



ISBN 3 901 906 48 7

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

TECHNICAL REPORT

UV PROTECTION AND CLOTHING

CIE 172:2006

UDC: 612.014.481-06
535.31

Descriptor: Optical radiation effects on humans
Ultraviolet rays

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3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
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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

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This Technical Report has been prepared by CIE Technical Committee 6-29 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 élaboré par le Comité Technique CIE 6-29 de la Division 6 "Photobiologie et Photochimie" et a été approuvé par le Bureau de la Commission Internationale de l'Eclairage, pour étude et emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Il faut consulter les plus récents comptes rendus de la CIE, ou le CIE NEWS, en ce qui concerne des amendements nouveaux éventuels.

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UV PROTECTION AND CLOTHING

SUMMARY

Clothing can provide substantial protection against solar ultraviolet radiation (UVR) and quantifying the amount of protection can have useful applications to recreational, occupational and medical situations.

Various test methods for measurement of UVR transmittance through fabrics are discussed. The measured transmittances can be used to calculate the erythemally weighted UVR transmitted by the fabric and thus the amount of protection provided. Factors affecting the UVR transmission of fabrics are also detailed. Currently existing standard documents are discussed, and then the document outlines a recommended test method for the determination of the UVR transmitted by fabrics and details a rating scheme using Ultraviolet Protection Factors (UPFs) to quantify the protection. Areas where research and standardisation efforts are still needed are discussed.

PROTECTION UV ET VÊTEMENTS

RESUME

Les vêtements constituent une protection importante contre les radiations ultraviolettes (RUV) solaires et l'évaluation de la dimension de protection peut avoir des applications utiles dans les domaines de la médecine, du travail et des loisirs.

Plusieurs méthodes de tests, pour mesurer la transmission des RUV à travers les tissus, sont discutées. Des mesures de transmissions peuvent être réalisées pour calculer la quantité de RUV, pondérée par l'efficacité érythémale, transmise par les tissus et, par conséquent, pour évaluer l'importance de la protection ainsi procurée. Les facteurs affectant la transmission des RUV par les tissus sont également détaillés. Les documents correspondant aux standards existant actuellement sont discutés. Enfin, le document met en valeur une méthode test recommandée pour la détermination des RUV transmises par les tissus et détaille une proposition de classement utilisant les Facteurs de Protection contre les radiations Ultraviolettes (FPU) pour quantifier la protection. Les domaines où des efforts de recherche et de standardisation sont encore nécessaires, sont soulignés.

BEKLEIDUNG ALS SCHUTZ VOR UV-STRALHUNG

ZUSAMMENFASSUNG

Die Bekleidung kann einen wesentlichen Schutz vor solarer Ultraviolettstrahlung bieten, und eine Quantifizierung des Schutzgrades kann im Freizeit-, Berufs- und medizinischen Bereich praktische Anwendung finden.

In diesem Bericht werden verschiedene Testverfahren zur Bestimmung des UV-Transmissionsgrades von Geweben besprochen. Die gemessenen Transmissionsgrade können zur Berechnung der vom Gewebe durchgelassenen erythemal gewichteten UV-Strahlung verwendet werden, wodurch der Schutzgrad bestimmt werden kann. Auf Faktoren, die den UV-Transmissionsgrad beeinflussen, wird genauer eingegangen. Es werden aktuelle Normen erörtert, weiters wird ein empfohlenes Testverfahren zur Bestimmung der durchgelassenen UV-Strahlung beschrieben sowie ein detailliertes Klassifizierungsverfahren anhand von Ultraviolett-Schutzfaktoren zur Quantifizierung des Schutzgrades geliefert. Bereiche für weiterführende Forschung und Normung werden ebenfalls diskutiert.

