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Contents

Monitoring of Low- and Medium Pressure Mercury Lamps in UV-Disinfection Plants for Drinking Water

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Keywords: Sensors, spectral response, angular response, linearity, disinfection, temperature response, UV-radiation

Introduction

An Austrian standard for disinfection plants for drinking water using low pressure mercury lamps was established in 2001 (ÖNORM M5873-1, 2001) and a pre-standard for plants with medium pressure lamps has been finished in 2003 (VORNORM ÖNORM M5873-2, 2003). An example of a UV-disinfection plant can be seen in figs. 1a,b. The efficiency of UV-plants is tested by biodosimetry in using calibrated spores of *Bacillus subtilis* as "measuring instrument". Biodosimetry gives as result the Reduction Equivalent Fluence (REF) and in measuring the reference irradiance during the biodosimetric test, a parameter is defined which can be used for monitoring the UV-plant in the water work. The two above mentioned standards define, among others, requirements for the monitoring sensors. The standards distinguish between reference sensors and plant sensors. For the reference sensor the parameters which have to be tested are: calibration of irradiance, spectral response, measuring range and linearity, measurement uncertainty, temperature response, stability over time and the geometrical dimensions of the sensor. The plant sensor has to be tested with respect to the maximum measurement uncertainty, measuring range and resolution, temperature response, temporal stability, geometrical dimensions and marking. Both sensor types have to fulfill requirements for angular response.

Results

Angular response

The requirements for the angular response of the sensor are given by the Austrian standard as a function of inclination. The measurements were done in tilting the sensor against the beam whereas the UV-source and a sensor for control of the lamp were left in a constant position. The angular response is calculated as the ratio between the measured irradiance and the irradiance which would be expected by assuming an ideal cosine response.

Figure 1a (Top) UV-disinfection plant for 1 800 m³/h in Vienna. Figure 1b (Bottom) sensor and sensor port.

Linearity

Linearity was tested either by the method of beam addition or by a comparison of the sensor which was tested with a linearity corrected instrument. Our laboratory standard radiometer (International Light IL 1700 with sensor SED240) deviates 2% over a range of 5 magnitudes of irradiance. Figure 2 shows the relative deviations from linearity for another hand held device. The second monitoring system in this plot consists of the same type of sensor but an electronic control unit from another manufacturer. This example demonstrates clearly the influence of the electronic control unit.

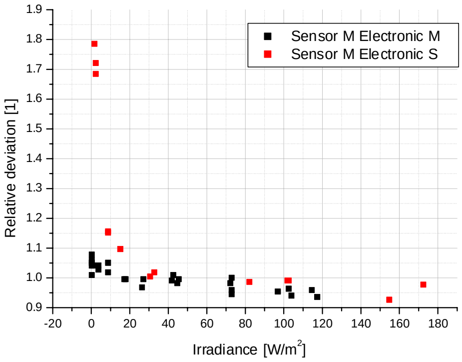

Figure 2. Relative deviation from linearity for two different radiometers. While both use the same type of sensor electronics, the control units are different.

Temperature response

The temperature response is another critical point of sensors and electronic control units. For reference sensors the Austrian Standard purports an upper limit for the temperature drift of 0.1%/K in the range from 0°C to 40°C, that is 4% for the whole range. Figure 3 shows the temperature behaviour of two UV-radiometers.

Spectral response

For medium pressure plants the spectral response of the sensor has to correspond to the spectral action spectrum of microorganisms. To proof the accordance first of all a spectral measurement of the Hg-medium pressure lamp used for the test is necessary. In weighting its spectrum with the microbicidal action spectrum the effective irradiance is gained. A measurement of this irradiance then has to be done with the sensor to be tested. The difference between values of weighted irradiance measured with the sensor and calculated weighted irradiances (weighting of spectral irradiance, measured by spectroradiometer) delivers a measure of quality. For our test the polychromatic radiation came from a medium pressure mercury lamp Heraeus DFH DQ 1023. While for wavelengths shorter than 240 nm relatively good agreements could be found, high deviations occur due to radiation with wavelengths longer than 280 nm. The sensors show high overestimation of longwave UV radiation and therefore overestimation of disinfection efficiency.

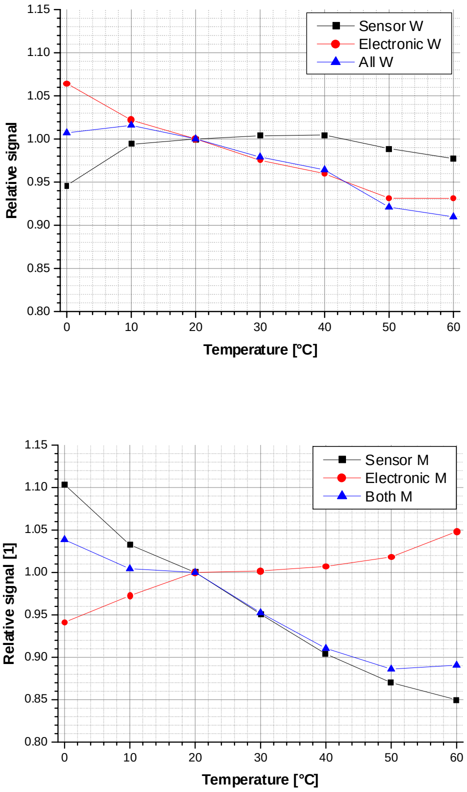

Figure 3. Relative signal depending on temperature for two UV-control systems. Shown are the results for the pure sensor (black), the electronic unit (red) and the whole system (blue).

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Optical Characterization of GaP and GaAsP Photodiodes

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Keywords: Photodiode, Responsivity, Uniformity, Linearity

Spectral measurements in radiometry are mainly based on solid-state detectors. Therefore accurate determination of the spectral responsivity of solid-state detectors and their characteristics with respect to important parameters are highly desired. The change of responsivity on the surface of the detector (i.e. non-uniformity), response change with the power of the light (i.e.nonlinearity), the effect of the temperature on the responsivity behaviour, reflection by the surface and polarization of the incoming light make this measurements quite difficult.

In this study, results of the uniformity maps of research-grade Gallium Phosphate (GaP) and Gallium Arsenic Phosphate photodiodes which were measured on purpose-built step-motor controlled two axis stage are presented. The intensity stabilized AC/DC set-up for linearity measurements are introduced with obtained results. The observed change in the photodiode responsivity in different ambient temperatures taken on a temperature controlled housing are also given. The new 3-diode geometrical construction of so called reflection trap-detectors and its improved properties for polarization, reflection and uniformity are described by experimental results.

Improved entrance optic for global irradiance measurements with a Brewer spectrophotometer

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This presentation outlines a new input optic for measuring spectral UV irradiance with a Brewer spectrophotometer. The first system was installed in 2002 (Fig. 1) in the Brewer MKIII #163 [1].

Figure 1. Brewer MKIII #163 with the global input optic for measuring spectral UV irradiance. The first optic was installed in 2002. It was replaced in 2004 by the new and further improved global input optic. Courtesy J. Gröbner, JRC, Ispra.

The system provides considerably improved measurement accuracy in comparison to the traditional flat input optic (Fig. 2). The direct cosine error of this system is less than 5% for incidence angles between 0° and 80° [2].The integral cosine error for isotropic radiation is less than 2.4% with an uncertainty of +-1%.

This system was replaced in 2004 by the further improved and now commercially available system UV-J1015 (Fig. 4).

Traditionally, the Brewer spectrophotometer uses a flat global input optic which underestimates the true global solar irradiance by a factor of up to and exceeding 10%. This factor is not constant but depends on the time of day and the atmospheric conditions [3].

So far, special shaped global input optics with nearly perfect characteristics have become available only for instruments using optical light guides that link the entrance optic to the detector [4].

The new global optic is flexible enough to be easily installed on every brewer spectrophotometer. An initial optimization of the angular response function for each individual Brewer spectrophotometer is required.

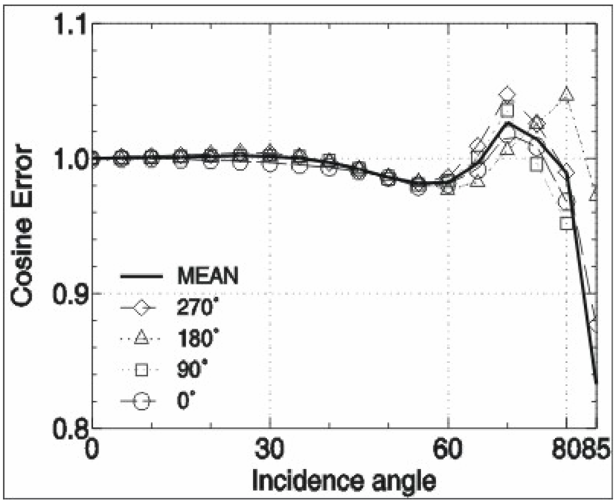

Figure 2. Ratio of the angular response function of the new entrance optic relative to the desired cosine relation in four planes. The angular responses of all four planes are within 5% of the ideal response for incidence angles. Figure taken from [1].

The uncertainties in global irradiance measurements due to the angular response of the new global input optic have been shown to be around +-1% [1]. This is a substantial improvement to the traditional Brewer spectrophotometers.

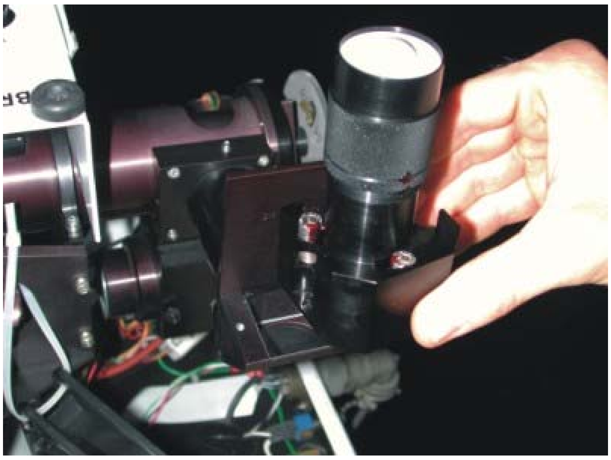

Figure 3. Installation of the improved entrance optic for global irradiance measurements.

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Personal UV-monitoring in health prevention and risk analysis

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Efficient protection measures against the risks due to UV-radiation regarding essential beneficial UV-effects require the knowledge of the biologically effective levels of the UV-exposures in the different sections of the population.

For the mean UV-source - the solar UV-radiation - a world wide measurement network exist. In Germany a UV-monitoring network of 10 measurement stations spread throughout the country was established in 1994. It provides scientific data of the global solar UV-radiation and is used to present the global UV-index forecast to the public.

The fractions of this total solar UV-exposure what will be received individually and will get effective had to be investigated by a personal UV-monitoring. The individually measured exposure level varies between the social behaviour group in the population in more than two orders. It strongly depends on the behaviour on workdays, in leisure time and in holiday time.

Embedded in the UVB-programme of the German Ministry of Education and Research (BMBF) in a research project a routine method of a personal UV-monitoring was established. Beside the measurement of the biological effective personal UV-dose the influencing UV-exposure relevant personal data and the influencing global factors (e.g. global radiation data, meteorological data) will be stored in a database system for further assessments. Basing on this technique a cross section study of the UV-exposure level of the population was carried out in the course of two years seasonally. The investigated 13 German population groups ranged from a group of kindergarten children up to inhabitants of an old people’s home (Dresden/Germany). In the same way, selected similar characterized groups were measured in Köln/Germany, Diekirch/Luxembourg, Madrid/Spain (Knuschke P, Krins A. (2000) Personal-UV-Dosimetry using polysulphone films as a UV-Sensor. Final report BMBF-research project 07UVB54B, TIB Hannover F00B1544).

Important fractions of the annual UV-dose of individuals are the holiday exposures (up to 50 %). The personal UV-monitoring was carried out in seven typical regions and times of German holiday makers. Furthermore, the personal UV-monitoring data base include the investigated distribution of the UV-exposure to the different body sides. The UV-body distribution depends on the solar elevation in the course of the year and depends on the characterization of the outdoor behaviour (outdoor worker, person in leisure time). In this way, the data base system enables the biometric calculations of mean annual UV-exposures to the different body sides of selectable sections of the population taken into account the different workday activities, leisure time behaviour and furthermore the different times and locations of the holidays (Knuschke P, Kurpiers M, Koch R, Kuhlisch W, Witte K (2004) Mean individual UV-exposures in the population. Final report BMBF-research project 07UVB54C/3, TIB Hannover F05B898).

In health prevention and care on workplaces to be at risk on increased exposure level due to artificial or solar UV-radiation the measurement and assessment shall be stated (Directive of the European parliament and of the council: On the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (optical radiation)). In an European Standard EN 14255-1 (artificial UV-sources) and in a draft of a EN 14255-3 (solar UV-radiation) the different methods of measurement and assessment are/will be defined. Depending on the actual situation the personal UV-monitoring can be the preferable method.

In basic research of heath prevention on UV-exposed outdoor workplace the exposure levels and relations of times at workplace, leisure time and holiday exposure were investigated by personal UV-monitoring. The investigations were carried out to establish well balanced recommendations of solar UV-exposure levels on outdoor workplaces and/or with respect to recommended exposure limits (Federal Institute for Occupational Safety and Health / FIOSH-project F 1777). To investigate the natural photoprotection of the skin against UV-radiation by melanin pigmentation and skin thickening in outdoor workers in the course of one year monthly, a personal UV-monitoring provides the individual UV-exposure data leading to the alteration in the skin (FIOSH-project F 1986).

In medicine the personal UV-monitoring is a usable method in photodiagnostics of patients with photodermatosis. The measured patient data can be related to healthy groups of comparable person to estimate the necessary protection level or/and to correct the behaviour of the patient.

Long-term decreased solar UV-exposure levels (especially in elderlies) leads to diseases caused by a vitamin D-deficiency. The vitamin D-deficiency and the decreased UV-exposure levels (measured by personal UV-dosimetry) in the course of the year can be correlated. Normal ranges can be found in relation to investigations in younger person groups.

In conclusion, the data pool of the personal UV-monitoring presents a quantitative base to support public UV-education and UV-prevention programs. It is a valid measurement method in scientific research, in occupational healthy control and in medicine.

Photobiological quality control in UV phototherapy

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Up to now in Germany there are no preconditions of a measurement, evaluation and documentation for patient exposure data comparable in general. Often, there is no compatibility between the data set of the photodermatological departments in each case. Therefore there are also no assessments of the life-long received treatment exposures of the patients possible.

To overcome this distinct shortcoming we proposed the following procedure which facilitate the documentation of comparable, additive and in future retrospective assessable exposure data of patients in UV phototherapy:

1. Before starting the UV-phototherapy cycle: determination of the actual minimum erythema dose (MED) of the patient on-site in therapeutic irradiation position.
2. Documentation of the MED of the patient in units of the standard-erythema dose (SED).
3. Carrying the treatment in relation to the determined actual MED and documentation of the MED-related exposure data together with its expression in SED-units (UV single dose, fraction of UV dose increase, cumulative UV dose of the treatment cycle).

The aim of the proposed procedure is that on one hand the UV phototherapy is orientated to the UV-erythema with the MED as an upper limit of treatment exposure. On the other hand, the relative action spectrum the UV erythema and of the risk to produce a nonmelanoma skin cancer are similar. So, basing on the proposed procedure a retrospective risk assessment of patients life-long accumulated UV treatment exposures will be possible (Remark: In case of additional photochemical treatments the procedure will be the same basing on the minimum phototoxic dose MPD. Because of its quiet different action spectrum to the phototherapy the exposure data had to be documented separately.).

