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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
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INTERNATIONALE BELEUCHTUNGSKOMMISSION

RESEARCH NOTE

HAND PROTECTION BY DISPOSABLE GLOVES AGAINST OCCUPATIONAL UV EXPOSURE

CIE 181:2007

UDC: 612.014.481-06
535.31

Descriptor: Optical radiation effects on humans
Ultraviolet rays

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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.

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The Research Note in this publication was submitted by the Director of Division 6 "Photobiology and Photochemistry" after refereeing by two experts in the field of the Note, both of whom supported publication. The authors provided an introductory summary replying to reviewers' comments, as well as giving a brief background and some recommendations for the work of CIE. 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.

La Note de Recherche contenue dans cette publication a été soumise par le Directeur de la Division 6 "Photobiologie et Photochimie", après revue et approbation par deux experts dans le domaine de la note. Les auteurs ont également fourni un résumé introductoire, prenant en considération les commentaires des ces experts et donnant des informations supplémentaires ainsi que quelques recommandations pour le travail de la CIE. 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.

Der Forschungsbericht in dieser Publikation wurde, nachdem er von zwei Experten auf dem Gebiet des Berichtes geprüft und für publikationsreif befunden wurde, vom Direktor der Division 6 "Photobiologie und Photochemie" unterbreitet. Die Autoren lieferten eine einführende Zusammenfassung, in der sie auf die Stellungnahme dieser Experten eingingen und eine kurze Hintergrundinformation sowie Empfehlungen für die weitere Arbeit der CIE gaben. 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.

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The following members of the CIE reportership "Occupational UV Protection by Disposable Gloves" took part in the preparation of this research note. The reportership comes under Division 6 "Photobiology and Photochemistry".

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HAND PROTECTION BY DISPOSABLE GLOVES AGAINST OCCUPATIONAL UV EXPOSURE

SUMMARY

A number of applications in industry, research and medicine involve occupational exposure to ultraviolet radiation (UVR) from a variety of lamps and lasers. While solar UVR exposure has been extensively studied, there is little information on methods to evaluate the efficiency of personal protective equipment (PPE) against exposure to artificial UVR sources.

Various test methods and instrumentation for measuring the spectral attenuation of disposable gloves are discussed. Factors affecting the UVR transmission through disposable gloves are investigated, and a method of assessing the level of protection provided by the glove when protecting against monochromatic or broad-band UVR sources is discussed. Application-specific examples are provided, and areas where research and standardisation efforts are still needed are discussed.

PROTECTION DES MAINS CONTRE LES EXPOSITIONS UV LIEES A L'ACTIVITÉ PROFESSIONNELLE PAR DES GANTS JETABLES

RESUME

Un certain nombre d'activités dans l'industrie, la recherche et la médecine impliquent des expositions liées à l'activité professionnelle au rayonnement ultraviolet (UVR) émis par une grande variété de lampes et de lasers. Alors que l'exposition à l'UVR solaire a été largement étudiée, il y a peu d'informations sur les méthodes employées pour évaluer l'efficacité des équipements des protections personnelles (PPE) contre l'exposition aux sources artificielles émettant l'UVR.

Les différentes méthodes de test et l'instrumentation destinées au mesurage de l'atténuation spectrale par les gants jetables sont discutées. Les facteurs affectant la transmission de l'UVR à travers les gants jetables sont analysés et une méthode permettant l'évaluation du niveau de protection offerte par les gants quand ils protègent contre les sources d'UVR monochromatique ou à large bande est discutée. Des exemples d'applications spécifiques sont fournis et les domaines où des efforts de recherche et de standardisation sont encore nécessaires, sont discutés.