ABBREVIATIONS AND DEFINITIONS

Erythema	reddening of the skin caused by various physical or chemical agents;
SPF	sun protection factor;
UV-A	ultraviolet radiation, $\lambda = 315\ldots400$ nm;
UV-B	ultraviolet radiation, $\lambda = 280\ldots315$ nm;
UVR	ultraviolet radiation, $\lambda = 180\ldots400$ nm;
UPF	ultraviolet protection factor;
SED	standard erythema dose;
G_{MED-i}	erythema dose reaching unprotected skin, <i>in vivo</i> testing;
G_{MED-f}	erythema dose reaching fabric-covered skin, <i>in vivo</i> testing;
FWA	fluorescent whitening agent;
OWA	optical whitening agent;
UVCA	UV cutting agent;
DSBP	distyrylbiphenil;
owf	on weight of fibre;
E_{λ}	solar UVR spectral irradiance in $W \cdot m^{-2} \cdot nm^{-1}$, (see Appendices B and C);
$s(\lambda)$	ultraviolet hazard spectral weighting function (unitless);
$s_{er}(\lambda)$	CIE erythema action spectrum (unitless) (see Appendix A);
τ_{λ}	spectral transmission;
$\Delta\lambda$	bandwidth in nm; and
λ	wavelength in nm.

1. INTRODUCTION

Members of the general public have become much more aware of the potential hazards of solar ultraviolet radiation (UVR) and have begun to take positive steps to protect themselves, which should help greatly in the reduction of recreational UVR exposures. In the last few years there has also been an interest in protection of outdoor workers against solar UVR including more recently the provision of UVR rated clothing. Unless protected, the UVR exposures to outdoor workers at mid-latitudes can exceed the exposure guidelines of the International Non-Ionising Radiation Committee of the International Radiation Protection Association [now the International Commission on Non-Ionising Radiation Protection (ICNIRP)] (ICNIRP, C-1997, IRPA, C-1989¹), in approximately 10 to 15 minutes near noon in summer.

1.1 Purpose

The purpose of this technical report is to set out recommendations for the development of a new international standard document that will govern the testing of fabrics items claiming to be UV protective for the general public and for fabrics used by people whose employment requires considerable time out-of-doors. To achieve this objective, this document describes the two fundamental approaches for determining sunburn protective capability of fabrics, summarizes and compares current national/regional standard documents pertaining to measurement of sunburn protective capability of fabric and reviews research that has importance to determining exactly how an international standard should be written. Recommendations are made for future research, and a test method is recommended for development of a future standard.

1.2 Scope

This document provides information that may be used for developing a future standardised test method for the determination of the biologically (e.g., erythemally) weighted UVR transmitted by clothing fabrics. The results for such a test method would be valid only for fabrics in close proximity to the skin. This document does not address other related issues such as the design of clothing to maximise protection.

The recommendations in this report for development of a new standard are not to be used:

- a) for a standard method of test for fabrics used by photosensitive patients (as it is more than sunburn protection that is required for their safety and health);
- b) for a standard method of test for fabrics used in shading materials (e.g. awnings and umbrellas) as these fabrics do not directly cover the skin thus allowing indirect solar radiation to strike the skin;
- c) for a standard method of test for fabrics used in clothing for people exposed to UV radiation from sources other than the sun (e.g. welding arcs), because the UV spectra from sources other than the sun renders the label value invalid and places the worker at risk.

1.3 Background - previous work

The protective properties of fabrics against ultraviolet radiation (UVR) have long been recognized. Recently there has been considerable interest in quantifying the amount of protection against solar UVR provided by fabrics and garments, due to concerns about overexposure to general populations during leisure time, and also due to the requirements of occupational protection for outdoor workers.

The UVR transmission of fabrics and clothing has been investigated previously in a number of studies. Berne and Fischer (A-1980) examined a small number of garments worn

¹ References were organized in five sections. In the citations the letters A ... E in front of the publication year refer to the individual sections of the references, 9A ... 9E.