We investigated the realisation in practice. To determine patients MED in the later treatment position (see 1.) we can present an own developed MED-test set using in routine since 1995.

In a study using a UV broadband radiometer well adapted to the standard erythema action spectrum and the cosine function (Fa. Gigahertz-Optik GmbH Puchheim/Germany) we could demonstrate that the deviation between -in each case four in one person-MED determinations expressed in SED-units and the mean of these SED-values is less than 20% in the controlled 30 healthy volunteers. We compared 8 UVB-sources, UVAB-source and device geometries typically used in UV phototherapy.

In result we can propose a set of tables for therapy cycle documentation and a long-term documentation to offer the possibility of comparable, additive and retrospective assessable UV exposure date of patients in dermatological phototherapy.

Realization of a new commercial radiometer for measurement of the total UV effective irradiance of sunbeds

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Long exposition to sun radiation cause burns, skin aging, erythema and even melanoma cancer. In the European regulation EN60335-2-27 the toxicity of UV radiation emitting machines for domestic use is discussed and upper-limit exposition effective dose are established. As well as other artificial sources, sun tanning units should be monitored and certified according with the law. There is the necessity to develop a clear measurement procedure to verify sunbed irradiance in metrological laboratories, and to develop portable instrumentation for the irradiance verification in situ. In order to measure the total effective irradiance of sunbed and sun lamp a new radiometer with a spectral response curve equivalent to the CIE erythemal action one has been designed and realized. The sensor is hand portable, user friendly and competitive on the market. A request for an Italian patent has been deposited by Istituto Nazionale per la Fisica della Materia (INFM), Italy.

The system consists of a transmission diffuser, an interferential filter and a photodiode detector (Fig.1).

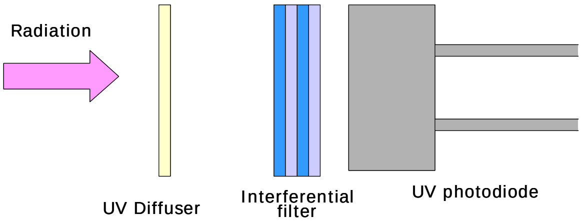

Figure 1. Radiometer optical scheme.

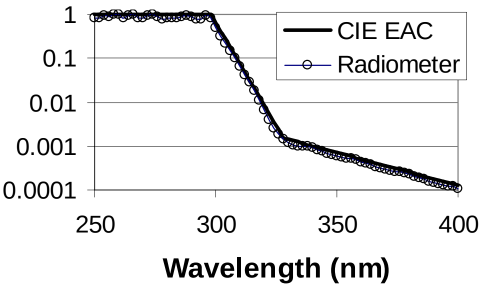

Figure 2. Radiometer theoretical spectral response (normalized) compared to the CIE Erythemal Action Curve.

The diffuser can be either a teflon film or a quartz glass, being the first more indicated for its diffusion properties. In order to select the most appropriate detector, the absolute efficiency of many different commercial photodiodes have been measured [1]. SiC have been selected for the higher efficiency, high shunt resistance and stability over time. In order to match the CIE Erytemal Action Curve response an innovative interferential filter has been designed. It consists of about 35 layers of two different materials deposited alternately on a quartz substrate. The filter transmission curve is optimized in such a way that its product with the photodiode spectral responce curve matches the Erythemal Action Curve (Fig.3). Filter has been deposited by LUXEL Corp. and its optical properties have been verified as stable after thermal cycling. A first prototype has been assembled. The theoretical response of the whole system has been evaluated and compared to CIE Erythemal Action Curve (Fig.4), giving a very interesting results. Further improvement is expected after optimization of the filter deposition process. The new instrument concept can be used to develop an outdoor radiometer for ambient UV monitoring.

Figure 3. Radiometer prototype.

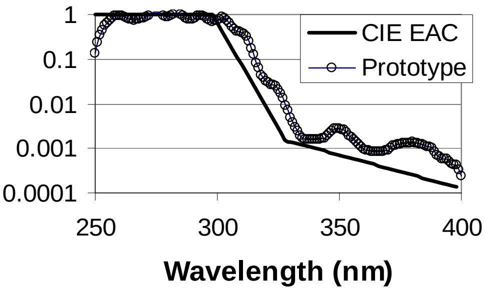

Figure 4. Radiometer measured spectral response (normalized) compared to the CIE Erythemal Action Curve.

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Measurement of High Output UV sources - Medium Pressure Mercury Arc Lamps

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Conventionally, measurement of the total output of a lamp is performed by placing the light source inside an integrating sphere and comparing it with a calibration lamp. For spectrally sensitive measurements a spectrometer may be used as a light detector.

For physically large light sources, or light sources with a very different output to typical calibration lamps, this can be a difficult process.

Typical medium pressure (MP) lamps* can therefore provide a problem due to:

- Large length of lamps ~150-1000mm between electrodes, plus any supporting frame etc.
- The lamps are often operated at high power levels ~0.5-15kW. As the lamps may have to run for 5-10 minutes before reaching stable operating conditions, a lot of energy goes into heating the lamps surroundings.
- The UV flux from the test lamp may be much higher than from the calibration lamp.

This paper describes how these issues may be mitigated, mainly by exploiting the physical characteristics, including shape, of the MP lamp. The UV output from the lamp, when running at design output, is emitted from an arc of limited diameter, running between points near to each electrode. From a sufficient distance the light source therefore approximates to a line source.

A slit can therefore be used to define a section of the arc, and measurements extrapolated to predict the UV output of the entire lamp.

Comparison of the MP and calibration lamps allows a direct measurement of spectral intensity at a known distance from the arc section. Treating the arc section as a uniformly radiating point source we can calculate its total spectral output, and that of the whole length of the arc.

A detailed methodology for this approach is presented.

A further observation is that the arc intensity varies consistently along the length of the arc. The optimal point for UV monitor location is therefore discussed.

A comparison of predicted reactor performance and system biological test results is also presented.

* MP lamps considered are all Hanovia standard products

Solar UV monitoring using a mini-spectrometer

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Advantages of mini-spectrometers are the simultaneous recording of spectra, flexibility of the system, computer compatibility and low cost . We have developed a computer-aided system to retrieve global irradiance UV spectra based on the miniature spectrometer Avantes AvaSpec-256.

The AvaSpec-256 fiber optic spectrometer is based on the symmetrical Czerny-Turner design with 256 pixel CMOS detector array. The CMOS detector HAM 256 is connected to an electronics board with a 14 bit AD converter and USB/RS-232 interfaces. The grating 600 lines/mm was selected to cover the spectral range of 237-444 nm with blaze by 250 nm, slit width is 50 μm. The integration time can be adjusted from 2 ms to 60 s.

The system configuration consists of the optical input head, motor-driven shutter, optical fiber, spectrometer, refrigeration box, control and data logging computer and a web server. The optical head and electro-mechanical shutter are placed on a rooftop, other devices reside in the laboratory.

The two cosine diffusers are made from Russian teflon (fluoroplast). The diffuser for the winter period is a horizontally positioned film with thickness of 0.4 mm, the other one for the summer period has a better cosine-correcting profile and thickness the 0.9 mm. For attenuation of longer wavelengths a blocking glass filter is used. The colored glass UFS-5 absorbs almost all light above 410 nm.

Fiber cable length is 4 m and fiber diameter 100 μm. The temperature of the AvaSpec 256 spectrometer is stabilized at $+7^{o}$ C +/- 0.5^{o} C by a Peltier type car refrigerator box, which reduces sensitivity to temperature changes to a great extent; the lower operating temperature also reduces the dark current.

Absolute spectral responsivity was determined by radiometric calibration using a NIST traceable FEL type irradiance standard (Oriel Corp.).

The collection of spectra may be performed at variable integration times, adjustable by 1 s steps from 1 to 60 s. To improve the signal to noise ratio, the integration time will be estimated by the computer for gathering maximum in the spectrum (16000 counts). For this purpose the test spectra are measured all the remaining time. The dark current is measured for each spectrum prior to its recording. Computer-controlled shutter covers the input diffuser from the front. The dark count rate of spectrometer is 50 counts per second at 7 ^{0}C. As the spectrometer requires 1 - 60 s to acquire a complete spectrum and it takes about 1 – 2 minutes for the shutter to operate, we can measure 10 – 20 spectra per hour.

The software for pre-processing, archiving and visualization is developed in-house and is running under GNU/Linux. The measured spectra together with auxiliary data are saved to a MySQL database.

The graphical user interface for viewing and post processing the spectra is located in the web server. The user is able to browse either raw or physical spectra or spectra weighted by some action spectrum, see the status of measuring equipment and view calibration information. There are also web pages for wider audiences such as displaying the UV-index, UV-B etc. Also individual spectra can be saved in structural data file or FLEXTOR format for further in-depth analysis. Preliminary quality control of spectra is performed using the CheckUVspec package.

The auxiliary data on the weather conditions are from the nearby Tartu-Tõravere BSRN meteorological station. In the 2004 campaign, observations were made throughout the days and, as a result, about 6000 spectra have been collected.

UVEMA: A new project exploring degrading effects of UV radiation on materials

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UV radiation belongs to the most important environmental factors that deteriorate a variety of materials, resulting in considerable limitations in the useful life time of many articles and structures. Albeit the phenomenon of degradation itself is well known and recognisable, the underlying chemical and physical processes are not fully understood. Ageing experiments in laboratory do yield valuable information on these intricate processes. In natural conditions, however, interaction between UV radiation and the other environmental parameters, including temperature, humidity, precipitation, wind and air pollutants, makes the picture utterly complicated. Due to the synergistic effect of these various factors, the contribution of UV radiation is not by any means easily distinguished.

Within the UVEMA project, a programme of long-term outdoor material testing will be set up at seven European observatories, covering a wide range of latitudes (28°N-68°N) and various climatological environments. Prevailing UV radiation and weather conditions will be monitored alongside with the programme at each station. Various properties of the exposed materials will be studied, with an objective to develop an ageing model incorporating all the different ageing factors. In addition, a spectral UV irradiating device will be designed and constructed for accelerated degrading of materials. This is expected to yield material-specific action spectra for the properties significant to the appearance or performance of the materials. Furthermore, radiative characteristics of a weatherometer widely used in artificial and accelerated weathering tests will be measured. As a result, a reliable estimate for the comparability of these artificial conditions to those prevailing outdoors will be obtained.

The study focuses on rubber compounds (also in tension), natural fibre composites (both painted and unpainted), and carbon fibres. Using appropriate tests, materials exposed to UV radiation will be investigated in respect of various properties. These include colour, quality/coarseness of the surface and compression/flexural/tensile strength. Testing methods range from visual inspection and non-destructive testing to dynamical mechanical analysis.

The project is a joint effort of the Finnish Meteorological Institute, the Helsinki University of Technology and the Tampere University of Technology, Elastopoli Oy, and the following industrial partners: Oy All-Plast Ab, Exel Oyj, MacGregor (FIN) Oy, and Nokian Tyres plc. The project is financed by the National Technology Agency (Tekes), the Finnish Meteorological Institute and the industrial partners. The project has been launched on the 1st of May 2005, with a time frame of four years.

Standard ultraviolet radiation for non extreme exposure conditions: Definition and indoor reproduction

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The skin is exposed to ultraviolet radiation (UVR) from natural or artificial sources on a daily basis. The solar UV irradiance is variable as it depends on geo-orbital and environmental parameters. Although ground level solar spectral irradiance is continuously varying, the research community has found it convenient to use reference spectra to assess the effects of solar UV radiation. Many of these reference spectra are representative of the "worst" case scenario, i.e. summer global sunlight (diffuse skylight + direct beam sunlight) with a clear sky, and the sun elevation being at least 80° (quasi-zenithal sun irradiance). Such extreme exposure conditions only occur at limited dates (e.g. around the 21st of June for the Capricorn Tropics), with a clear sky, near solar noon, and at specific locations ranging from 33.5° North to 33.5° South, i.e. 10° wider than the Tropical area. Now, only a part of the global population is exposed to such radiation and many people never receive this extreme spectral power distribution. There has been much less interest in what is likely to happen under more usual conditions.

At high latitudes and shortly after sunrise or before sunset, the solar elevation angle (SEA) may be lower than 10° for time periods longer than one hour. Although the irradiance is low, long exposure is possible and can lead to biologically relevant UV doses; e.g. more than 7 Standard Erythema Doses (SED) may be received by a horizontal plane between 3 p.m. and 7 p.m. at latitude of 60 °N in mid-June. The UVB proportions of the corresponding irradiance values are significantly lower than those found in zenithal sunlight. The effects of chronic cumulative low dose exposure merit investigation, even when these effects are neither conspicuous nor clinically assessable.

The first purpose of the present study was to define a relative spectral UV irradiance that is representative of frequent non-extreme sun exposure conditions. Solar spectral UV irradiance values were calculated for different dates and locations, using a radiative transfer model. The spectral irradiance values obtained when the solar elevation is lower than 45° were averaged. An important feature is the dUVA (320-400 nm) to dUVB (290-320 nm) irradiance values ratio, which was found to be 27.3 for the overall average (standard deviation estimated using the bootstrap method, i.e. re-sampling 50 paired dUVA and dUVB irradiance values: 0.18). When the months corresponding to extreme irradiance values (low or high) were excluded from the calculations, the dUVA to dUVB ratio ranged from 27.2 to 27.5. [dUVB stands for "dermatological UV-B", a convenient short-hand notation that designates the 290-320 nm wavelength range and which is already widely used in scientific communications, in comparison to the 280-315 nm UV-B waveband which was designated by the International Commission on Illumination (CIE). In turn, the 320-400 nm waveband is referred to as dUVA.]

The second purpose of this study was to create standard UV daylight simulators and to define and use criteria in order to assess their compliance with the above spectrum.

The aim of solar UV simulation is to study, under laboratory conditions, what would happen to people exposed outdoors. Solar UV simulators are designed in a way that their spectrum resembles the spectrum of summer sunlight at noontime. These exposure conditions maximize the content of dUVB radiation. Specific simulators are needed to study and assess the effects of exposure to the standard UV daylight. Furthermore, criteria to assess the goodness of fit of standard UV daylight simulators are required.

As a first criterion, it is proposed that the dUVA / dUVB irradiance values ratio for UV daylight simulators be close to 27.3, e.g. within the range 23-32.

Sources that include a xenon bulb are the best choice for solar UV simulation. These sources must be equipped with short cut-off filters that reproduce the steep slope of the atmospheric ozone absorption. Schott WG320 filters of appropriate thickness (around 2 mm) enable to achieve this result. To guarantee the steepness of the slope (and by the way indirect requirements on the measuring device), a second criterion can be proposed, which is thus: the ratio of the spectral irradiance value at 320 nm over the spectral irradiance value at 295 nm should be more than 1,500.

In accelerated tests, it may be needed that the irradiance be higher than the irradiance of the standard UV daylight, implicitly assuming that the effects depend on the dose and not on the irradiance. However, the irradiance integrated over the 250-2500 nm waveband should not exceed 1200 $W.m^{-2}$, to avoid overheating of exposed volunteers or cells. This can be obtained by adjusting the radiation output of the solar simulators.

Using commercially available Oriel solar UV simulators, we calculated and have fabricated Schott WG320 filters so, once the filter equipped the simulators, the irradiance values complied with the three criteria above.