SCHUTZ DER HÄNDE MITTELS WEGWERFHANDSCHUHEN VOR BERUFSBEDINGTER UV-BESTRAHLUNG MITTELS WEGWERFHANDSCHUHEN

ZUSAMMENFASSUNG

Viele Anwendungen in Industrie, Forschung und im medizinischen Bereich bringen Ultraviolett-Bestrahlungen durch unterschiedliche Lampen und durch Laser mit sich. Während die UV-Bestrahlung durch die Sonne eingehend untersucht wurde, gibt es bisher wenige Informationen über Bewertungsmethoden der Leistungsfähigkeit von persönlichen Schutzmitteln gegen die Bestrahlung durch künstliche UV-Strahlungsquellen.

Verschiedene Testmethoden und Instrumente für die Messung der spektralen Schwächung durch Wegwerfhandschuhe werden diskutiert. Faktoren, die die UV-Transmission von Wegwerfhandschuhen beeinflussen, werden untersucht. Außerdem wird eine Methode zur Bewertung des Schutzgrades von Handschuhen gegen monochromatische oder breitbandige UV-Strahlungsquellen diskutiert. Anwendungsspezifische Beispiele werden gezeigt und Bereiche für weiterführende Forschung und Normung weiter diskutiert.

1. INTRODUCTION

A number of applications in industry, research and medicine involve occupational exposure to ultraviolet radiation (UVR) from a variety of lamps and lasers.

Excessive exposure to the UVR from the sun and artificial sources can cause serious adverse health effects. Exposure to broad spectrum UVR is a recognised risk factor for skin cancer [1]. There is experimental evidence of suppressive effects of UVR on the immune system. Excessive exposure also causes erythema and skin ageing.

There is a need to limit exposures to UVR at work, both outdoors and indoors. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommended Exposure Limit Values (ELVs) for occupational UVR exposures for broad-band sources [2] and lasers [3]. Whereas solar UVR exposure is extensively studied, there is very little information on non-solar occupational UVR exposure and efficiency of personal protective equipment. An EU Directive on Artificial Optical Radiation [4] will place specific requirements on employers to provide adequate safety measures to reduce exposure to UVR, including gloves for hand protection.

1.1 Purpose

The purpose of this Research Note is to set out recommendations for occupational guidance for the assessment of the UV protection level for disposable gloves and for the development of an international standard which will govern the UV testing of disposable gloves. To achieve these objectives, the document reviews research in occupational hand protection and describes a methodology for the assessment of the UV protection of disposable gloves. A test method is recommended for the potential development of a future standard.

1.2 Scope

This document provides information that may be used for the development of a future standardised test method for the assessment of UV protection of disposable gloves. The document examines only the UVR attenuation of disposable gloves, e.g. their suitability to provide required protection. It doesn't address other related issues, such as permeation of chemical agents, allergy to glove material or UVR damage threshold of materials.

1.3 Background - Previous work

A number of industrial applications and public services involve occupational exposure to ultraviolet radiation from a variety of lamps and lasers, for example, in forensic examination, biological trans-illuminators, dentistry, laser material processing, microelectronics, printing, etc.

There is a need to limit UVR exposures in the workplace. Personal protective equipment (PPE) should be used as a control measure only as a "last resort" and where other methods of control are not reasonably practicable. PPE against occupational UVR exposure include eye (goggles and face shields) and skin protection (protective clothing, gloves). The selection of PPE should be based on a risk assessment and on the performance characteristics of the PPE for the task.

Whereas adequate eye protection against UVR overexposure is recognised and widely used, skin and, especially, hand protection is often overlooked. Of course, the severity of potential eye injury to UVR overexposure may be more serious than for skin, but the level of UVR exposure to hands may be substantially higher when there is a need to perform manual operations close to the UVR source. Furthermore, ELVs for the skin and eye are identical in the spectral range of 180 nm - 315 nm. For operational and economical reasons, in the majority of applications the protective gloves are disposable, chosen to provide protection against other hazards such as chemical, biological or contamination of products, without taking into consideration their UVR protective properties.

When PPE are used to reduce UVR exposure and for the risk assessment to be useful, the attenuation offered by PPE, including gloves, should be quantified.