by photosensitive patients in a hospital environment. They found a wide range of protection factors when they used simple radiometric methods and looked at the average of three wavelengths (313 nm, 365 nm and 436 nm). Welsh and Diffey (A-1981) used an irradiation monochromator across the wavelength region 290 nm to 320 nm to investigate the UVR transmission of a number of different fabrics. They weighted their transmission measurements with an erythral effectiveness function to determine protection factors and concluded that the tightness of weave was the most important factor in determining the amount of UVR transmitted by fabrics. Roy et al. (A-1988) examined the spectral UVR transmission of a number of fabric types in relation to personal protection against solar UVR. Robson and Diffey (A-1990) used a spectroradiometer incorporating a PTFE diffuser optical input to determine the UVR spectral transmission of a large range of fabrics. Protection factors were then calculated by weighting with an erythral action spectrum (CIE, C-1987; CIE, C-1993; CIE, C-1997; CIE/ISO, C-1998). Jevtic (A-1990) determined the protection factors for a number of fabrics, including beachwear, using a solar simulator and *in vivo* testing and concluded that the effectiveness of the UVR protection is reduced significantly when the fabric is wet. Menzies et al. (A-1992) showed good correlation between spectrophotometric determination of UVR protection with that determined using *in vivo* testing. Gies et al (A-1992; A-1994) examined the protection offered by fabrics using a number of different test methods and suggested a classification scheme using Ultraviolet Protection Factors (UPFs) and a modified version of this scheme was adopted in AS/NZS 4399 (B-1996) in 1996. Subsequent work has shown that the protection provided by garments when worn is generally higher than that determined in the laboratory where worst case conditions are simulated by using collimated radiation at right angles to the sample (Ravishankar and Diffey, A-1997). Much research continues in this area, including (but not limited to) factors which affect the UVR transmission of fabrics, such as stretch, wetting, wash and wear (Clifton, A-2000; Osterwalder et al., A-2000; Stanford et al., A-1995a, A-1995b; Zhou and Crews, A-1998), test method comparisons, effects of fabric construction and type, effects of laundering additives to increase protective quality, and other research (see references in Sections 9D and 9E). There is an obvious need for safety standards and documents. *Note: This is not an all-inclusive list of all the research that has been done on this topic.*

Worldwide, professional organizations, laboratories, and standards-setting organizations have developed hazard limits for typical and special-case exposures to ultraviolet radiation (see references in Section 9C) and have developed test methods to measure UVR protective factors (e.g., in Australia, South Africa, Europe, France, UK and US), but these have differed in detail and in the means of reporting this information to the public (see references in Section 9B). Again, these references are not an all-inclusive list. A brief sampling of organizations is provided below:

- American Society for Testing and Materials (ASTM);
- American Association of Textile Chemists and Colorists;
- Australia/New Zealand Standards Organization (AS/NZS);
- Australian Radiation Protection and Nuclear Safety Agency (formerly the Australian Radiation Laboratory);
- British Standards Institution;
- Cancer Association of South Africa;
- Comité Européen de Normalisation (European Committee for Standardisation, abbreviated in this document as CEN).

All of these use the *in vitro* test approach rather than the *in vivo* approach. Also, much of the quantification of the UVR (sunburn) protection has been done in laboratories using the *in vitro* approach (see references in Section 9A). Over time, confusion has been introduced in the scientific community and in the public marketplace because sunburn protection values of fabrics may not be directly comparable, depending on the underlying methods that were used for testing (Gies, Roy, McLennan, Diffey, et al., A-1997; Gies et al., A-2000; Hoffman et al., A-2000; references in Section 9B).

2. SUNBURN PROTECTIVE FABRIC MEASUREMENTS - MEASUREMENT GEOMETRY, MATERIALS AND METHODS

The measurement geometry of the system used to study fabric transmission should imitate the real-world human exposure geometry as well as possible. Persons exposed to solar UVR that has been transmitted and scattered through clothing fabrics are receiving light from a source that is neither truly collimated nor truly diffuse (with a cosine response), but rather a combination of the two as shown in Fig. 1. The degree to which fabric test methods imitate the real-world exposure environment is discussed in Sections 2.1 and 2.2.