The daylight spectral irradiance is representative of mean environmental UV exposure conditions that most of the population is exposed to. In addition, it has been easily reproduced indoors and appropriately used both as a standard to investigate the biological effects of a non-extreme UVR and to assess the effectiveness of skin care products for daily protection. Some *in vitro* and *in vivo* biological effects induced by simulated standard UV daylight as defined in this paper have been studied in our laboratory and will be published subsequently.

Expanded Measurement Uncertainty of Spectral Measurements Outside of the Laboratory

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In an accredited optical radiation calibration laboratory all variables that can affect measurement results are well regulated and documented. On site, variables such as temperature, electromagnetic and magnetic fields very often cannot be controlled and can influence detection devices. Also lack of mechanical positioning equipment like an optical bench can add to the overall measurement uncertainty. In order to produce accurate measurements in the field the uncertainties introduced through the entire calibration chain starting from the primary standard obtained from the national or international standards laboratory to the internal transfer standards used by the secondary calibration organization must be known as well as the uncertainty added due to the performance of the measurement outside the laboratory. This paper will discuss sources of error in the field and how to calculate the expanded uncertainty.

Solar UV measurements: The temperature dependence of the diffuser head sensitivity

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In order to establish the trend in surface UV-irradiation levels, for instance due to the ozone depletion, accurate and stable long term measurements of the solar UV spectrum are required. The required accuracy drives the ongoing improvements of UV radiometers. At the current accuracy level small effects affecting the instruments sensitivity become important. Small differences between instruments become clear as a result of intercomparison campaigns and, in particular, visits of the QASUME traveling spectrometer. RIVM operates a DILOR double spectrometer with a, widely used, standard Teflon diffuser, and has been visited three times by the QASUME instrument between 2002-2004. Triggered by a diurnal variation between both instruments we could establish a temperature sensitivity of the diffuser head. Laboratory measurements showed that the sensitivity decreases by 1-2% per 10 degrees temperature rise and turned out to be wavelength dependent. Since the diffuser head can heat up to over 45 ^{o}C in Dutch summers, corrections should be carried out. A method was developed to estimate diffuser temperatures from pyranometer measurements and meteorological data which enables a temperature correction for our history data record when diffuser temperature information is not available. This method is applicable for other instruments as well. The impact on annual UV-sums and UV-trends will be discussed as well.

UV-Monitoring at Outdoor Workplaces - A Base for Well-Balanced Health Prevention Regulations

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The effects of ultraviolet (UV) radiation on skin and eyes of work time exposure cannot be separated from the effects of spare time exposure. The actual individual UV exposures for workers with a solar exposure during working hours depend strongly on the specific character of their respective tasks and jobs, as well as the workers' habits during holidays. Therefore, the relations between the different professions with a varying extent of outside work time were to be collected and the different objective and subjective influencing factors were to be analyzed within the scope of a personal UV monitoring during the course of a year (BAuA (Federal Institute for Occupational Safety and Health) research project F1777).

The results from those research activities for the different groups of workers with solar UV exposure during work time were to be evaluated and compared to analogous investigations among indoor workers.

The biologically effective yearly doses acquired from the solar UV exposure show that workers permanently employed outside are strained much more during the 218 working days of a year (e.g. 6 to 7 times more in face and neck) than workers permanently employed indoors.

It turned out that the exposure relations between the different groups working outside are largely independent from the season of year.

The workers' individual behavior during their spare time on weekends and on holiday has a further impact of about 40…100% (indoor workers: 200…750%) for the entire UV exposure of one year, relating to their yearly share of workdays and depending on their activities. This means that the value of the year-long UV exposure for an employee permanently working outside is dominated by the exposure during worktime.

Guidelines on occupational safety and health for outdoor workplaces cannot be based on the ICNIRP-Guidelines for UV-exposed indoor workplaces. The latter have to consider exposures of unexposed skin durnig wintertime, while the skin builds up a certain (currently not quantifiable) self-protection when constantly exposed. As an orientation guideline, a year's medium individual UV exposure of workers not employed outside should be consulted, whose levels of exposure shouldn't be exceeded by a justifiable amount.

The use of a single-monochromator diode array spectroradiometer for UV-radiation measurements

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Abstract. The suitability of single-monochromator diode array spectroradiometer for UV-radiation measurements, especially sunbed measurements, was evaluated. The spectroradiometer was characterized and correction methods for major error sources were developed. The uncertainty of the corrected UV measurements is estimated to be 14% (2σ).

Introduction

The suitability of an Ocean Optics S2000 spectroradiometer for sunbed UV-radiation measurements was evaluated [Ylianttila et. al. 2005]. The spectroradiometer was characterized and correction methods for major error sources were developed. The corrected spectra measured with the Ocean Optics S2000 spectroradiometer were compared to the spectra measured with Optronic 742 and Bentham 150 double-monochromator spectroradiometers. The measurement uncertainty of Ocean optics S2000 spectroradiometer in sunbed measurements was estimated.

Material and Methods

The Ocean Optics S2000 is a single-monochromator CCD-array spectroradiometer. The wavelength range is 200 nm - 800 nm and the FWHM bandwidth is 1.6 nm. The input optics consists of a PTFE (Teflon®) diffuser and a 4 m long optical fiber. An Oriel 51122 visible-light absorbing filter is used to reduce stray-light.

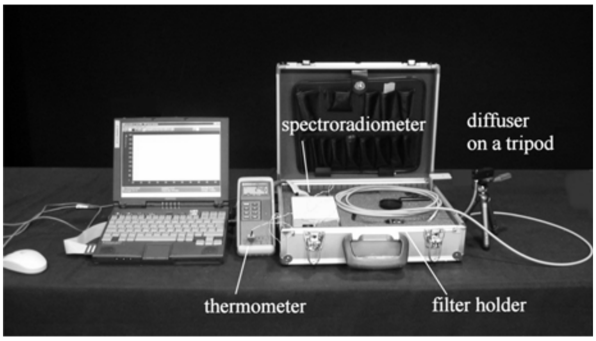

Figure 1. The Ocean Optics S2000 spectroradiometer in the measuring setup. The spectroradiometer is not removed from the transport case in normal use.

The linearity, dark signal, stray-light and slit function, angular response, and temperature response of the spectroradiometer were measured. A stray-light correction method based on the measured slit function was developed. The cosine correction factors for sunbed use were calculated. The standard wavelength scale determination method was improved.

The spectroradiometer was calibrated with a quartz-halogen 1000 W FEL lamp. A 40 W deuterium lamp was used to improve the signal-noise ratio in the UV-B range.

To verify the accuracy of the corrected spectra measured with the Ocean Optics S2000 spectroradiometer, various sunbed and medical UV therapy lamps, a sunbed and solar spectra were measured. The spectra were compared to the spectra measured with Optronic 742 and Bentham 150 double-monochromator spectroradiometers. The measurement uncertainty of Ocean Optics S2000 spectroradiometer in sunbed measurements was estimated.

Results

The main error sources are cosine response and stray-light. The cosine response was not good, the cosine correction factor in sunbed measurements is 1.25 and the correction for uniform diffuse radiation is 1.20.

The correction of stray-light is essential, when the UV-B part of UV-radiation source should be measured accurately. The developed stray-light correction method works satisfactorily, but without any stray-light correction the measured UV-B irradiance could have over 50% error.

The temperature of the instrument and the integration time influence the instrument’s dark signal. Therefore the dark signal should be measured jointly with each spectral measurement.

The wavelength shift due the temperature change is around 0.03 nm/°C. The sensitivity change caused by temperature is small between 20°C - 30°C. Outside this temperature range the sensitivity fell of by 5-30%, thus making the temperatures between 20°C and 30°C practical limits for instrument’s temperature.

The instrument has small 5% non-linearity, for which a correction is applied. By using a quasi-Gaussian fit of the slit function for wavelength scale determination, wavelength accuracy of 0.05 nm can be achieved between 250 nm and 400 nm.

In the single lamp comparison measurements the integrated UV, UV-A, UV-B, and CIE-erythema weighted irradiances were within 10% from the values measured with the double-monochromator spectroradiometers. In the sunbed and solar irradiance measurements the differences were below 13%.

An example of spectral comparison is presented in figure 2, where a spectrum of a Philips Cleo Natural sunbed lamp measured with Ocean Optics S2000 spectroradiometer and Optronic 742 double-monochromator spectroradiometer are drawn. In the figure 2 b the ratio between Ocean Optics S2000 spectrum and Optronic 742 spectrum is drawn. The Ocean Optics S2000 spectrum has been interpolated for the comparison. (The wavelength of data points is defined by the pixel position in Ocean Optics S2000 spectrum, whereas the spectrum of Optronic 742 was measured with 1 nm steps.) In the UV-A the agreement is excellent, whereas in the UV-B the irradiance measured by Ocean Optics S2000 is slightly smaller and the detection limit is higher.

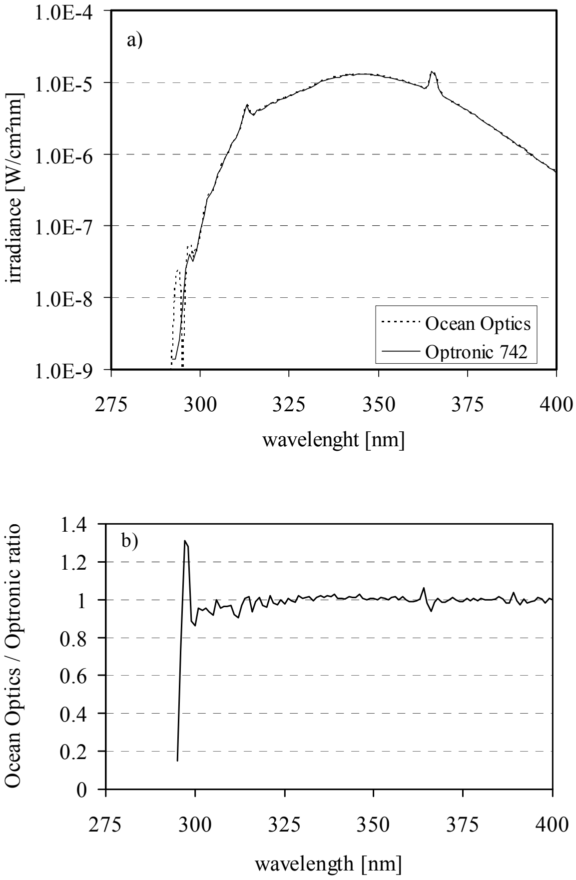

Figure 2. A comparison between sunbed-lamp spectra measured with single-monochromator Ocean Optics S2000 and double-monochromator Optronic 742 spectroradiometers. The measured spectra are drawn in a) and the ratio of the spectra is drawn in b). Note that the Ocean Optics spectrum has been interpolated for the comparison.

An uncertainty estimation for sunbed measurement that takes into account the major error sources is presented in table 1. The combined standard uncertainty of the UV measurement is 6.9% (confidence level 63%). With coverage factor 2 (95% confidence level), the expanded uncertainty is 14%. For typical sunbed measurements this uncertainty is sufficient. By improving the cosine response, stabilizing the temperature, and refining the stray-light correction, the expanded uncertainty could be decreased slightly below 10%. Without any corrections the measurement error could exceed 50%.

Table 1. Uncertainty budget for UV-dose measurements.

uncertainty component	*relative standard uncertainty [%]*
calibration	3
stray-light	4
cosine response	3
temperature	3
wavelength	1
other sources	2
combined uncertainty	6.9
expanded uncertainty (k = 2)	13.9

Conclusions

The achieved measurement accuracy is sufficient for sunbed UV-radiation measurements. The easy portability of the Ocean Optics S2000 spectroradiometer makes the market surveillance measurements easier than with the conventional double-monochromator spectroradiometers. However, an extensive and laborious instrument characterization and complicated corrections are needed to make the measurements accurate. For the proper use of the instrument, the user should have knowledge of the instruments operating principles and potential error sources.

Acknowledgments This work has been supported by the Finnish National Agency for Medicines.

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Realising a Primary Spectral Irradiance Scale on Deuterium Lamps in the Ultraviolet

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Abstract. The NPL 2003 spectral irradiance scale is based on the spectral radiance from a high temperature blackbody source. This paper describes the extension of this scale down to 200 nm and the transfer of the scale to deuterium lamps. As the spectral irradiance of deuterium lamps is very different from that of a blackbody or tungsten lamp source, issues such as monochromator bandwidth and system linearity, must be considered with great care.

Introduction

The NPL spectral irradiance scale from 250 to 2500 nm [1,2] was formerly integrated into our measurement services and consequently became our disseminated scale in May 2003. This paper describes the extension of this scale down to 200 nm and the transfer of the scale to deuterium lamps. The scale is based on the use of the absolute spectral radiance emitted from a high temperature blackbody through Planck's law. The critical input variable being thermodynamic temperature, which is determined by a filter radiometer whose spectral response has been calibrated against the NPL primary standard cryogenic radiometer.

Measurement facility

The scale was realised on the Spectral Radiance and Irradiance Primary Scale (SRIPS) facility, shown schematically in Figure 1. The primary source was a BB3500 blackbody source, operated at temperatures around 3060 K and 3170 K. The thermodynamic temperature of the blackbody was determined absolutely using a group of filter radiometers calibrated traceably to NPL's primary cryogenic radiometer.

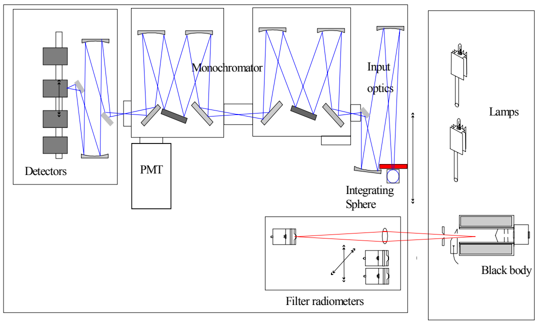

Figure 1. Schematic representation of the SRIPS facility.

A double-grating monochromator was used to select the wavelengths and measurements were made with a photo-multiplier tube. The monochromator and detector were mounted on a large translation stage that could be moved in front of each source in turn. The defining aperture for the system was on the input of an integrating sphere, the output port of which was focussed by parabolic mirrors onto the monochromator entrance slits.

Signal level

Because the blackbody and lamp have very different spectral shapes (Figure 2), issues such as detector linearity and amplifier gain must be well understood. For example, at 200 nm the signal from the lamp was 60 times higher than that from the blackbody and at 350 nm the blackbody signal was 100 times higher. The PMT detector was tested for linearity, and found to be linear to better than 0.1 % for signals below 1 μA. Care was taken to ensure that the signal did not increase above this value.

As the signal level was low for the blackbody source at 200 nm, it was not possible to use the same measurement procedures at the shortest wavelengths as elsewhere. To increase the signal, the integrating sphere was replaced by a flat PTFE diffuser. The short wavelength measurements could therefore only be considered relative, and were renormalized to the sphere results at longer wavelengths.

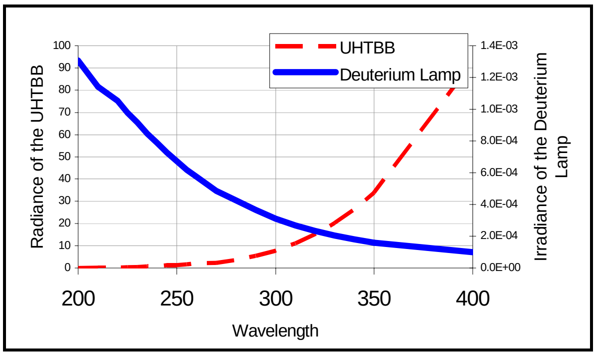

Figure 2. Irradiance of the UHTBB and deuterium lamps.