However, current legislation and standards do not describe procedures for the evaluation of disposable gloves as personal protective equipment for hand protection against

non-ionising radiation. The wide range of possible sources of UVR and the real-life conditions of glove use (stretching and wetting the surface by liquids) add further complexity to the problem.

1.3.1 Current legislation and standard documents

UK Personal Protective Equipment at Work Regulations 1992 [5], derived from Council Directive 89/656/EEC [6], in Regulation 4 requires that, "suitable protective equipment is provided to his employees who may be exposed to a risk to their health or safety while at work". Regulation 6 (1) says: "Before choosing any protective equipment which by virtue of Regulation 4 he is required to ensure is provided, an employer or self-employed person shall ensure that an assessment is made to determine where the personal protective equipment he intends will be provided is suitable".

Clause 102 of the UK Health and Safety Executive (HSE) Guidance to these Regulations [7] further states that "Gloves or other hand protection should be capable of giving protection from hazards... The choice should be made on the basis of suitability for protection...". The list of processes and activities which involve risk of injury to the hands from hazards for which hand protection may be necessary includes:

- manual handling;
- vibration;
- construction and outdoor work;
- hot and cold material;
- electricity;
- chemical;
- radioactivity.

The Regulations or HSE Guidance do not specifically mention ultraviolet radiation, or optical radiation in general.

Draft International Standard ISO 22613-1 "Protective Clothing – Part 1: Test Methods for Gloves" [8] provides methods for the classification and testing of hand protection for specific performance properties related to chemical and industrial applications. The Standard does not address protection from hazards such as ionising and non-ionising radiation. In Annex C (informative) "Other factors for consideration" it recognises that "in addition to the test methods in this International Standard, there are many characteristics that should be taken into account when selecting appropriate hand protection depending on the application and types of hazards present. Additional consideration should be given to:

- C.2 Medical (Biological) Hazards;
- C.3 Extreme Temperature Conditions;
- C.4 Clean-room Applications (TC author's note: UVR protection is not included);
- C.5 Hazardous Materials Response Applications;
- C.6 Electrical Hazards;
- C.7 Human Factors;
- C.8 Other Factors."

IEC 60825-1:2007 "Safety of laser products" [9] refers to the laser beam hazard to the skin and in Table A.3 gives maximum permissible exposure (MPE) values for the skin to laser radiation from 180 nm - 1400 nm. However, there are no references to the assessment of PPE for skin protection.

EN 13758-1:2002 "Textiles – Solar UV properties. Part 1: Method of test for apparel fabrics" [10] describes the method of testing of UV protection characteristics of fabrics against solar radiation. It suggests the use of Ultraviolet Protection Factor (UPF) as a time-scale increase in the permitted solar exposure for the skin protected by fabric with respect to unprotected skin.

UPF is defined for a flat, tensionless dry fabric as

$$UPF = \frac{\sum_{\lambda=290}^{\lambda=400} E(\lambda) \cdot s_{er}(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=290}^{\lambda=400} E(\lambda) \cdot \tau(\lambda) \cdot s_{er} \cdot \Delta\lambda} \quad (1)$$

where

$E(\lambda)$ is the solar spectral irradiance, in $W\ m^{-2}\ nm^{-1}$, measured at Albuquerque;

$s_{er}\lambda$ is the erythema action spectrum;

$\Delta\lambda$ is the wavelength interval of the measurements;

$\tau(\lambda)$ is the spectral transmittance at wavelength λ .

The Standard specifically emphasises that the method is not suitable for artificial sources: *UPF* is defined as a measure of attenuation of weighted sun exposure.