There are two distinct approaches to determining the sunburn protective quality of a fabric. *In vivo* testing is performed by placing fabric swatches on a human subject's skin, and then irradiating the subject's protected skin (i.e. fabric-covered skin) with optical radiation from a solar simulator. The doses of UVR required to produce just-perceptible erythema in the protected and unprotected skin would then be used to calculate a Sun Protection Factor (*SPF*) value for the test fabric. *In vitro* testing is performed by using scientific instruments to determine the transmittance of UV-A and UV-B radiation through fabric swatches, and then using this data along with biological spectrum data to calculate an Ultraviolet Protection Factor (*UPF*) value for the fabric.

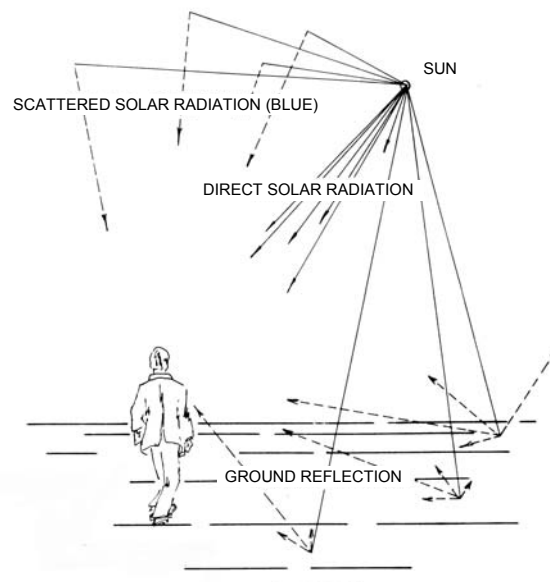


Fig.1. Geometry of exposure to solar UVR, to be replicated in fabric testing (Slinney and Wolbarsht, D-1980).

2.1 *In vivo* testing

In this method (AS/NZS, B-1996, B-1997), the protective quality of the fabric sample is based on the levels of UVR dose required to produce just-perceptible erythema in UVR-irradiated test subjects with and without the fabric in position. This is determined by calculating the ratio of the erythemally weighted solar UVR dose required to cause minimal erythema in a human test subject with the fabric sample in place to that measured with no fabric present. This ratio is referred to as the Sun Protection Factor (*SPF*) for that fabric.

The *SPF* is calculated as follows: the "initial" minimum erythemal dose required to produce the first detectable reddening of the skin is referred to by the abbreviation G_{MED-i} . The corresponding minimum erythemal dose required to produce detectable reddening of fabric-protected skin is referred to by the abbreviation G_{MED-f} . The resulting *SPF* for the fabric is calculated as follows:

$$SPF = \frac{G_{MED-i}}{G_{MED-f}} \quad (1)$$

One advantage of this test method involves exposure geometry - the exposure geometry to the test subject is similar to the outdoor exposure geometry that would be experienced in day-to-day life. Shortcomings of this test method include the following: fabrics which do not protect well may allow for non-uniform spatial transmittances to the test subject, resulting in very different degrees of reddening in small test areas. Conversely, fabrics that protect strongly and transmit only small amounts of UVR would require extremely long exposure times to cause minimal erythema in the test subject, or stronger light sources would be required. This would generate significant heat loads. The reproducibility of the measurements between different countries using this test method should also be investigated. This is due to the fact that the solar simulators used as the irradiation sources may differ significantly from country to country and laboratory to laboratory. The methods of quantifying the erythema endpoints observed in the test subject also need to be standardised.

2.2 Instrumental *in vitro* testing

In this method, the protective quality of the fabric sample is based on measuring the transmittance of solar UVR through the fabric. This is determined by calculating the ratio of the erythemally weighted solar UVR irradiance measured by a detector with the fabric sample in place to that measured with no fabric present. For *in vitro* testing, the optical radiation source is typically a solar simulator. This ratio is referred to as the Ultraviolet Protection Factor (*UPF*) for that fabric.