Bandwidth

Monochromator based measurements incorporate the effect of a non-zero bandwidth, so it is necessary to correct the results to a zero bandwidth situation. This problem has been investigated [3] and for a triangular slit function an approximation can be made. For a triangular slit function, of full width $2\Delta\lambda$ and a unit area, the following equation holds:

$$V(\lambda) = \tilde{V}(\lambda) - \tfrac{1}{12}(\Delta\lambda)^2 \tilde{V}''(\lambda) + \tfrac{1}{240}(\Delta\lambda)^4 \tilde{V}^{iv}(\lambda) + \ldots \qquad (1)$$

Equation (1) must be applied to each source and the ratio taken. If the two sources are very similar (as is the case for an FEL calibrated against a blackbody), the correction to the ratio is tiny, even if the correction to each individual source is significant. However as the blackbody and deuterium lamp are changing rapidly and non-linearly in opposite directions (Figure 2), a correction is required.

This correction was applied to all of the lamp data before the weighted shifts were applied. In order to have sufficient wavelengths to determine an accurate second derivative, measurements were made in 2.5 nm steps.

The bandwidth was determined by scanning a mercury line with the monochromator for the two slit widths used for the comparison measurements (slits of [3-3-5] corresponded to a bandwidth of 4.06 ± 0.05 nm, and slits [1-1-3] corresponded to a bandwidth of 1.46 ± 0.05 nm).

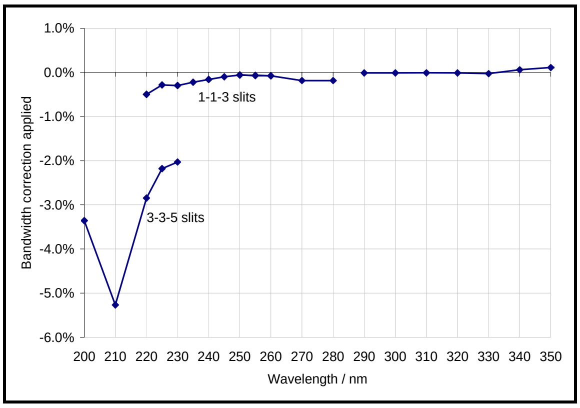

Figure 3. Bandwidth correction applied. Where there are two values for one wavelength it is because the monochromator is operated with different sized slits at those wavelengths.

Absorption Correction

Investigations have shown [4,1] that the blackbody suffers from ultraviolet absorption due to carbon sublimation around 380 nm. To understand this absorption effect at shorter wavelengths, the blackbody was measured at different temperatures and the ratio of the measured signals between the hotter and cooler blackbodies was compared with the expected ratio from Planck’s law. A cooler blackbody is assumed to show less absorption because there is less carbon sublimation, therefore a comparison of a blackbody at operational temperature with the blackbody at a cooler temperature, can be used to determine the absorption at the higher temperature.

For the UV scale realisation, the blackbody was operated at 3050 K where possible but for the shortest wavelengths sufficient signal was only obtained with the blackbody operating at 3170 K. It was not possible to make a comparison to a blackbody cool enough to show no absorption; instead the blackbody at 3170 K and 3050 K was compared to itself at 3000 K. Some absorption around 210 nm was discovered (Figure 4). The absorption is probably due to C_2N_2, which has strong lines at 209.31 nm and 210.74 nm.

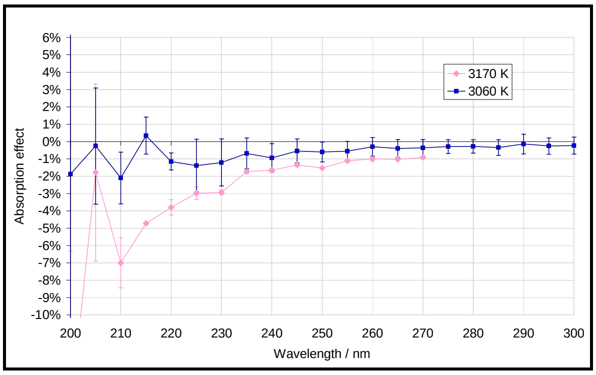

Figure 4. Absorption of blackbody – comparison of blackbody spectrum at 3170 K and 3060 K to that at 3000 K.

Transfer standard sources

As the ability to realise spectral irradiance scales at the NMIs has improved, the dominant uncertainty has become that associated with the transfer standard sources themselves. For wavelengths above 250 nm, one in three FEL lamps changes on transportation or after ~150 on-off cycles [5]. Deuterium lamps can show significant differences in absolute level between switch-ons. However, more recent lamps suffer less from this than older lamps and it is possible to monitor, and thus correct for, the changes using a photodiode [6].

Uncertainties

At the shortest wavelengths, where the signal levels are very low, the uncertainty associated with the spectral irradiance measurement is dominated by uncertainties associated with signal-to-noise. The uncertainty associated with the lamp stability can be important for older types of lamps. Lamp stability and signal-to-noise can be reduced by averaging multiple measurements of the test lamp. If this is done, then the dominant uncertainty remaining is the uncertainty associated with the blackbody radiance, which depends on the determination of temperature and the ability to correct for the absorption effect. Overall, the uncertainty associated with the spectral irradiance of a good deuterium lamp measured on three occasions ($k = 2$) drops from 9 % at 200 nm, through 3 % at 230 nm to 1 % at 350 nm.

Acknowledgements This work was supported by the National Measurement System Policy Unit of the UK Department of Trade and Industry.

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UV Dosimetry Programme at the PTB

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UV dosimetry, which is often modified by various action spectra, may be described as UV radiometry at high levels of irradiance and/or radiant exposure. While, however, calibration and measurement capabilities and uncertainties of both detector-based and source-based UV radiometry (irradiance level < 1 mW cm^{-2}) have significantly been improved recently, requirements for *traceable* calibrations at higher irradiance levels cannot be met at present. An example of the importance of traceability and international equivalence is presented considering the related field of high-power laser radiometry.

Based on those quantities in UV dosimetry that require traceability and equivalence, the basic principles of spectroradiometry are illustrated: (i) calibration of a source or a spectroradiometer against a standard source; (ii) calibration of a detector or filter radiometer against a standard detector. Spectral corrections to be considered in the case of detector calibration under multi-line irradiation are described and illustrated. Examples and applications of the monitor method and the substitution method in the case of lamp (spectral irradiance) and detector (irradiance responsivity) calibrations are presented.

Specific aspects as well as calibration and measurement capabilities of three fields closely related to UV dosimetry and in operation at the PTB are illustrated:

1. high-power UV laser radiometry including TULIP facility (TUnable Laser In Photo-metry);
2. gonioradiometry using the new robot-based goniophotometer;
3. the DSR facility (Differential Spectral Responsivity) for the calibration of large-area solar cells and filter radiometers based on the transfer from low-level, small-area to high-level, large-area radiometry.

Different approaches to the establishment of traceability chains needed in UV dosimetry are described and illustrated by way of examples covering the extension of

(i) dynamic range (based on linearity tests),
(ii) spectral range,
(iii) angular range,
(iv) area / aperture (describing geometric conditions).

First results of linearity tests in the UV are presented.

Finally, the programme for establishing UV dosimetry in the Photometry and Applied Radiometry Department of the PTB is described, where, in addition, a summary of the reply to questionnaires checking the need for "*traceable UV dosimetry*" is shortly presented and discussed.

Extreme Ultra-Violet Phototherapy

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There are three standard methods of applying UV phototherapy. One involves the combination of psoralen and UVA (known as PUVA); the other two relate to the use of UVB, namely broad-band and narrow-band (or TL01). All of these techniques have been shown to be useful in the management of certain skin conditions, particularly psoriasis.

In 1981,a group working in Munich developed a new lamp that emitted very high levels of UVA1 (340-400nm) radiation. It was claimed that this emitted 10 times more UV than a conventional phototherapy cabinet. Although technically interesting, this lamp aroused little curiosity within the dermatological community. At the mechanistic level, it was shown that UVA1 induced T-lymphocyte apoptosis, reduced the number of Langerhans cells and mast cells, increased production of collagenase, and induced photoprotection by tanning. Recently, interest has been kindled in clinical application in conditions that do not respond well to current treatments and where, based on the possible mechanisms of action, this therapy could have a role. These conditions include atopic dermatitis, systemic lupus erythematosus, and scleroderma.

Accordingly, we took delivery of a High Dose UVA1 Dermalight system manufactured by Dr Sellmeier. This comprised twenty four filtered 2 kW metal halide lamps. It has a power rating of 26.5 kW; air exchange of 1600 cbm/h; 2 intake and 2 extraction ducts each of 25 cm diameter.

We have developed a reliable and reproducible method of dosimetry. According to our measurements, UV levels are considerably higher than in conventional phototherapy cabins but only about half as much as stated by other investigators. This will allow an objective scientifically-based evaluation of the treatment, since much of the literature to date has been anecdotal in nature with no evidence to support any stated light dose. We have now treated over 50 patients, with conditions that were difficult to control and severely debilitating, and our initial impression is that many have derived considerable benefit from this new extreme form of ultra-violet phototherapy. Our treatments are all supported by dosimetry that is traceable to national measurement standards.

Further study is required before it will be known where high dose UVA1 fits within dermatological practice but early results are encouraging.

Polysulfon and spore-film UV-dosimeters compared to a UVI-monitoring instrument and two radiation transfer model systems for a UV-dosimetry study 2004 of preschool children

U. Wester

Swedish Radiation Protection Authority (SSI)

Background

SSI has cooperated with the Stocholm County Council, Center of Public Health, May 24 - June 9 2004 in a study to measure 199 preschool children´s UV-exposure at eleven daycare centers and how the exposures depend on environmental shade structures from different physical surrondings at playgrounds. The children wore polysulfon film badges each day of their stay at the preschools to measure accumulated erythemal UV-exposure during the study period. The study was part of a larger project at the Stockholm County with the main objective to assess the influence of environmental playground factors on childrens physical activity and health. The study also was a follow-up of a previous pilot project 2002 where bacteria spore dosimeters (viospore, BioSense) had been used for personal UV-dosimetry of preschool children (UV-News #7, 35-38, 2002).

Comparisons

Polysulfon film dosimeters from Newcastle General Hospital in UK (Prof B. Diffey) were used daily in parallell with commercial spore dosimeters (BioSense, Germany) at three sites on roofs or at positions with a free horizon for recording total global UV-exposure from dawn to dusk on a horizontal surface. The accuracy of the dosimeters has been evaluated by comparing the daily exposure results from one of the sites to a solar UV monitoring instrument and by comparing the data from all three sites to data from two radiation transfer models (by JRC* and SMHI**), which utilize satellite collected actual weather- and ozone-parameters.

Results of the comparisons

Comparison of the dosimeters at the reference sites during the measurement period show polysulfon measured exposures slightly below viospore measured exposures. Model calculations by SMHI and JRC respectively either are in between the dosimeters results, closer to the viospore results or higher. Variability of polysulfon measured exposures is slightly less than exposures measured with spore dosimeters. The two models agree well with each other on the average and with SSI´s solar UV-instrument that continously measures and reports the UV-index for Stockholm. The JRC-model offers higher temporal resolution than the SMHI-model and follows better a continously measuring instrument. Measurements with polysulfon badges in the study did not need corrections.

Results of the study

Will briefly be presented.

* European Commission Joint Research Centre, Institute for Health and Consumer Protection

** Swedish Meteorological and Hydrological Institute

Time resolved measurements of spectral radiant flux from VUV to NIR ($160\ \text{nm} < \lambda < \approx 1000\ \text{nm}$) on Xe excimer lamps

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Abstract A radiometric set-up is presented to measure the radiant efficacy of pulsed Xe excimer lamps. It allows time and spectral resolved radiant flux measurements from the VUV to NIR region. The results will provide a better understanding of the plasma processes in Xe excimer lamps. We measure the Xe excimer emission $\lambda_{Xe2*} = 172$ nm in the VUV and spectral lines at $\lambda_{XE*} \approx 828$ nm. We use two different monochromators with fast photomultipliers because the duration of Xe excimer micro discharges is only several 10 ns. To determine the total flux of the lamp, we choose a goniometric set-up.

Xe excimer lamp

Recent papers show that its possible to increase the radiant efficacy of dielectric barrier discharges (DBD) by using very fast pulse excitation. Improvements by a factor of 3.2 in comparison with the AC excitation were reported (Mildren et al. 2000).

The authors measured the VUV output indirectly by means of phosphor conversion from VUV into the VIS. Furthermore up to now, the radiant flux of excimer lamps has been determined by interpolation from a single determined radiant value. So the reported flux values have big experimental uncertainties and are difficult to be compared. (Falkenstein et al. 1997). The large differences between reported efficacies of Xe excimer lamps would be better understood if the VUV measurements were less uncertain. The absence of reliable standard lamps in this spectral region might be the reason why commercially available Xe excimer lamps are used to calibrate UV sensors. (Carman et al. 2004)

The Xe_2^* excimer molecule emits the main part of its radiation by spontaneous decay of Xe_2^* into an emission band in the VUV around a wavelength of $\lambda = 172$ nm (10 nm FWHM). For a better understanding of the plasma processes, it is also very interesting to measure lines from higher energy levels. Here lines in the NIR are of special interest, e.g. $\lambda = 823$ nm and $\lambda = 828$ nm. They fill the excimer levels. This is why the ratio between the VUV emission and these lines is an indicator for the radiant efficacy of a Xe_2^* plasma. Time-, wavelength- and angle- resolved measurements on cylindrical lamps from the VUV $\lambda = 120$ nm up to the NIR $\lambda = 1000$ nm have been performed.

VUV - NIR goniophotometer

In air, radiation with wavelength below $\lambda < 200$ nm is nearly totally absorbed by oxygen. To measure such wavelengths it is necessary to eliminate the oxygen out of the optical path. Either you use an non-absorbing atmosphere like N_2 or Ar, or you evacuate the hole path. We use a vacuum chamber to make long term measurements affordable. Figure 1 shows the set-up with two monochromators, one for the VUV-UV region ($120\ \text{nm} < \lambda < 320\ \text{nm}$) and another for the UV to NIR region ($200 < \lambda < 1000$ nm) and a turning arm which supports the lamp in the vacuum chamber.

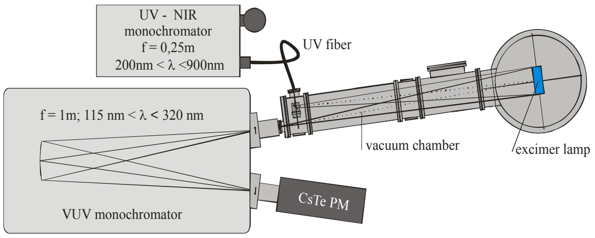

Figure 1. Set-Up with vacuum chamber, one Monochromator for VUV and one for UV to NIR and the turnable lamp at the right.

To determine the radiant intensity, a diffuser made of MgF_2 is placed in front of the VUV monochromator entrance. As the distance between lamp and diffuser was chosen ten times of the largest radiation field dimension the photometric distance law can be applied. So it was possible to calibrate the irradiance on the diffuser with a deuterium lamp, though this lamp is only a standard of radiant intensity.

