs, 1994.
112 Glare evaluation system for use within outdoor sports- and area lighting, 1994.
113 Maintained night-time visibility of retroreflective road signs, 1995.
114 CIE Collection in photometry and radiometry, 1994:
  114/1 Survey of reference materials for testing the performance of spectrophotometers and colorimeters
  114/2 International intercomparison on transmittance measurement - Report of results and conclusions
  114/3 Intercomparison of luminous flux measurements on HPMV lamps
  114/4 Distribution temperature and ratio temperature
  114/5 Terminology relating to non-selective detectors
  114/6 Photometry of thermally sensitive lamps.
115 Recommendations for the lighting of roads for motor and pedestrian traffic, 1995.
116 Industrial colour-difference evaluation, 1995.
117 Discomfort glare in interior lighting, 1995.
118 CIE Collection in colour and vision, 1995:
  118/1 Evaluation of the attribute of appearance called gloss
  118/2 Models of heterochromatic brightness matching
  118/3 Brightness-luminance relations
  118/4 CIE guidelines for co-ordinated research on evaluation of colour appearance models for reflection print and self-luminous display image comparisons
  118/5 Testing colour appearance models: Guidelines for co-ordinated research
  118/6 Report on color difference literature
  118/7 CIE guidelines for co-ordinated future work on industrial colour-difference evaluation.
121 Photometry and goniophotometry of luminaires, 1996.
122 The relationship between digital and colorimetric data for computer-controlled CRT displays, 1996.
123 Low Vision - Lighting needs for the partially sighted, 1997.
124 CIE Collection in Colour and Vision, 1997:
  124/1 CIE TC 1-31 Report: Colour notations and colour order systems
  124/2 CIE TC 1-18 Chairman's Report: On the course of the disability glare function and its attribution to components of ocular scatter
  124/3 Next step in industrial colour difference evaluation, Report on a colour difference research meeting.
125 Standard erythemal dose — A review, 1997.
126 Guidelines for minimizing sky glow, 1997.
127 Measurement of LEDs, 1997.
128 Guide to the lighting for open-cast mines, 1998.
129 Guide for lighting exterior work areas, 1998.
130 Practical methods for the measurement of reflectance and transmittance, 1998.
131 The CIE 1997 interim colour appearance model (simple version), CIECAM97s, 1998.

132 Design methods for lighting of roads, 1999.
134 CIE Collection in Photobiology and Photochemistry, 1999.
- 134/1 CIE TC 6-26 Report: Standardization of the terms UV-A1, UV-A2 and UV-B
- 134/2 CIE TC 6-30 Report: UV protection of the eye
- 134/3 CIE TC 6-38 Report: Recommendation on photobiological safety of lamps. A review of standards

135 CIE Collection 1999: Vision and colour, physical measurement of light and radiation.
- 135/1 Disability Glare
- 135/2 Colour rendering, closing remarks
- 135/3 Virtual metamers for assessing the quality of simulators of CIE illuminant D50 (Supplement 1-1999 to CIE 51-1981)
- 135/4 Some recent developments in colour-difference evaluation
- 135/5 Visual adaptation to complex luminance distribution
- 135/6 45°/0° Spectral reflectance factors of pressed polytetrafluoroethylene (PTFE) power (Reprint of NIST Technical Note 1413)

136 Guide to the lighting of urban areas, 2000.
137 The conspicuity of traffic signs in complex background, 2000.
138 CIE Collection 2000: Photobiology and Photochemistry.
- 138/1 Blue-light photochemical retinal hazard
- 138/2 Action spectrum for photocarcino-genesis (non-melanoma skin cancers)
- 138/3 Standardized protocols for photocarcinogenesis safety testing
- 138/4 A proposed global UV index.

139 The influence of daylight and artificial light on diurnal and seasonal variations in humans. A bibliography, 2001.
140 Road lighting calculations, 2000.
141 Testing of supplementary systems of photometry, 2001.
142 Improvement to industrial colour difference evaluation, 2001.
143 International recommendations for colour vision requirements for transport, 2001.
144 Road surface and road marking reflection characteristics, 2001.
145 The correlation of models for vision and visual performance, 2002.
146 – 147 CIE Collection on glare.
- 146 CIE equations for disability glare.
- 147 Glare from small, large and complex sources.