The *UPF* is calculated as follows: The effective irradiance incident on unprotected skin is calculated by convolving the incident solar spectral power distribution E_λ with the erythema action spectrum and summing over the wavelength range 290 nm to 400 nm. The effective irradiance for protected skin is also calculated with the spectral transmittance of the protective fabric as an additional weighting. The *UPF* is then defined as the ratio of these doses and is given by the following equation:

$$UPF = \frac{\text{effective irradiance without fabric}}{\text{effective irradiance through fabric}} = \frac{\sum_{290}^{400} E_\lambda \cdot s_{er}(\lambda) \cdot \Delta\lambda}{\sum_{290}^{400} E_\lambda \cdot s_{er}(\lambda) \cdot \tau(\lambda) \cdot \Delta\lambda} \quad (2)$$

where:

- s_{er} CIE erythema action spectrum (CIE/ISO, C-1998), (see Appendix A);
- E_λ solar UVR spectral irradiance in $\text{W} \cdot \text{m}^{-2} \cdot \text{nm}^{-1}$, (see Appendices B and C), see also (AS/NZS, B-1996; Sayre et al., D-1990);
- $\tau(\lambda)$ measured spectral transmittance of the item;
- $\Delta\lambda$ bandwidth in nm; and
- λ wavelength in nm.

The inclusion of the CIE erythema action spectrum (CIE/ISO, C-1998) (see Appendix A) in the calculation ensures that sufficient weighting is given to the biologically effective wavelengths below 315 nm. Use of different solar spectra does not significantly affect the calculated *UPFs* (Gies, Roy, McLennan, Diffey, et al, A-1997) as long as the spectra are for clear sky conditions with the sun high in the sky (small solar zenith angles). Calculation of *UPF* using a 5 nm wavelength measurement interval instead of 1 nm generally results in a difference of calculated *UPF* of less than 1% (Gies, Roy, McLennan, Diffey, et al., A-1997) but depends upon the *UPF*.

Shortcomings and advantages of this test method vary with the instruments used for measurement, and are discussed in detail in the Sections 2.2.1.1-2.2.1.4. The reproducibility of the measurements between different countries using various types of instrumentation for this test method continues to be investigated (Gies, Roy, McLennan, Diffey, et al., A-1997; Gies et al., A-2003; Laperre et al., A-2001).

2.2.1 Transmittance measurement instrumentation

2.2.1.1 Spectroradiometers

The input optics of the spectroradiometer must collect both the transmitted and scattered radiation (e.g. with an integrating sphere, see Fig. 2) to reproduce the actual exposure situation when a garment is being worn and the skin is subjected to both the scattered and transmitted UVR, which passes through the garment. This measurement has also been performed using a "reversed" geometry technique, in which the fabric is irradiated by diffuse UVR from an integrating sphere and the radiation is detected at normal incidence (see Fig. 3) and has been experimentally shown to give comparable results (Gies et al., A-2003; Laperre et al., A-2001; Gies, D-2003). The transmission of the material at each wavelength is then calculated by taking the ratio of the photocurrent with the material in position to that without the material.

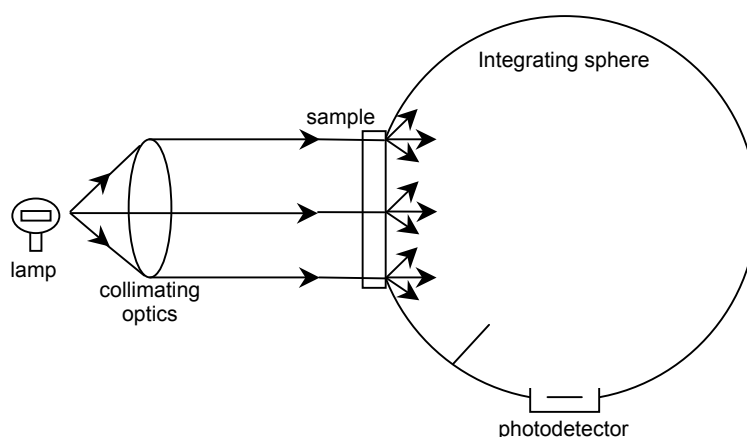


Fig. 2. Schematic diagram of an integrating sphere used by a measurement system to collect light transmitted and scattered through a fabric.