The timescale of the DBD is in the range of several 10 ns. To dissolve the time dependent behavior of the plasma fast photomultipliers are used. In the lower spectral range ($120\ \text{nm} < \lambda < 320\ \text{nm}$) a solar blind CsTe PM is used. This PM is mounted at the exit port of a 1 m monochromator with normal incident grating. The longer wavelengths are detected with an f = 0.25 m Czerney-Tuner monochromator with multi alkali PM. The radiation is guided through a special UV fiber to the entrance slit. At the entrance of the fiber a quartz diffuser is used.

Stray light reduction

The vacuum chamber is made of stainless steel and reflects down to the VUV. For absolutely calibrated measurements it is necessary to have a special focus on stray light reduction. For this reason we put in both optical paths three apertures. We experienced out that carbon black gives a good and cheap absorbing coating for the wall behind the lamp. The disadvantage of this coating is that carbon black should not be touched anytime. Carbon black hardly adsorbs oxygen so that the vacuum will not be reduced.

To measure the stray light ratio we put a shutter in front of the lamp so that only the rear reflected part of the lamp output is detected. (Figure 2) To reduce the stray light fraction we also coated the rear absorber with carbon black. At the moment we analyze how the carbon in the vacuum influences the transmission of the MgF_2 in the VUV.

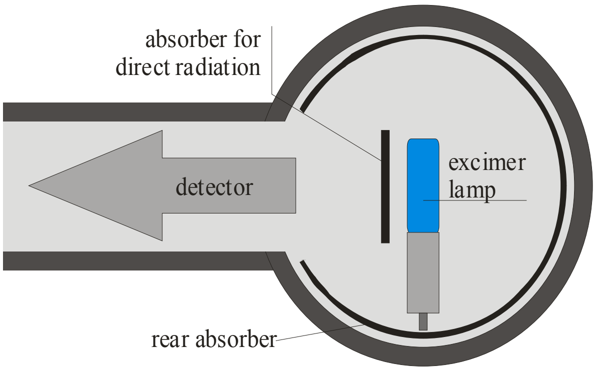

Figure 2. Set-up for stray light measurement.

Calibration

We calibrate our set-up with an deuterium lamp of known radiant intensity. For wavelengths below 160 nm this is the only available calibrated lamp. Unfortunately the spectrum of the Deuterium lamp is as shown in Figure 3. The spectrum exists of many lines. So it is indispensable to measure with the same resolution as it was done during calibration.

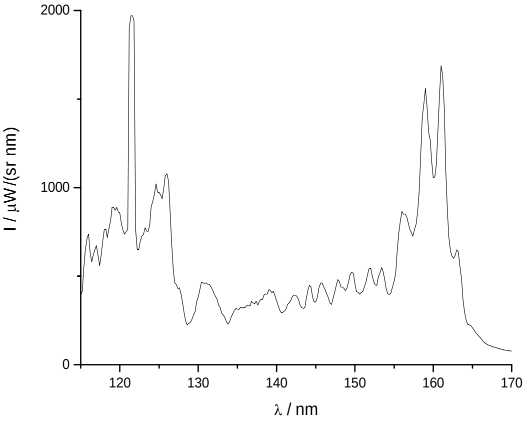

Figure 3. Spectrum of an deuterium lamp in the VUV region

To specify the spectral resolution of our monochromator we measured the lines of Hg low pressure lamp (PenRay®) in dependence of the slit width.

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Comparison of Measurement Devices for the Measurement of Erythemal Solar Ultraviolet Radiation during an Outdoor-Worker Study in Austria

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To quantify erythemal ultraviolet radiation (UVR) exposure of road construction workers involved in typical outdoor work, a study was conducted using UVR-sensitive polysulphone film badges (thickness: 26 µm, Dr. Kockott UV-Technik, data interpretation by the medical faculty of TU Dresden). While conducting personal observation on site, information on the environmental, personal and work practice factors that affect personal UVR exposure was collected. A total of more than 1000 man day exposures, involving 37 workers, were measured between July and September at 50 different construction sites in the surrounding of Vienna (latitude: 48 °N, altitude: approx. 150 m).

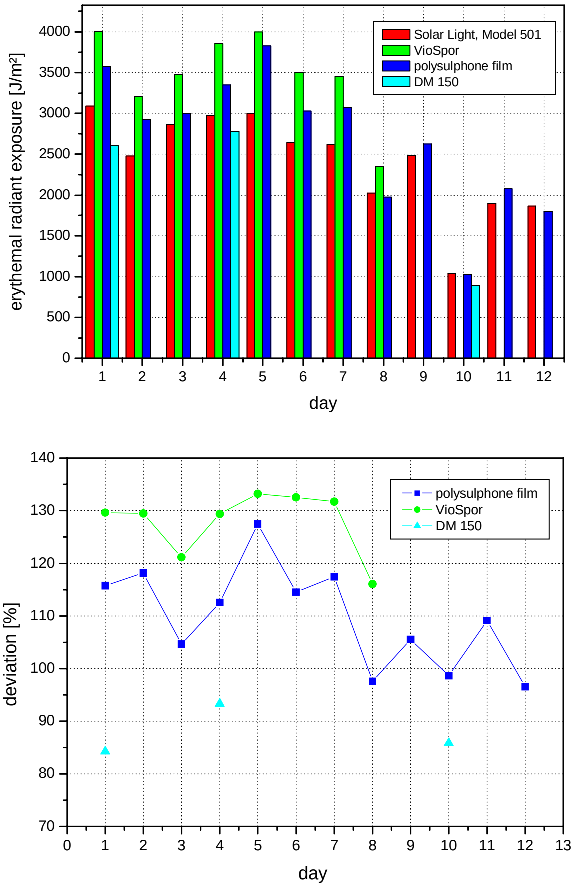
A conversion factor was calculated giving the ratio between the measured erythemal radiant exposure at different parts of the body and the global erythemal radiant exposure. With this factor it was possible to extrapolate the erythemal radiant exposure for the workers for the whole year.

To verify the measurements with the polysulphone film badges, additional UVR measurements were carried out involving the following calibrated measurement devices:

- double monochromator DM 150 (Bentham) with bialkali photomultiplier tube DH3.
- solar UV-biometer model 501 (Solar Light Inc.)
- VioSpor dosimeters which consist of an UV-sensitive photo film (immobilized spores) and a special filter-optic system.

In order to measure the horizontal erythemal radiant exposure the VioSpor and polysulphone film dosimeters were exposed to the sun from 9 a.m. to 5 p.m. on several days, being placed on a plane horizontal surface in a shadeless area. At the same location, measurements with the double monochromator (bandwidth: 2 nm) were carried out hourly and the erythemal radiant exposure was calculated afterwards. Measurements with the solar light model 501 UV-biometer were made by the University of Veterinary Medicine in Vienna, which participates in the Austrian UV-index network, some 30 km from the location of the measurements with the VioSpor and the polysulphone film dosimeters.

A comparison of the results of the various measurement devices is given in figure 1, figure 2 shows the variation of the effective radiant exposure between the devices in percent (the reference results herein are the results from the Solar Light Model 501).



Figures 1 (top) and 2 (bottom). Erythemal radiant exposure as measured by the different devices (top), and deviation of the results in percent compared to the Solar Light model 501 (bottom).

Figure 2 shows that the variation of the results between the polysulphone film dosimeters and the other devices is less than 30 %, which justifies using polysulphone films for quantitative exposure studies.

Concerning the erythemal radiant exposure of the road construction workers, the results showed that the workers received an erythemal radiant exposure between 1000 J m^{-2} and 1400 J m^{-2} per day on roughly 100 days per year. On approximately 220 days the workers exposure exceeded 2 standard erythemal doses (SED) which are typical to induce UV-erythema in people of skin type I. Workers received more than 4.5 SED on 180 days, indicating that even workers of skin type IV receive significant doses of UVR. Depending on the ground reflection and the reflection of the working materials, the recommended UV-A exposure limit for the eye was exceeded by up to a factor of 4.

GaAsP trap detector for UV measurement

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Abstract. Several GaAsP detectors have been studied mainly in linearity and local responsivity. The stability under UV irradiation has also been studied. After these studies a trap detector has been realized and calibrated several time over a four year period of time in order to check if this type of detector could be used as transfer standard for radiometric measurements in the UV spectral range.

Introduction

In order to develop transfer standard detectors and a scale of spectral irradiance based on filter radiometers in the UV spectral range, studies have been undertaken on GaAsP detectors which could be an interesting candidate for realizing trap detectors. These detectors have a good responsivity in the UV spectral range. The maximum of responsivity at 610 nm and a spectral range from 190 to 680 nm could provide a good rejection of the stray light coming from long wavelengths. The studied photodiodes were the G 2119 type from Hamamatsu with an active area of 10x10 mm^2. The following characteristics have been checked : linearity, local responsivity, stability under strong UV irradiation, short term and long term stability.

Characterization of GaAsP photodiodes

Linearity measurement : The linearity of the photodiodes was measured using a flux addition method. The radiation impinging on the detectors was provided by quartz halogen lamps running at a color temperature of about 3000 K and filtered by a Schott KG 1 filter in order to remove the IR radiation. Metal on quartz filters were used for extending the dynamic range. The results of this study are shown in figure 1 for two photodiodes referenced 98 E and 98 F respectively. The linearity is better than 10^{-4} from approximately 10 nA to 100 µA.

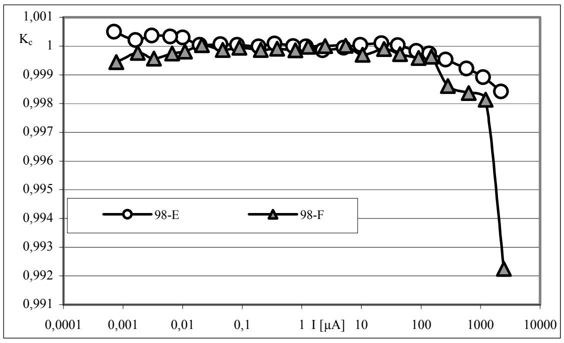

Figure 1. Linearity correction factor, for two GaAsP photodiodes versus the photocurrent of the photodiodes.

The shunt resistance and the noise in the using conditions have also been measured. For all the checked photodiodes the shunt resistance was greater than 1 GΩ and the noise was in the range of 0.5 to 2 pA.(standard deviation of dark current measurement).

Local responsivity measurement : The local responsivity of more than 10 photodiodes was measured at, at least, 3 wavelengths, 260, 300 and 380 nm with a spectral bandwidth of 3 nm. The spot on the detector had a diameter of little less than 1 mm and the scanning step was 1 mm. In general the local responsivity of these photodiodes was not very good ranging from some percent for the best (figure 2) to some tenth of percent for the worst.

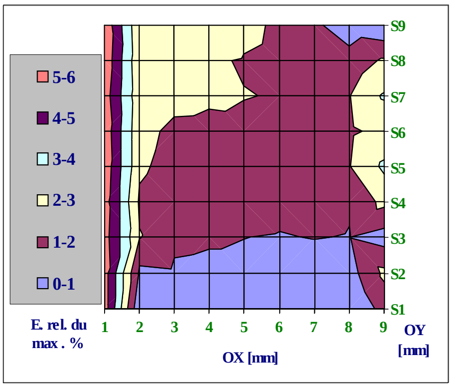

Figure 2. Local responsivity of a GaAsP photodiode of a reasonably good quality.

The local responsivity of some of the detectors was also checked at 488nm using an argon laser. The results were of the same type as the results in the UV range and generally worse. The reflectance factor of the photodiodes have also been measured in the spectral range 250 to 400 nm for two incidence angles, 10° and 45°. It was fond in the range of 45% to 50% varying slightly with wavelength.

Stability under UV irradiance : The stability of the detectors under UV irradiance was checked using. a deuterium lamp at an irradiance level of 130 mW.cm^{-2} (total irradiance) during about 20 hours. The variation of the responsivity was measured at 220, 260, 300, 340 and 380 nm every hour. During about the 5 first hours of irradiation the detectors have exhibited a variation of 1% to 5% depending on the wavelength. After that, they seemed to become stable with variations lower than the uncertainty of measurements.

Realization of a trap detector

Starting from the results obtained on GaAsP photodiodes it was decided to realize a three elements reflection trap detector to be used as reference detector in the UV spectral range. For that 12 photodiodes of G 2119 type from Hamamatsu with an active area of 10x10 mm^2 have been bought and three of them having the best local responsivity have been used for realizing the trap detector. But before mounting them in the trap they have been aged under UV radiation coming from a deuterium lamp at a level of irradiance of 130 mW. After that, the trap detector called P-UV-1 have been calibrated in spectral responsivity. The calibration have been carried out in a 2 step method. In a first step the relative spectral responsivity is measured by comparison with a non selective cavity shape pyroelectric detector. In a second step the absolute spectral responsivity is measured by direct or indirect comparison to the cryogenic radiometer at some laser wavelengths in the visible range.

A typical absolute spectral responsivity curve of the GaAsP trap detector P-UV-1 is shown in figure 3.

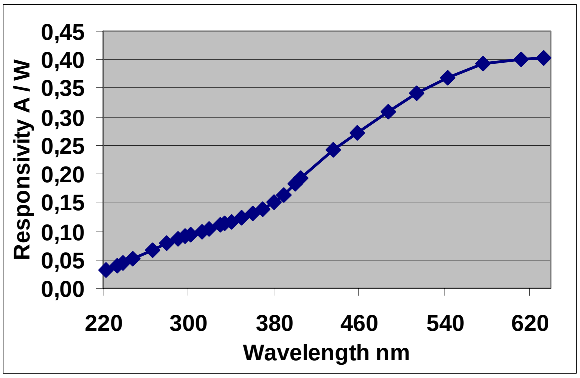

Figure 3. Spectral responsivity curve of the GaAsP trap detector P-UV-1.

Absolute calibrations : The first absolute calibration of this detector was carried out in April 2001 at the laser wavelengths of 487, 514, 543, 612 and 633 nm. Then it was again calibrated at the same wavelengths in February 2002, April 2004 and May 2005. The relative variation of the spectral responsivity of the detector between the various calibrations are shown in figure 4 taking as reference the first calibration.

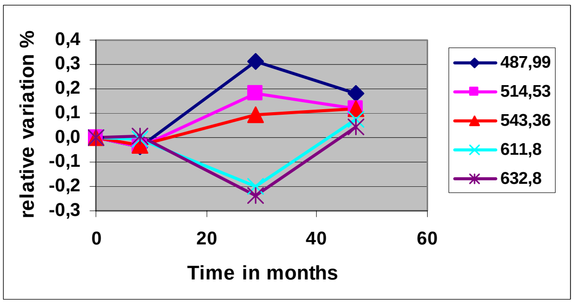

Figure 4. Stability of the absolute spectral responsivity of the trap detector P-UV-1 over a four year period.

The first, the second and the fourth calibration have been carried out by comparison behind a monochromator with a rather large beam, to a silicon trap detector calibrated against the cryogenic radiometer with laser beams. The third calibration has been carried out directly against the cryogenic radiometer with laser beams. In order to explain the different behavior of the third calibration compared to the others the local responsivity of the detector was checked at the wavelength of 543 nm over a diameter of 3 mm with a diameter of the laser beam less than 1 mm. The maximum deviation was 5.2 10^{-4}. The calibration have been also carried out at the wavelength of 488 nm, at two power levels of 100 and 50 µW in order to check potential linearity problems. The two results were well within the uncertainties.