The new Radiation Protection Standard for Occupational Exposure to Ultraviolet Radiation [11] was developed in Australia by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and the Radiation Health Committee, and it is proposed that it will be adopted in Edition 2 of the National Directory for Radiation Protection, which is now in preparation. The National Directory is the mechanism for uniformity of radiation protection practice and adoption of the Standard in the Directory places an obligation on all jurisdictions to adopt it within their regulatory frameworks. The ARPANSA Regulations will be updated to apply the Standard to all Commonwealth Government departments and agencies so that it will apply nationally. The Standard sets mandatory limits on exposures to artificial sources and recommends compliance with exposure guidelines for solar UVR. Because the limits are mandatory for artificial sources, employers will be required to assess and provide an inventory of their UVR sources, to limit UVR exposures, to implement the plan and to provide personal protective equipment. In the situations where employees are required to work in the vicinity of UVR sources, the employees will need to be provided with appropriate protection. Information on what constitutes appropriate protection in the case of clothing and eyewear is covered by both Australian and international standards. However, no Australian standard currently exists for hand protection.

The Occupational Safety and Health Administration (OSHA) of the US Department of Labor in the Standard Interpretation document of 02/26/2003 Workplace exposure limits for ultra-violet radiation [12] states that "...there are no OSHA-mandated employee exposure limits to ultraviolet radiation". However, OSHA provides technical guidance regarding protection against UVR from lasers [13] and supports the American Conference of Governmental Industrial Hygienists (ACGIH) recommendations for Threshold Limit Values (TLVs) for direct ocular and skin exposures to ultraviolet radiation [14].

In the position Statement of the Board of Directors of American Industrial Hygiene Association (AIHA) of March 2006 [15], AIHA supports and encourages:

"2. Regulatory agency inspection and enforcement of existing standards and guidelines for environmental surveillance and worker protection. This may include the use of existing ACGIH TLVs for UV radiation.

3. Development of programs and procedures for the control of exposures and protection of workers from harmful UV radiation in the workplace."

The OSHA guide on Personal Protective Equipment [16] provides a general overview of PPE related to OSHA standards. It advises that it is essential that employees use gloves specifically designed for the hazards and tasks of the workplace and refers to 29 CFR 1910.138 for the requirements for hand protection [17]. Documents do not describe hand protection against non-ionising radiation.

1.3.2 Research

Cazzuli and Giroletti [18,19] conducted an assessment of personal exposures for researchers and students from the range of UVR sources used at University of Pavia, Italy in chemistry, biochemistry, genetics and microbiology. They concluded that there is a substantial risk of UVR overexposure (Table 1) and outlined preventive and protective

measures to reduce it, with the emphasis on engineering and administrative controls. The list of skin PPE includes clothing, muffs and gloves but their UV protection level is not quantified.

Table 1. Medium and high risk application areas [19].

Application area	Source	Type of UVR source
Chemistry	High pressure Hg lamp	LHG, LBAN
	Medium pressure Hg lamp	LB254
	TLC plate viewer	TLC, CHINO
Genetics and microbiology	Trans-illuminator	T320, TGEN, SANTAO1
	Germicide hood	CAP
Biology	Animal pound lamp	PATL

Klein [20] studied UVR exposure from trans-illuminators in biological laboratories of Yale University, USA and reviewed the suitability of protective equipment. He measured UVR attenuation of the available PPE (Table 2) and recommended a range of control measures to reduce the risk of UVR overexposure.

Table 2. UVR attenuation of PPE used with biological trans-illuminators [20].

Equipment tested	Transmitted light, in $\mu\text{W cm}^{-2}$ (% absorption)		
	UV-B	UV-C	UV-B&C
None - unshielded	337,52	222,51	560,03
Latex exam glove, 1 layer	2,20 (99,3%)	0,67 (99,7%)	2,87 (99,5%)
Latex exam glove, 2 layers	0,02 (>99,9%)	<0,01 (>99,9%)	0,02 (>99,9%)
Stretched latex exam glove, 1 layer	3,50 (99,0%)	1,10 (99,5%)	4,60 (99,2%)
Safety glasses, polycarbonate	0,03 (>99,9%)	<0,01 (>99,9%)	0,03 (>99,9%)
Faceshield, thin polycarbonate	0,26 (99,9%)	0,02 (>99,9%)	0,28 (99,9%)
Lab coat, cotton/polyester weave	6,31 (98,1%)	1,03 (99,6%)	7,32 (98,7%)