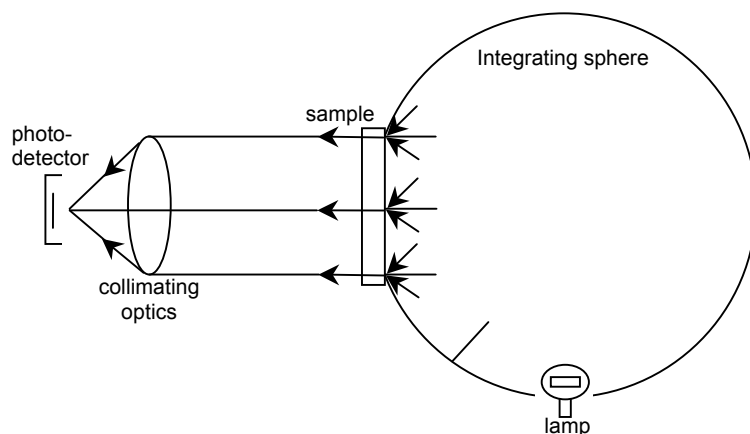


Fig. 3. Schematic diagram of an integrating sphere used by a measurement system to irradiate a fabric with diffuse light which is then detected by a photodetector at normal incidence. This is sometimes referred to as "reversed" geometry.

The use of spectroradiometers, in particular systems with double monochromators, with their characteristic low stray light levels, confers a number of advantages for measurements of transmission in the UVR. If the light source and the spectrometer are both stable, then the scan results should be accurate and reproducible. These systems also reproduce the exposure conditions that would occur in practice when a garment is worn, e.g. total UVR spectrum incident with attendant fluorescence, which is discriminated by having the wavelength selection after irradiation of the sample. The disadvantages of spectroradiometers

in comparison to some other systems are that regular scans of the source are required to provide the reference data, and that the measurements are generally time consuming and therefore expensive.

2.2.1.2 Spectrophotometers

Spectrophotometers will measure directly transmitted radiation plus radiation scattered at small angles only and will therefore tend to underestimate the amount of transmission unless fitted with an integrating sphere attachment. With an integrating sphere both the transmitted and scattered radiation is collected, more closely approximating the actual exposure situation. Since most spectrophotometers have both sample and reference beams, there is no necessity for regular scans of the reference light source. In general, the scanning speeds are significantly greater for spectrophotometers. One disadvantage, however, is that most "off-the-shelf" spectrophotometers separate the source radiation into its respective wavelengths before reaching the sample; hence the detector measures both the transmission through the fabric as well as the fluorescence emission (if any). This fluorescence emission, if present will increase the apparent transmission and hence underestimate the *UPF*.

White (bleached) fabrics, in particular, are usually treated commercially with fluorescent whitening agents (FWA). This fluorescence emission adds blue-violet energy to the total reflectance of the sample and hence increases perceived whiteness and brightness of fabrics. Menzies et al. (A-1992) found that, in such cases, a Schott UG 11 filter could be used to minimize the effects of fluorescence emission from fabrics, whose emission begins by design at approximately 390 nm and peaks at approximately 420 nm - 450 nm, and as a consequence such a filter is recommended for use in spectrophotometers using monochromatic input radiation (BSI, B-1998; AS/NZS, B-1996). However, this may not be sufficient for fabrics treated with FWAs in which the wavelength emission begins below 390 nm.

2.2.1.3 Diode array spectrometers

These measure the spectral transmission of fabrics across the wavelength range of interest using a diode array to monitor transmission at the different wavelengths. The latest versions are fast, easy to use, cost effective and give comparable results to conventional spectroradiometers and spectrophotometers (Gies et al., A-2003; Laperre et al., A-2001). One other significant advantage is the speed to generate a protection factor measurement. However, stray light errors are a major limitation of these systems.