Relative calibrations : The relative spectral responsivity calibration were carried out three times in June 2001, in February 2002 and in May 2005 by direct or indirect comparison to a non selective cavity pyroelectric detector over the spectral range 280 to 633 nm.

The results of these measurements are shown in figure 5. The reference value used for determining the relative spectral responsivity was the mean value of the spectral responsivity at the wavelengths of 487, 514, 543, 612 and 633 nm. This reference value has been chosen because the absolute calibrations for linking the relative and the absolute values are done using all these wavelengths.

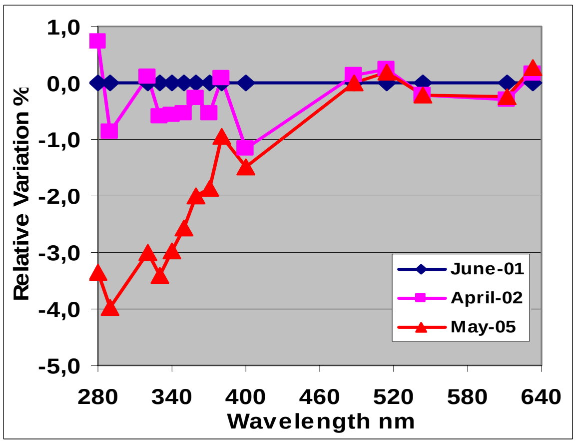

Figure 5. Stability of the relative spectral responsivity of the trap detector P-UV-1 over a four year period.

Conclusion

Several GaAsP detectors have been studied in order to realize a trap detector to be used as transfer detector. The linearity of this type of detector is good over a dynamic range of more than 5 decades but the local responsivity is rather poor. Mounting in a trap configuration this type of detector improves the local responsivity.

The spectral responsivity of the detector exhibit a small drift during the first hours of UV irradiation and after that become stable (short term stability). The long term stability checked over a four year period has shown a very small drift in the visible range. This drift increases for decreasing wavelengths. The annual drift is about 1% a year at 280 nm. This drift is too large for using this detector as transfer standard for very accurate measurements. Nevertheless it could be useful for usual calibrations du to its rather high spectral responsivity in the UV range and its limited spectral range in the visible.

Improvements of a fast Scanning Double Monochromator for UV-B Monitoring

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The SPECTRO 320 D scanning double monochromator was first introduced in 1995 as a fast measurement system for the monitoring of UV-B radiation. The measurement of the complete UV-B range up to 450 nm is accomplished within 1 minute. Later the extension of the scan range to visible and infrared radiation was available. The paper describes new developments and improvements regarding the optomechanical layout and the control electronics.

The SPECTRO 320 D is based on a modified Czerny-Turner monochromator with a focal length of 320 mm. In figure 1 the optical layout of the double monochromator is shown. To record the spectra quickly at high wavelength accuracy, the diffraction grating is driven directly by a steadily rotating DC motor. A complex, mechanical drive is no longer essential as a precision angle encoder synchronizes the data acquisition during rotation. This guarantees a high absolute wavelength accuracy and linearity. Since all available diffraction gratings are located on the same axis, irregular rotational movements between the two individual monochromator parts during the scan are thus eliminated. A wide spectral range from UV to IR within one single instrument is offered. Moreover, up to three detectors can be located at the exit slit of the monochromator. A movable mirror guides the light beam to one of the detectors as required. The change-over of the gratings and detectors in use takes place automatically. The overlapping area of the respective spectral ranges is used by the software in order to join the individual spectra to each other correctly.

In the new release 5 of the SPECTRO 320 D several new features were implemented:

- An improved mechanical design of the mirror mounts leads to a significantly smaller temperature drift of the measurement signal.
- The measurement parameters are no longer fixed for the whole wavelength range. An unlimited number of sub-ranges can be defined, each of it with individual measurement parameters due to specific requirements of the test source. This enables the user to define ranges with faster or slower scan speeds which is essential to achieve short measurement times.
- The new control electronics is equipped with electronic switches instead of mechanical relays. This makes the switching between different amplifier gains much faster.
- Due to a new mechanical layout a cooled UV optimized photomultiplier can be used together with two other detectors, like InGaAs, PbS, etc. This offers the possibility for a measurement over a broad wavelength range using up to three different gratings in a single scan.

The new release of the SPECTRO 320 D provides a variety of features in a unique combination. Short measurement times can be realized whereas the unsurpassed flexibility of the measurement system regarding wavelength range, launching optics etc. remains untouched.

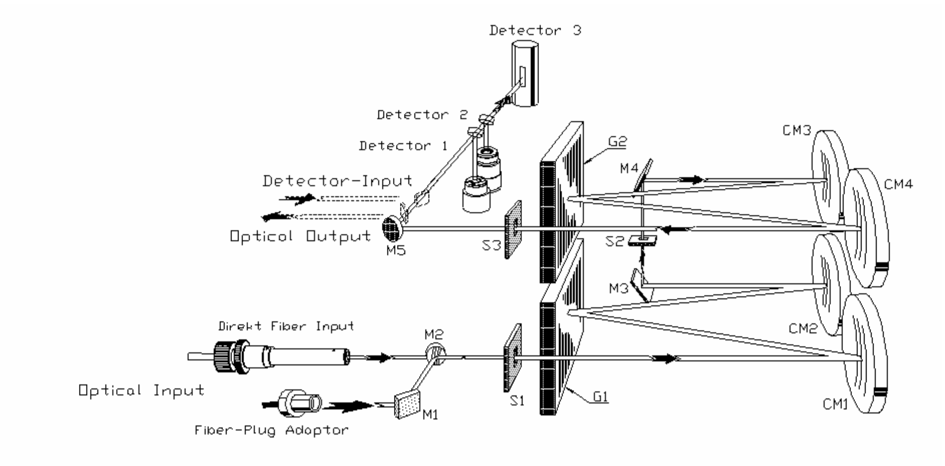

Figure 1. Optomechanical layout of the SPECTRO 320 D. Up to three different pairs of gratings are mounted on a common turret.

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A non-scanning UV spectroradiometer for long-term measurements in polar regions

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Spectral UVB irradiance (280-320 nm) is being monitored at the NDSC primary site at Ny-Alesund, Spitsbergen (78.9° N, 11.9° E) and at the German Antarctic Neumayer Station (70.65° S, 8.25° W, complementary NSDC site) by the Alfred Wegener Institute for Polar and Marine Research (AWI). A third polar site operated by AWI, where spectral UV irradiance is monitored, is the Dallmann Laboratory/Jubany Station at the Antarctic Pensinsula (62° 14' S, 58° 40'W).

The UVB-spectroradiometer is based on a Bentham DTM150 double monochromator and a Microchannel Photomultiplier Plate with 32 channels. Additional instruments were installed at Ny-Alesund in 2000 and at Neumayer station in 2001 to cover also the UVA range (320-400 nm) of the solar spectrum. This instrument contains a single monochromator as the dynamic range is low in the UVA compared to the UVB. The detector is a photodiode array with 256 detection channels. Single spectra can be taken every second. In routine operation the spectra are stored as 5-minute averages.

Currently, the UV spectroradiometer is in the NDSC research mode. Since Ny-Alesund is a primary NDSC site and Neumayer station a complementary NDSC site, it is also desirable for the measurements of spectral UV irradiance to comply with the NDSC spectral UV specifications. Thus, the main focus is directed to the characterization of the instrument and its performance.

Procedures for quality control have been developed and applied to check the data quality. At the Arctic site in Ny-Alesund, the UV spectroradiometer is returned every winter to the home laboratory in Bremerhaven, Germany, for recalibration. Until 2004, the recalibration was performed in the radiation laboratory with a 1000 W FEL lamp traceable to PTB. In 2005 the main standard has been replaced by a horizontal DXW lamp, also traceable to PTB. This change in lamp type was necessary due to the design of the instrument. The instruments at the two Antarctic sites, Neumayer and Dallmann, are also exchanged on a regular basis for recalibration. During operation at the polar sites, the sensitivity and wavelength stability of the instrument is checked regularly by the station staff.

Sensitivity changes due to transport are monitored with a mobile calibration unit. This calibration unit includes a 150 W tungsten halogen lamp which is contained inside a lamp housing. The lamp housing was especially designed for our instruments. It is cylindrical with a diameter of about 15 cm and a height of 35 cm. The inner surface is coated with a non-reflecting black matt varnish. During operation this lamp housing is ventilated from outside to prevent overheating and thus an instability of the lamp. The portable power supply has an internal data storage, where the voltage across the lamp and the current through the lamp can be recorded. This way, the performance of the mobile calibration lamp can be monitored as well.

Time series of daily doses of UVB, UVA, and erythemal irradiance will be shown for all three polar sites. Differences in the UV radiation climate will be pointed out. At two of these sites the measured UV irradiance are not only important with respect to establishing a UV climatology. They are also important for studies of UV effects on biological systems. At Ny-Alesund and Dallmann, effects of UV radiation on different species of algae are investigated by a biological research group of AWI. This group at our institute further underlines the importance and need to conduct measurements of spectral UV radiation in polar regions.

Spectral UV-Measurements in the Arctic and Antarctica

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Non-scanning UV-(A&B) spectroradiometers of our own design have been deployed for long-term measurements at NDSC sites in both polar regions. Since 1997 spectral resolved UV-spectra are continuously recorded at Neumayer Station (Antarctica, 70.65°S, 8.25°W) and at Ny-Aalesund (Spitsbergen, 78.9°N, 11.9°E). Concerning some parameters which are important for UV radiative transfer the conditions differ significantly at these two stations. Due to the differences in the stability of the northern and southern polar vortex ozone depletion in spring is found only in some years at Spitsbergen whereas the Antarctic ozone hole can be observed every year over Antarctica. Our UV measurements are evaluated by taking into account total ozone data from ozone sondes and TOMS (Total Ozone Mapping Spectrometer) satellite data. To suppress the dominating influence of cloud variations on the UV radiative transfer, the ratio of the irradiation at two wavelengths (300nm/320nm), the so-called ozone index, is being used. By making use of the daily available TOMS data the expected anticorrelation of the ozone index and the total ozone could be verified. For the observation period the comparison of changes in the ozone index and total ozone for different years leads to a quantitative relation between the two measurands, the radiation amplification factor of total ozone. Apart from the different variability in total ozone, there is a distinctive seasonal variation in ground albedo and cloud cover at Spitsbergen, which is not found at Neumayer Station. These parameters are determinative for UV fluxes at the ground. A comparison of the datasets from the two sites will be presented.

Surveillance of UV-sensors in UV-disinfection plants in water works

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Keywords: Sensors, drinking water, UV-radiation, disinfection

Introduction

In the frame of two projects [one by American Water Works Association Research Foundation (AWWARF RFP 2977), the other by Niederösterreichische Landesregierung] water works with UV-disinfection plants for drinking water were visited and the reference irradiances measured by the plant sensors were compared with measurements done with reference sensors. Except of these sensor measurements the UV-transmittance of the water and other parameters were checked. The measurements mainly were based on the Austrian standard for disinfection plants for drinking water using low pressure mercury lamps (ÖNORM M5873-1, 2001) and a pre-standard for plants with medium pressure lamps (VORNORM ÖNORM M5873-2, 2003). Measurements were performed in several countries: Austria, Germany, Finland and Sweden. The measurement in Paderborn/Germany was based on the work-sheet W294(1997) from DVGW (Deutsche Vereinigung für das Gas- und Wasserfach). An examples of UV-disinfection plants can be seen in figs. 1a,b. The efficiency of UV-plants is tested by biodosimetry in using calibrated spores of *Bacillus subtilis* as "measuring instrument". Biodosimetry gives as result the Reduction Equivalent Fluence (REF) and in measuring the reference irradiance during the biodosimetric test, a parameter is defined which can be used for monitoring the UV-plant in the water work. The above mentioned standards define, among others, requirements for the monitoring sensors. The standards distinguish between reference sensors and plant sensors. For the reference sensor the parameters which have to be tested are: calibration of irradiance, spectral response, measuring range and linearity, measurement uncertainty, temperature response, stability over time and the geometrical dimensions of the sensor. The measurements in the water works often showed high discrepancies between the values measured with a reference sensor compared with the plant sensor.

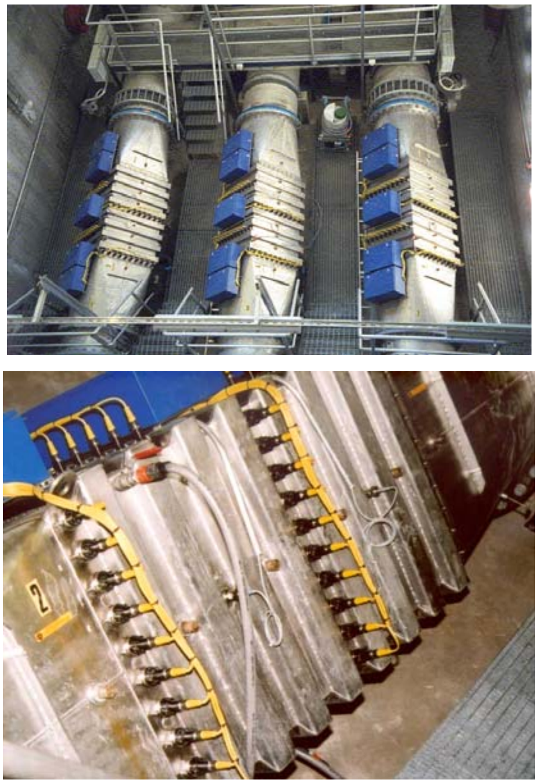


Figure 1a (top) UV-disinfection plants in water work Pitkäkoski/Helsinki, Finland. Figure 1b (bottom) several plant sensors can be seen at the side of the UV-plant.

Measurements were performed in water works with low-pressure mercury lamps which emit predominantly UV-radiation at 253,7 nm and in one water work with medium pressure lamps. The measurement of the reference irradiance for low pressure plants is much easier because of the quasi-monochromatic nature of the radiation. When medium pressure lamps are used the sensor must weight the radiation according to the microbicidal action spectrum of Bacillus subtilis, the biodosimeter. In figure 2 this action spectrum is given (ÖNORM M5873-2).

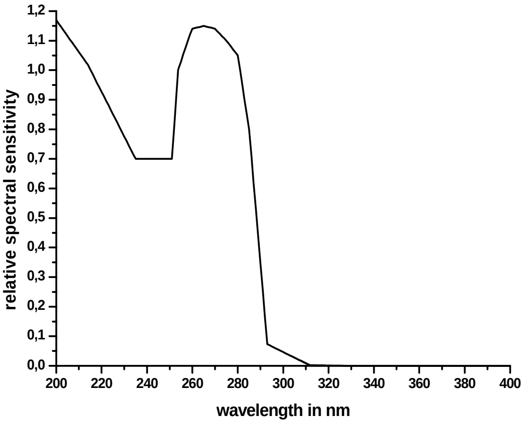
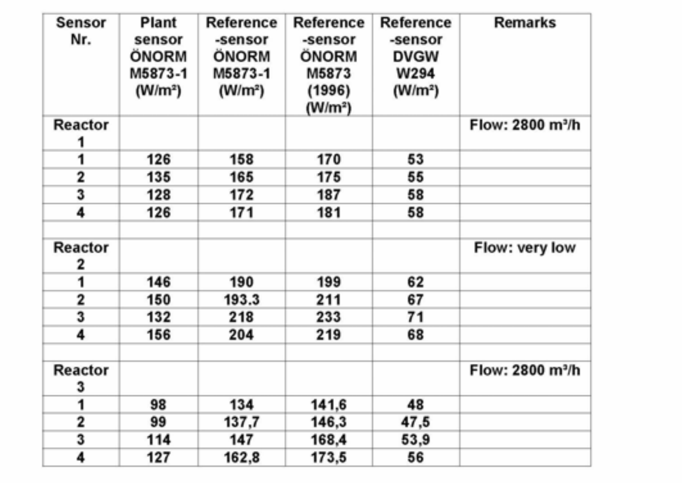


Figure 2. spectral response of spores of Bacillus subtilis according to ÖNORM M5873-2.