Gazdik, Rosenthal and Wang [21] studied the attenuation properties of laboratory gloves for UV trans-illuminators. They measured the transmission of vinyl, latex and nitrile gloves of different thickness, evaluated instrumentation for the transmittance measurements, assessed the changes due to stretching, contact with saline and long-term UVR exposure. The study concluded that vinyl gloves do not provide adequate protection against UVR exposure from trans-illuminators.

Akbar-Khanzadeh and Jahangir-Blourchian [22] evaluated personal exposures from UV trans-illuminators at the Medical University of Ohio at Toledo, USA. The results of this study suggest that the ELVs may be exceeded in less than 15 sec within 15 cm from some of the devices and recommended safety control measures to reduce exposure, including personal protective equipment.

Collins and Ackland [23, 24] tested 15 types of surgical and examination gloves for UV-A and UV-B absorption. They concluded that the UV-B transmittance of vinyl gloves is

above 36% and that UV-A transmittance is above 68%, which makes vinyl gloves unsuitable for hand protection against UVR exposure.

The potential hazards associated with the use of dental curing equipment were analysed by a number of research groups [25 - 30]. Thus, Chadwick et al. [26] studied some commonly used polymerisation sources and assessed the level of protection afforded by six brands of surgical gloves by measuring their transmission. They demonstrated that the transmittance of some of the gloves was above 10% at 300 nm, and increased with stretching. Lehtinen and Kuusilehto [25] showed that latex examination gloves absorb 76% of the radiation from dental curing equipment, whereas vinyl gloves absorb only 33%, making them less effective for the protection against UVR exposure.

Khazova, O'Hagan and Grainger [31, 32] studied the UVR attenuation of disposable gloves made of different materials and suggested a methodology for the assessment of UV protection and a simple measurement protocol based on a common approach with UV protection by clothing and sunscreens.

Many health and safety guidance documents for printers, furniture and parquet industry [33-35] include recommendations to protect eyes and skin from UVR but do not provide any quantitative assessment or advice on the rational choice of gloves as PPE.

There is no published research for the assessment of UVR exposures and efficiency of gloves as PPE for the processes in micro- or opto-electronics, though UVR sources are extensively used in lithography and in the assembly of devices.

2. UVR PROTECTIVE CHARACTERISTICS OF GLOVES: MEASUREMENTS AND METHODS

2.1 Glove UV Protection Factor

For occupational exposure to broadband artificial UVR sources it is recommended that exposure limit values (ELVs) proposed by ICNIRP should be adopted [2, 3]. The basic ELV for occupational exposure for skin is an effective radiant exposure of 30 Jm^{-2} within any 8 hour period. To calculate the Exposure Limit Value (ELV) for the skin protected by a disposable glove, the ELV for unprotected skin should be multiplied by the glove UVR Protection Factor (PF):

$$ELV_{\text{glove}} = ELV_{\text{unprotected}} \times PF \quad (2)$$

The glove UV Protection Factor (PF) is defined as a time-scale increase in exposure permitted for the hand protected by the glove with respect to the unprotected hand. The glove UV PF could be used as a characteristic of UVR protection efficiency of a glove as PPE.

$$PF = \frac{\sum_{\lambda=180}^{\lambda=400} E(\lambda) \cdot s(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=180}^{\lambda=400} E(\lambda) \cdot \tau(\lambda) \cdot s \cdot \Delta\lambda} \quad (3)$$

where

$E(\lambda)$ is the UVR lamp spectral irradiance;

$s(\lambda)$ is the UVR spectral weighting values outlined by ICNIRP [2];

$\Delta\lambda$ is the wavelength interval of the measurements;

$\tau(\lambda)$ is the spectral transmittance at wavelength λ .