2.2.1.4 Broadband radiometric measurements of UVR transmission

Spectral measurements of the transmission of UVR through materials are accurate but the technique has generally been time consuming and the testing procedure can be simplified by using broadband radiometric testing. However, the speed of measurement of current release spectrophotometers and diode arrays now approaches that of radiometric detectors and this advantage is less marked. When using radiometric techniques to determine fabric protection, the use of an optical radiation source, which has a significantly different UV spectral emission from that of the solar spectrum, or detectors, which do not respond to UVR in a manner similar to human skin, can easily give misleading results. It has been suggested that, in the absence of the effects of fluorescence, it is enough for the combined "source - detector spectrum" to correspond to the product of (UV solar spectral emission) x (human skin responsivity). However, because many fabrics contain fluorophores, it is necessary in this testing to ensure that the light source has a UV spectral emission similar to the solar spectrum, and that the detector responds to UVR in a manner similar to human skin.

Broadband radiometric testing is best suited to spot testing where the relative variation in the *UPF* is required. For example, the effect of stretching the material has been investigated radiometrically, the maximum protection (minimum transmission) naturally occurred in the unstretched state, the amount of UVR passing through the material increasing the more it was stretched. The variation of *UPF* from site to site within a fabric sample was also investigated radiometrically, and was found to vary as much as 30% to 50% for some samples with low quality control.

2.2.2 Effect of instrument choice on *UPF* values determined from *in vitro* testing

Comparison of measurement results of UVR protection from laboratories around the world utilizing numerous different measurement systems (Gies et al., A-2003; Laperre et al., A-2001) such as double monochromator spectroradiometers, spectrophotometers with integrating spheres, diode array spectrometers, synchronized monochromators positioned before and after the fabric sample and *SPF* analysers indicated better agreement below *UPF* 50; however, above *UPF* 100, correlation was poor. This indicates that the laboratory-based measurement method can be reproducible and consistent, although quality assurance procedures of *UPF* testing laboratories should be checked periodically.

For *UPF* values at 50 or less, stray radiation, wavelength precision, and the use of a specific solar-like source are not of significant concern. For *UPF* values greater than 50, knowledge of the optical uncertainties associated with measurement become increasingly important. Clearly, if measurements of high *UPFs* are required, specialized equipment must be used and uncertainties must be analysed and precisely determined.

2.2.3 A *UPF* scheme

Any scheme to rate the UVR protective properties of fabrics and clothing should take into account the ambient levels of solar UVR as well as the amount of protection, which is reasonably achievable with present day fabrics. The amount of UVR required to specify sunburn or erythema in normal human skin is now designated in standard erythema dose (*SED*) units. Using the CIE erythral effectiveness function, one *SED* is defined as $100 \text{ J}\cdot\text{m}^{-2}$ (CIE/ISO, C-1998; CIE, C-1997). For skin types I to IV, the minimum erythral doses are approximately 1.5 to 6 *SED* (i.e., effective radiant exposures of $150 \text{ J}\cdot\text{m}^{-2}$ to $600 \text{ J}\cdot\text{m}^{-2}$) (CIE/ISO, C-1998). On a typical cloudless summer day at mid-latitudes the daily total ambient solar UVR is of the order of 50 to 60 *SEDs*. Therefore a person who spends most of the day outdoors will need a total protection factor of at least 30 in order to reduce his or her exposure to less than 2 *SED*. Factors which will influence this include spending less than the full day outdoors, the possibility that some shading of the subject will occur, that solar UVR is rarely at normal incidence to the fabric, and that skin types other than type I may apply. To maintain exposures below the ICNIRP exposure limit (which is approximately 0.6 *SED*), *UPFs* of up to 100 would be required. Considering that the lowest dose required for individuals with "typical" skin sensitivity is approximately 2 *SED*, *UPF* 50 should be considered to offer suitable protection against erythema for most of the population. For persons who have medical conditions that caused higher skin sensitivity, special fabrics with *UPF* 50+ or higher should be recommended. Finally, for fabrics that are typically designed for wear while tanning, a minimal *UPF* in the UV-B range should be provided to prevent sunburn.