Results

Some results from the measurements in Helsinki are given in table 1.

Table 1. Reference irradiances measured with plant sensors and reference sensors. Measurements were also done with an older version of the ÖNORM-sensor which gives slightly higher irradiances.The German DVGW-sensor cannot be directly compared with the ÖNORM-sensor because of different entrance optics.



Sensor Nr.	Plant sensor ÖNORM M5873-1 (W/m^2)	Reference -sensor ÖNORM M5873-1 (W/m^2)	Reference -sensor ÖNORM M5873 (1996) (W/m^2)	Reference -sensor DVGW W294 (W/m^2)	Remarks
Reactor 1					Flow: 2800 m^3/h
1	126	158	170	53	
2	135	165	175	55	
3	128	172	187	58	
4	126	171	181	58	
Reactor 2					Flow: very low
1	146	190	199	62	
2	150	193.3	211	67	
3	132	218	233	71	
4	156	204	219	68	
Reactor 3					Flow: 2800 m^3/h
1	98	134	141,6	48	
2	99	137,7	146,3	47,5	
3	114	147	168,4	53,9	
4	127	162,8	173,5	56	

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DVGW W294(1997), Bonn, Germany

Stray light correction of array spectroradiometers and implications for UV metrology

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In measurements of ultraviolet (UV) radiation, the integrated total UV exposure over a defined spectral interval is often of interest. In other cases, the action initiated by UV radiation is of interest. In this situation, UV source measurements are often weighted by a particular action spectrum (e.g. the erythema function). Meters that measure UV radiation are often filter-based instruments, comprised of several optical elements, including a detector and a filter. In most cases, the match between a UV meter's spectral responsivity and a particular action spectrum is poor, resulting in potentially large errors in the measurement of a desired quantity.

There is continued demand for increased measurement accuracy in UV metrology, and array spectrometers offer an attractive alternative to filter-based UV meters. In particular, measurement results can be weighted mathematically to produce any desired action spectrum. Stray light scattered within UV spectrometers can cause large errors in measurements with these systems, and currently limits their widespread use in UV metrology. In this work, we describe the characterization and stray light correction of a UV array spectrometer, and discuss implications for the use of spectrographs in the measurement of UV radiation.

In an example application, the stray-light-corrected UV spectrograph was calibrated for absolute spectral responsivity against a tungsten quartz halogen lamp and was used to transfer the absolute spectral responsivity to a reference diode array spectrometer over the spectral range from 290 nm to 400 nm. The reference spectrometer measures the total dose exposure from an integrating sphere-based ultraviolet (UV) exposure chamber developed at the National Institute of Standards and Technology (NIST) for accelerated UV irradiance studies of a wide range of commercial polymer products and advanced materials such as colored filters for space-based applications. In interpreting the effects of long-term UV irradiance on a material sample, it is important to know the total flux (total dose exposure) incident on the object over the spectral range from 300 nm to 400 nm.

The calibration was transferred from the UV spectrograph to the reference spectroradiometer using the UV exposure chamber itself. Using the source being measured to transfer the calibration, wavelength errors, errors arising from stray light, and other sources of error in measurements with the reference spectroradiometer cancel, and the calibration can be transferred with minimal increase in measurement uncertainty.

Calibration and Characterization of UV Sensors for Water Disinfection

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Introduction

Ultraviolet radiation (UV) effectively inactivates common pathogens found in ground and surface waters such as *Cryptosporidium*, *Giardia*, and most bacterial pathogens (e.g., *E. coli*). Water treatment facilities recently started using ultraviolet radiation for disinfection of drinking water, replacing standard chemical treatment. Typically, low-pressure and medium-pressure mercury lamps (LPM and MPM, respectively) are used in the UV reactors at the facilities. In these reactors, water flowing at a given rate should receive an appropriate UV dose. UV sensors mounted on the wall of the UV reactor or inserted into the water flow monitor the dose level by measuring the irradiance from the lamps. The UV sensors currently in use have a variety of designs and performance characteristics. Austria and Germany have developed or are developing standards for the sensor design and performance. These two standards differ in their requirements and do not address many of the problems associated with the UV monitors. Furthermore, there are already many water plants employing UV sensor systems consistent with one or the other standard. To resolve this confusion, American Water Works Association Research Foundation (AwwaRF) decided to develop new guidelines for UV monitors. The National Institute of Standards and Technology, USA (NIST) is participating in this project in collaboration with Carollo Engineers (Boise, ID), CDM (Denver, CO), and the University of Veterinary Medicine (Vienna, Austria). NIST studied the current UV water disinfection standards, ÖNORM M5873-1 and M5873-2 [1] (Austria), and DVGW W294 3 [2] (Germany), on the requirements for UV sensors for LPM and MPM lamp systems. Pertinent to the study, NIST is measuring and analyzing the characteristics of various types of UV sensors. This information will aid in the development of new guidelines which will address issues such as sensor requirements, calibration methods, uncertainty, and traceability.

Problems with irradiance calibration of sensors

The physical quantity to be measured is the microbicidal irradiance, defined as the total irradiance (W/m^2) weighted by the microbicidal action spectrum $s_{\mathrm{mik,rel}}(\lambda)$ as shown in Fig. 1. According to ÖNORM M5873-1, M5873-2, and DVGW W294-3, UV sensors for both LPM and MPM systems are calibrated for irradiance responsivity against an LPM lamp. Since the value of $s_{\mathrm{mik,rel}}(\lambda)$ is unity at 254 nm, and LPM lamps only have significant flux at 254 nm, the measured irradiance from an LPM lamp is equal to the microbicidal irradiance. Instruments can be calibrated for microbicidal irradiance responsivity using an LPM lamp, regardless of the sensor's spectral responsivity. This method works very well for LPM lamp systems. However, there is a problem for MPM lamp systems. The spectral output from MPM lamps differs significantly from LPM lamps. In addition, real UV sensors never have spectral responsivities perfectly matched to $s_{\mathrm{mik,rel}}(\lambda)$. In fact, many of the sensors used for MPM lamp systems have fairly large deviations from $s_{\mathrm{mik,rel}}(\lambda)$. As a consequence of the differences between LPM and MPM spectral distributions and differences between the sensor spectral responsivities and $s_{\mathrm{mik,rel}}(\lambda)$, measurement errors of the microbicidal irradiance occur. This source of measurement error, called a spectral mismatch error, is well known in other applications, e.g., photometry, where a detector's responsivity is tuned to match the action spectrum, $V(\lambda)$. Note that if a UV sensor had a spectral responsivity perfectly matched to $s_{\mathrm{mik,rel}}(\lambda)$, there would be no problem, that is, the measured irradiance value would be equal to the microbicidal irradiance.

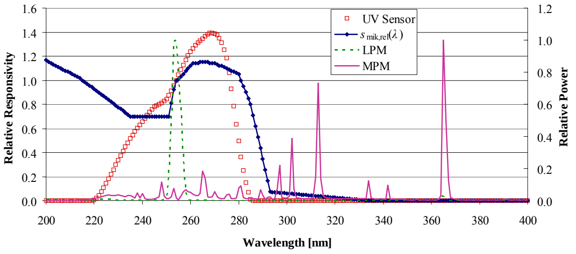

Figure 1. The microbicidal action spectrum, $s_{mik,rel}(\lambda)$; the spectrum of an LPM lamp and a MPM lamp; and the spectral responsivity of a UV sensor.

To ensure that such errors will not be significant, the ÖNORM and DVGW standards specify requirements for the relative spectral responsivity of sensors used for MPM lamp systems. DVGW W294-3 requires that a term $f_{1,z}$ be calculated from the relative spectral responsivity of the sensor, and the sensors must meet $f_{1,z} \leq 0.25$ (reference sensors) or $f_{1,z} \leq 0.40$ (duty sensors). ÖNORM M5873-2 does not require the relative spectral responsivity of the sensors. However, it requires measurement with two specified cutoff filters and a MPM lamp that is to be calibrated with a spectroradiometer. The D value (relative difference between the microbicidal irradiance measured by the sensor and spectroradiometer) is calculated from these results. The sensors must meet $D < 0.2$ for both filters. The evaluation of relative spectral responsivity is critical but not easy in either standard. In addition, NIST found that many of the currently used commercial sensors do not meet these requirements. Reference sensors that meet the requirements can still have errors as much as 20 %.

Proposed calibration scheme

To solve the practical problems found in the calibration methods and evaluation of spectral responsivity requirements for sensors designed for MPM lamp systems NIST is proposing an alternate sensor calibration method for MPM lamp systems. The root of the problem is that the MPM lamp has a very different (multi-line) spectrum than the LPM calibration lamp (a single emission line at 254 nm). The proposed method is to use a MPM lamp as a calibration source for the sensors used to measure MPM lamp systems. This approach is based on the well-established principle that errors are minimized in any measurement system when the standard and test sample are of the same type (strict substitution). In strict substitution, many of the measurement error components are cancelled out. If the UV sensor is calibrated using an MPM lamp, and subsequently measures MPM lamps having the same spectral distributions, the error will be zero, theoretically, regardless of the spectral responsivity of the sensor. In real cases, there are variations in the spectra of MPM lamps, so the errors will not be zero, but errors will be significantly reduced even with sensors having a large deviation from $s_{\mathrm{mik,rel}}(\lambda)$.

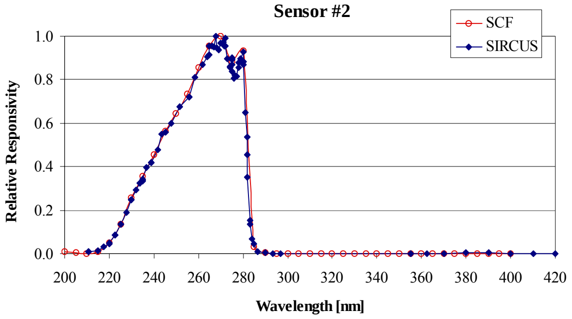

Figure 2. Relative spectral irradiance responsivity data of one of the sensors measured by SCF and SIRCUS.

The actual calibration of sensors with this method can be done simply. It only requires a MPM lamp and a reference standard sensor calibrated for MPM microbicidal irradiance responsivity. Then, the UV sensor under test can be calibrated simply by comparison to the reference standard sensor under illumination by a MPM lamp. This method is analogous the situation in photometry where the $V(\lambda)$ function defines the spectral response of a photometer. To ensure consistency in the calibration approach, a reference MPM lamp spectrum may need to be defined; ÖNORM M5873 2 already lists a nominal MPM lamp spectrum. A similar example exists in photometry with the CIE standard source, Illuminant A. The source has a standardized, defined spectral distribution, an incandescent source (lamp) approximating a blackbody at a temperature of 2856 K. All photometers are calibrated using a standard incandescent lamp having a spectrum close to the CIE standard Illuminant A. With this approach, photometric calibration results are universal.

Characterization of the UV sensors

10 different UV sensors from 6 different manufacturers designed for water disinfection monitoring have been characterized at NIST for several parameters. The relative spectral responsivity measurements were taken at two NIST facilities. The first is a monochromator-based spectral responsivity measurement facility referred to as the Spectral Comparator Facility (SCF). This system was designed for spectral power responsivity measurements. The facility also has the capability to measure a detector's irradiance responsivity. The absolute irradiance responsivity in V/(W/m^2) or A/(W/m^2) is measured by spatially scanning the beam across the detector entrance aperture in very small distance intervals using an X-Y stage. In this manner, NIST was able to measure the relative spectral irradiance responsivity of 10 sensors though measurements of some of the sensors had very large uncertainties due to extremely low signal. The incident flux in this facility is fairly low, on the order of 1 µW, while these sensors are designed for very high irradiance levels (up to 2000 W/m^2).

The relative spectral responsivity for eight of the sensors was also measured in another NIST facility capable of generating higher monochromatic UV flux. This facility, the Spectral Irradiance and Radiance Responsivity Calibrations using Uniform Sources facility (SIRCUS), can generate monochromatic beams with up to ~100 mW of power in the 200 nm to 400 nm region using the frequency doubled, tripled and quadrupled output from pulsed Ti-Sapphire laser, which has a quasi-CW emission (pulses at very high frequency, 76 MHz). To measure the irradiance responsivity of the sensors, a frosted quartz diffuser plate was placed in front of the detectors to generate a quasi-uniform irradiance field at the detector reference plane. The irradiance levels ranged from approximately 2 W/m^2 to 20 W/m^2 at 254 nm.

An example of relative spectral responsivity data is shown in Fig. 2. The responsivity measurement results indicate a large variation in the spectral responsivities of the commercial sensors. The spectral mismatch of these sensors (deviation of the relative spectral responsivity curve from the microbicidal action spectrum $s_{\mathrm{mik,rel}}(\lambda)$) causes significant errors in the measured microbicidal irradiance as large as 160 %. Many of the sensors did not meet ÖNORM M5873-2 and DVGW W294-3 requirements for relative spectral sensitivities of the sensors.

The linearity (limited range), temperature dependence (10°C to 35°C), and angular responsivity of these sensors at 254 nm have also been measured and evaluated. Some significant nonlinearity at low levels for some of the sensors was observed.

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2. DVGW W294-3 "UV Disinfection Devices for Drinking Water Supply - Requirements and Testing" (2003)

Long-term measurements of UV-solar radiation in Dortmund (Germany)

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The Federal Office for Radiation Protection (Neuherberg) and the Federal Environmental Agency (Berlin) run since 1993 a German UV-monitoring network with the aim to obtain long-term series of UV-data to be used in further assessments related to health and environmental issues. The measuring station of the Federal Institute for Occupational Safety and Health in Dortmund is an associated station of the network. Spectrally resolved measurements of UV-solar radiation are performed with a double monochromator which operates at $51^0$32'N , $7^0$27'E and 100 m above sea level. The global solar radiation is measured by a pyranometer. The data are measured continuously during last nine years. We will present non-weighted and biologically weighted UV-solar irradiance spectra, as well as the global solar irradiance data measured at our station.

Characterization of Integrating Spheres for Ultraviolet Radiometry

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In UV radiometry, concerns over the stability and contamination of diffusing materials, such as polytetrafluoroethylene (PTFE), have been raised for a long time. To date, there are only a few studies mostly on the material reflectance under UV irradiation from sources such as Hg or Xe lamps [1,2,3]. Significant degradation in reflectance was observed and it was attributed to contaminants [1]. For integrating spheres, whose throughput is highly sensitive to material reflectance, it was suggested that fluorescence under UV irradiation could be an additional issue for accurate radiometric measurements [4]. To the best knowledge of the authors, the cause for fluorescence and the stability of integrating spheres exposed to UV radiation are unknown.