148 Action spectroscopy of skin with tunable lasers, 2002.

Proceedings of the Sessions:

1921		Paris
1924		Genèva
1927		Bellagio
1928		Saranac
1931		Cambridge
1935		Berlin
1939		Scheweningen
1948		Paris
1951		Stockholm
1955		Zürich
1959	4-7	Bruxelles (Vol. A,B,C,D)
1963	11	Vienna (Vol. A,B,C,D)
1967	14	Washington (Vol. A,B)
1971	21	Barcelona (Vol. A,B,C)
1975	36	London
1979	50	Kyoto
1983	56	Amsterdam
1987	71	Venice, Vol.1-2
1991	91	Melbourne, Vol.1-2
1995	119-120	New Delhi, Vol. 1-2
1999	133	Warsaw, Vol. 1-2

Discs and other publications

D001 Disc version of CIE Colorimetric Data (S001 and S002 Tables), 1988.
D002 Disc version of CIE Colorimetric and Colour Rendering Data (Publ. 13.2 and 15.2 Tables), 1991.
D003 CIE Roster.
D005 A method for assessing the quality of D65 daylight simulators for colorimetry (based on CIE 51-1981) 1994.
D007 A computer program implementing the "Method of predicting corresponding colours under different chromatic and illuminance adaptation" (described in CIE 109-1994), 1994.
D008 Computer program to calculate CRIs (according to CIE 13.3-1995), 1995.

x003 Daylight and solar radiation measurement (CIE - WMO Symposium Proceedings, Berlin 9-11 Oct. 1989).
x004 Symposium on light and radiation measurement '81, Hajdúszoboszoló (CIE-Hungarian NC).
x005 Proceedings of the CIE Seminar '92 on Computer programs for light and lighting.
x006 Japan CIE Session at PRAKASH 91.
x007 Proceedings of the CIE Symposium '93 on Advanced Colorimetry.
x008 Urban sky glow - a worry for astronomy (Proceedings of a Symposium of CIE TC 4-21), 1994.
x009 Proceedings of the CIE Symposium '94 on Advances in Photometry.
x010 Proceedings of the CIE Expert Symposium '96 Colour Standards for Image Technology.
x011 Special volume, 23rd Session, New Dehli ’95, Late papers.
x012 NPL — CIE-UK Visual Scales Conference.
x013 Proceedings of the CIE LED Symposium ’97 on Standard Methods for Specifying and Measuring LED Characteristics, 1998.
x014 Proceedings of the CIE Expert Symposium ’97 on Colour Standards for Imaging Technology, 1998.
x015 Proceedings of the First CIE Symposium on Lighting Quality, 1998.
x016 Proceedings of the CIE/ICNIRP Conference on Measurements of Optical Radiation Hazards, 1998.
x017 Special volume, 24th Session, Warsaw ’99, Late papers, 2000.
x018 Proceedings of the CIE Symposium ’99 “75 Years of CIE Photometry”, 2000.
x019 Proceedings of three CIE workshops on Criteria for Road Lighting, 2001.
x020 Proceedings of the CIE Symposium 2001 “Uncertainty Evaluation, Methods for Analysis of Uncertainties in Optical Radiation Measurement”, 2001.
x021 Proceedings of the CIE Symposium 2000 “Extended range colour spaces”, 2001.

x022 Proceedings of the 2nd CIE Expert Symposium on LED Measurement, 2001.

x023 Proceedings of two CIE workshops on photometric measurement systems for road lighting installations, 2002.

CIE publications on CD-ROM

A CD-ROM with all current CIE Technical Reports and Standards is available from IHS,
Information Handling Services, 15 Inverness Way East, M/S B203 Englewood, Colorado 80112-5776 USA.

CIE-Journal	Vol.1 - Vol.8	1982 - 1989.	**CIE NEWS**	No. 1 - No. 61	1986 - 2002.

For latest information on CIE publications see the CIE Home Page on the World Wide Web:

http://www.cie.co.at/