The results of many thousands of tests indicate that for clothing fabrics the measured *UPFs* range from a low of approximately 2 to 10 to a maximum well in excess of 100, with most summer weight fabrics having *UPFs* of 20 to 40. In a similar way to the *SPF* scheme for sunscreens with its maximum *SPF*, it has been argued that a maximum category of *UPF* 50+ would prevent escalation of protection claims from various manufacturers. In addition, the large uncertainties associated with high-*UPF* measurements (see Section 2.2.2), suggests the use of a scheme whereby the label provided to typical consumers for the highest-*UPF* fabrics should be reported as *UPF* 50+. In fact, due to these large uncertainties, no standards at the time of this writing use *UPFs* of 100+ as a maximum category.

2.2.4 Use of other biological action spectra

Most of the previous *in vitro* studies have applied an erythral action spectrum such as the CIE Standard Erythral Action Spectrum developed by McKinlay and Diffey (CIE, C-1987; CIE/ISO, C-1998) in spectrally weighting the fabric transmittance and the simulated solar spectrum. The ICNIRP guidelines, however, specify a slightly different action spectrum $s(\lambda)$, known as the UV hazard function. Although this action spectrum appears at first examination to be quite different from the standard erythral action spectrum, the ratio between values at each wavelength beyond 300 nm does not vary significantly, and the result is that very little difference in the calculated *UPF* would be found through the use of the ICNIRP hazard spectrum instead of the standard erythral action spectrum. For this reason, even if health protection is a primary goal of determining the *UPF*, the retention of the erythral action

spectrum is recommended in the *UPF* assessment as it is slightly easier to use, and has been used in the past more widely in fabric testing applications.

2.3 Comparison of *UPF/SPF* values determined from *in vitro* and *in vivo* testing

A comparison of *in vivo* and *in vitro* tests of some sun protective garments (Gies et al., A-2000) found broad agreement between the protections measured by both test methods. This study included measurements according to the test methods of AS/NZS 2604 "Sunscreens - Evaluation and classification" (B-1997) with the fabric substituted for the sunscreen. These used a 150 W solar simulator with the fabric held stationary 2 mm off the skin. The irradiation increment was 1,25, but for clothing with *SPFs* greater than 25, this irradiation increment was the square root of 1,25. Comparison of *in vivo* derived *SPFs* with spectrally derived *in vitro* *UPFs* gave agreement to within 10% to 15%. Also there was only one misclassification of protection category (*SPF* 44 = *UPF* 50+) when compared to AS/NZS 4399 (B-1996) for 12 fabric samples ranging in *UPF* from 4 to 50+. Menzies et al. (A-1992) showed good correlation between spectrophotometric determinations of UVR protection with that determined using *in vivo* testing. More recently Hoffman et al. (A-2000) found that differences between *in vivo* and *in vitro* determination of the protection factors seemed to depend upon the types of fabric material. They found that untreated viscose fabrics showed lower *UPFs* than *SPFs* while lightweight, specially treated viscose and cotton fabrics gave slightly higher *SPFs* than *UPFs*.

2.4 Correlating laboratory tests and wear tests

Subsequent work has shown that the protection provided by garments when worn is generally higher than that determined in the laboratory where worst case conditions are simulated by using collimated radiation at right angles to the sample (Ravishankar and Diffey, A-1997).

3. FACTORS THAT AFFECT UVR TRANSMITTANCE THROUGH FABRICS

To understand why fabrics vary in capability to provide sunburn protection, it is necessary first to visualize the three possible interactions of solar UVR with fabric (Fig. 4). In this Figure, incident radiation is being directed perpendicular to the fabric surface. This direction is as occurs in instrumental (*in vitro*) transmittance testing of fabrics but is not that in a real-life situation where solar radiation strikes the fabric surface at many different angles.

Note that a ray may be reflected at the fabric surface, it may be absorbed by UV-absorbing materials comprising the fabric (fibres, colorants, chemical additives, etc.), and it may be transmitted through the fabric. Note that a ray may be directly transmitted (meaning that it emerges without interaction with the fabric). This transmitted radiation is called unchanged or directly transmitted radiation. Also note that transmitted rays may emerge from the lower fabric surface as diffuse or scattered rays. These rays emerge from the lower fabric surface of the fabric at any angle other than 90 degrees to that surface.