Similar to the Ultraviolet Protection Factor (UPF) for clothing [10], the PF for gloves takes into account the different efficiency of UVR of different wavelengths on skin and the spectral distribution of attenuation of the glove material. However, there are substantial differences for glove PF compared with UPF for clothing:

- there is no single illumination source - spectra of UVR lamps vary;
- the integration interval should be 180 nm - 400 nm, as recommended by ICNIRP [2];
- the transmission of a given glove changes with stretching and wetting.

For UV lasers, assuming emission at a single wavelength, PF is:

$$PF(\lambda) = \frac{1}{\tau(\lambda)} \quad (4)$$

This value is a time scale factor for the MPE for the skin, specified by Table A.3 of IEC 60825-1 [9]: to calculate the MPE for skin protected by a disposable glove, the MPE for the skin should be multiplied by the PF given by (3). The PF for laser applications does not include spectral weighting because the spectral weighting factor for skin sensitivity is included in the MPE for the skin, in a simplified form: see Table A.3 of IEC 60825-1 [9]. The simplified form of the skin spectral sensitivity weighting factor in the MPE definition leads to an underestimation of glove protection properties in the spectral range of 180 nm - 270 nm and above 315 nm.

The classification of glove PF based on the proposed approach, similar to the UPF for clothing, allows the development of a common methodology for the assessment of UVR protection efficiency for PPE which is defined as a time scale increase in permitted exposure for protected skin with respect to unprotected skin. This assessment methodology is applicable to any protective gloves, including those made of fabric.

2.2 Instrumentation and methods for transmission measurements

To define glove UVR PF , data on the spectral attenuation of the glove material is required (see equations 2 and 3). The spectral distribution of the transmittance is measured as the ratio of UVR passing through the glove to the incident radiation.

Instrumentation methods for the measurement of glove transmission are similar to the testing of UPF of fabrics, which are discussed in detail in CIE 172:2006 "UV Protection and Clothing" [36]. This Research Note analyses advantages of different instrumentation methods and presents results of inter-comparisons.

2.2.1 Radiometer measurements

Gazdik et al. [21] used a Gigahertz-Optik P 9710 radiometer with a 3708-02 actinic detector for the measurements of actinic UVR and a 3701-2 UVA for UV-A measurements. The radiometer detectors were placed such that the plane of the detector surface was parallel to the surface of a transilluminator. The glove material was placed across and in contact with the detectors, with the detector surface completely covered. The detectors had a built-in diffuser to assure a cosine spatial response of the detectors. Irradiance from the trans-illuminator was measured with and without the glove covering the detector.

The UV-A detector has a flat spectral response from 290 nm to 440 nm, while the actinic detector has a spectral response from 250 nm to 340 nm which closely follows the actinic response spectrum as defined by ACGIH [14].

2.2.2 Spectrophotometer measurements

Gazdik et al. [21] also compared the results of radiometer measurements with the dual-beam Cary 400 spectrophotometer (Fig. 1). The UVR attenuation was calculated as follows:

$$T = \frac{\text{Effective Irradiance Transmitted}}{\text{Effective Irradiance Incident}} = \frac{\sum_{\lambda=250}^{\lambda=400} E(\lambda) \cdot S(\lambda) \cdot \tau(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=250}^{\lambda=400} E(\lambda) \cdot S(\lambda) \cdot \Delta\lambda} \quad (5)$$

where

$E(\lambda)$ is the spectral irradiance of the source at the glove surface;

$S(\lambda)$ is the relative spectral response for the UV-A detector, or actinic UV detector, as specified by the manufacturer;

$\Delta\lambda$ is the wavelength increment on the spectral radiometer scan;

$\tau(\lambda)$ is the spectral transmittance of glove material at the wavelength λ .

The attenuation measured by this spectrophotometer was higher than the radiometric results by the method described in 2.2.1. It can be explained by the fact that in the