The excellent radiation diffusivity and depolarization properties of an integrating sphere makes it a good choice in preparing radiation from sources, such as deuterium lamps and synchrotron radiation, for high accuracy detection and transfer of radiation scales. The combination of deuterium lamp and integrating sphere could pose serious measurement challenges if UV radiation from the deuterium lamp either spoils the throughput over time or induces fluorescence. Here, we report the investigation of the performance of integrating spheres under UV irradiation from deuterium lamps. The integrating spheres studied are made with PTFE both in pressed and sintered forms. The pressed PTFE spheres are made at NIST and the sintered PTFE spheres are obtained from commercial products.

The study of integrating spheres under UV irradiation consists of two parts. In the first study, the integrating sphere under investigation is exposed to a deuterium lamp. The radiation exited from the integrating sphere is directed through a monochromator and detected by a photomultiplier tube. We measured and compared the spectral throughput for a variety of integrating spheres and observed different UV absorption spectra between integrating sphere. We also studied the change in the spectral throughput of integrating spheres after prolonged irradiation by the deuterium lamp. Furthermore, we used a second setup to identify fluorescence in the measured UV spectra. In this setup, the integrating sphere is exposed to a monochromatic UV laser beam as short as 210 nm from a tunable laser at NIST's SIRCUS facility. The output beam from the integrating sphere is analyzed by a spectrograph to identify any fluorescence excited by the incident laser. An example of measured results is shown in Fig. 1.

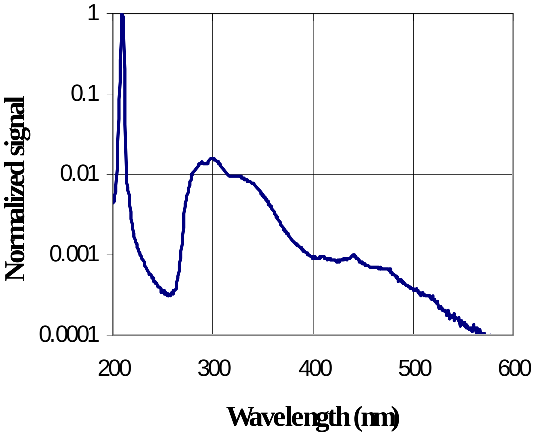

Figure 1. Spectral output from a sintered PTFE integrating sphere irradiated by a 210 nm laser beam. The structure around 300 nm is caused by fluorescence.

Our measurement results clearly show distinct UV absorption and fluorescence features by PTFE integrating spheres. In accordance with previous studies, we found contaminants are mostly responsible for the observed absorption and fluorescence as well as the degradation of integrating spheres. However, baking in vacuum can remove some but not all contaminants. In addition, fluorescence from the UV laser provided important clues for identifying the chemical nature of contaminants. We have identified several contaminants from the environment that have serious effects on the performance of PTFE integrating spheres. Detailed results and analysis as well as recommendation for the choice of integrating spheres for UV work will be given.

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Determination of UV radiation doses of asphalt and roof workers in Finland

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A project on outdoor asphalt and roof workers' exposure to heat and solar ultraviolet (UV) radiation was started in June 2005 by the Finnish Institute of Occupational Health. The project consists of three sub-projects which aim 1) to collect detailed data on the daily UV radiation doses, 2) to evaluate heat stress for the workers during sunny days, and 3) to provide guidance for protection against UV radiation and heat.

The UV exposure sub-project will be carried out in Southern, Central and Northern Finland during sunny summer days in 2005 and 2006. The specific goal of the measurements to be done in Northern Finland is to study the influence of the long daylight time and low solar elevation angles on the daily UV radiation doses.

For determination of the daily UV exposure doses, 10 personal electronic data loggers (Gigahertz-Optik Model X2000-2) will be used. Each dosemeter contains two detectors equipped with cosine corrected diffusers; one for measuring the total UV-A radiation (320 – 400 nm) and one for measuring the ICNIRP weighted UV radiation (200 – 400 nm). The diameter of the measurement aperture is 8 mm for both detectors. The loggers will be attached to the workers' clothing during the whole work day. Each test person will wear one or two dosemeters: one on the shoulder and, if two loggers are used, the other at the position of the back.

In addition to the personal UV doses, the solar radiation at a fixed point at the work area will be measured in the morning, at noon and in the afternoon, using a broadband CIE erythemal weighted UV meter (Solar Light Model 501) and/or a double monochromator spectroradiometer (Optronic Model 742). Both instruments will be directed vertically towards the sky (at 0° zenith angle).

The preliminary results of the UV measurements will be presented in the Workshop.

Determination of reference planes of spectroradiometer diffusers

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With spectroradiometer measurements, it is usually assumed that inverse square law is valid, that is, irradiance measurements at different distances are predictable. In such conditions, calibration of the spectroradiometer only needs to be carried out at one distance, and the calibration is valid for any other distance. This assumption is valid only, if distances are measured with respect to the correct reference plane of the input optics.

With optics involving diffusers, the location of this reference plane is not obvious. A typical selection with planar diffusers is that the distances are measured from the outermost surface of the diffuser. With dome-shaped diffusers, the curvature of the front surface may be accounted for mathematically from the geometry.

We have tested the validity of the inverse square law with four commonly used diffusers. Measurements were performed on an optical rail with accurate length measurement facility. Standard lamps with known reference planes were measured at various distances. The results were analysed with inverse square law to calculate the offsets for the diffusers.

The offsets obtained varied between 0 and 7 mm. The reference planes were typically inside the diffusers. Planar diffusers were generally better, but an offset of 3 mm was also found for one planar diffuser. Measurements were carried out separately for three wavelength regions; UV-region, visible region, and near-infrared region. The effect is wavelength dependent. Teflon diffusers typically have higher offsets in the near-infrared region. This might indicate that the effect is due to translucency of the diffuser materials.

The results suggest that errors up to 3% may occur if spectroradiometers are calibrated at a typical distance of 0.5 m without taking the reference plane effect into account.

The uncertainty of integral quantities used in UV meter calibrations

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Abstract. This paper presents an analysis of uncertainties as they propagate through an integral calculation, taking account of the correlations in the measured quantities. The approach is applied to the case of the calculation of the effective responsivity of a UV meter in a polychromatic beam based on measurements made of its responsivity in a monochromatic beam. This approach will be used to enable the UKAS calibration laboratory in the Medical Physics Department at St Thomas' Hospital to provide phototherapy centres with a value of the uncertainty associated with the effective responsivity of their meters.

1. Introduction

A system providing traceable calibration of the meters used to measure irradiance in phototherapy treatment cabins is widely considered important in the light of large reported variations between different calibration centres [1]. One approach to traceable calibration has been to measure the responsivity of the meter at a range of wavelengths and then to calculate the single value effective responsivity when the meter is used in a broadband source such as obtained from the fluorescent tubes used in many PUVA or UVB whole body treatment cabins [2]. Until now, it has not been possible to quote an uncertainty associated with the final value of the calculated integral quantity ie. the effective responsivity.

2. Methods

The uncertainty analysis used here follows the procedures described within the Guide to the Uncertainty of Measurement (GUM) [3]. The effective responsivity of the meter S_{eff} is described by the measurement equation

$$S_{\mathrm{eff}} = S(\lambda_{\mathrm{ref}})k\frac{\int_{\lambda_1}^{\lambda_2} s(\lambda)E(\lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2} a(\lambda)E(\lambda)d\lambda} \qquad (1)$$

where $S(\lambda_{\mathrm{ref}})$ is the absolute spectral responsivity of the meter at the normalisation wavelength, k is the correction to the responsivity that allows for the deviation of the test meter from the cosine angular response, λ_1 and λ_2 are the wavelength limits of the detector responsivity, $E(\lambda)$ is the relative spectral (ir)radiance of the source, $s(\lambda)$ is the relative spectral responsivity of the real meter and $a(\lambda)$ is the relative spectral responsivity of the 'ideal' meter.

The uncertainties associated with each term in Equation (1) can be propagated through a GUM model, considering the correlations between the measurements at different wavelengths.

If the measurements were entirely correlated, then the uncertainty associated with the integrated quantity would be the same as the uncertainties associated with the individual wavelengths. However, if the measurements were entirely uncorrelated then the uncertainty associated with the integrated quantity would be substantially lower than the uncertainty associated with individual quantities, because the integral would act as a kind of averaging. In practice the uncertainty associated with a real integrated quantity, with partial correlation, would be between these two extremes.

The analysis therefore begins with an estimate of the correlation between measurements at different wavelengths.

References

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Investigation of comparison methods for UVA irradiance responsivity calibration facilities

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2. STUK, Radiation and Nuclear Safety Authority, Helsinki, Finland.
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Abstract. A new method is described for comparing calibration facilities for broadband UV meters. The method is validated in a successful pilot comparison between five European laboratories performing UVA irradiance responsivity calibrations. Participating laboratories calibrated a broadband UVA detector using their ordinary procedures that differed both by calibration methodology and radiation sources used. Pilot laboratory calculated different reference values for each laboratory based on the specified calibration methods and prior knowledge on the calibrated artifact. The results were in agreement within ±5 % which demonstrates a factor of two improvement in agreement as compared to earlier intercomparisons.

Introduction

Broadband UV detectors find use in several fields of science and technology. Calibration of such detectors is a complicated task which requires fundamental understanding of the properties of the detector and the methodology used. The calibration of a broadband detector is source dependent; it applies only to the type of the source that was used in the calibration.[1,2]

There are several methods to calibrate broadband detectors.[1,2] If properly done, all methods should give the same result, but practice has shown that severe discrepancies may occur if the measurements and the analysis of the results are not done with care, or if the principle of the calibration is not fully understood.[3] Even in the most successful intercomparisons[4], deviations of the order of ±10 % have been reported for UVA meters.

In this pilot comparison, five European laboratories calibrated a commercial UVA meter. Each laboratory was to perform the measurements with the exact procedure that they utilize in their regular work. The laboratories would also specify to the TKK, the pilot laboratory in this comparison, the spectrum of their radiation source used and the exact geometry in the measurements. Using these data, together with earlier measured spectral irradiance responsivity and cosine response of the detector, TKK calculated different reference values for the individual laboratories. These numbers could then be compared with those measured by the participant laboratories.

Calibration methods and results

TKK as the pilot laboratory measured the spectral irradiance responsivity of the UVA meter (Gigahertz-Optik GmbH, model UV-3701) for collimated light in overfilled mode. Furthermore, the cosine response of the UVA meter was measured.

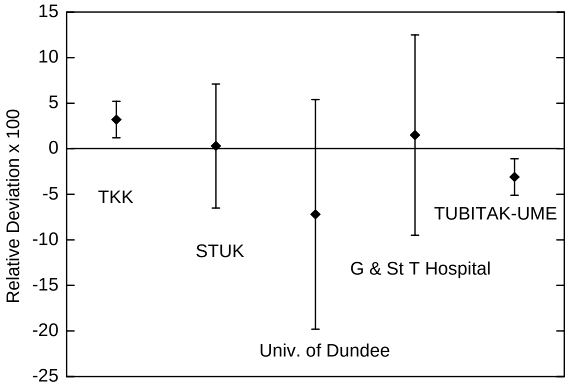

Figure 1. Results of the comparison, given as the relative deviation from the reference value. The error bars indicate the measurement uncertainties (k=2) specified by each laboratory. It should be noted that the uncertainty of the reference value has not been taken into account. This is potentially a significant component of uncertainty, since the reference value is obtained from a set of bilateral comparisons with largely varying measurement uncertainties.

STUK performed a spectroradiometric calibration using a single 180-cm long solarium tube of type Philips TL 100W/WW as the radiation source at a distance of 7 cm. University of Dundee performed a similar calibration at a distance of 30 cm using a bank of six 180-cm long tubes of type *Philips 100W R* as the radiation source. Guy's & St Thomas's Hospital measured the spectral irradiance responsivity of the meter and used the data to calculate responsivity for a measurement in a patient treatment chamber utilising tubes of type *Waldmann PUVA*. UME also measured the spectral irradiance responsivity. This data was used to calculate responsivity for a tube of type *Waldmann PUVA*.

The results of the pilot comparison are given in Figure 1. In the analysis of the results, TKK calculated reference values for each laboratory, against which the values of the participants were compared. From this set of numbers (TKK being unity, others being compared to TKK) a weighted average was calculated to be used as the reference value for the final comparison. The weight of each laboratory was the inverse of the stated measurement uncertainty squared.

Conclusions

The results of the comparison are within ±5 % and indicate excellent agreement between the participants, especially when compared to many earlier attempts in the field. The participating calibration laboratories seem to have a good understanding of their measurement capabilities. Participating national standards laboratories are perhaps somewhat optimistic with their uncertainties. Based on the experience gained we may propose that the presented method of comparison could be used as a basis for a larger international comparison.

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Solar simulators as a tool for assessing the impact of UV radiation on organisms and ecosystems

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Several researchers have pointed out that a realistic risk assessment of UVB induced damages in various organisms, especially in plants, can only be obtained if the experiments are performed under natural light and radiation conditions. This applies particularly to the balance between the UVB, UVA, and the visible or photosynthetic active component of solar radiation. The natural global radiation varies during the day and year by intensity and spectral composition, which has to be taken into account for a realistic simulation of the solar radiation.

This contribution describes the state of the solar simulators at the GSF using state-of-the-art techniques for lighting and spectral shaping methods obtain realistic and reproducible UV scenarios. The integrated irradiances reach values close to outdoor levels measured at our field station in Neuherberg near Munich, Germany. The spectral measurements demonstrate that our artificial sunlight provides a very close approximation of natural solar radiation in the range from 280 to 850 nm with the emphasis of a steep realistic UVB cut-off at the shortwave edge. The use of UV filters allows us to simulate the impact of increased UV radiation on various organisms and their behaviour under these conditions.

Analysis of UV-B solar radiation in C.I.B.A. Laboratory, Spain

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Abstract. Experimental data concerning the integrated ultraviolet-B solar radiation (280-315nm) on a horizontal surface measured at C.I.B.A. (Low Atmosphere Research Center), Valladolid, Spain, during the period June 2002 to May 2005 have been analyzed. A study of the most representative statistical indices: arithmetic mean, median, standard deviation, maximum, minimum, first and third quartiles, percentiles 5 and 95, inter-quartile range and coefficient of quartile variation, of the UV-B radiation for this period has been carried out. It has been found that maximum daily values are reached in June, 45 $kJm^{-2}day^{-1}$; standard deviation values are not high buy increases in central hours of the day when UV-B irradiance is higher; June month shows high stability.

Introduction

The UV-B solar radiation (280-315 nm) represents less than 1% of the total radiation reaching the earth surface, and it is very important for the earth-living systems because it is radiation of high energy. UV-B irradiance at the earth surface depends on geographical factors such as latitude, height, earth-sun distance, solar zenith angle (SZA), etc, (Palancar and Toselli, 2004). The influence of this factors can be evaluated using different radiative models. However UV-B solar radiation depends on atmospheric parameters like ozone, clouds and aerosols. Ozone is the gas that absorbs UV-C and some UV-B solar radiation and the effect of the total ozone column is included in all radiative models. Clouds are another attenuating factor of UV-B radiation and due to that due to their random nature is difficult to model. Aerosol is the factor that affects radiation levels under cloudless sky conditions, (Acosta and Evans, 2000). UVT (ultraviolet total solar irradiance) data have been studied by different authors, Martinez-Lozano et al., 1996, Miguel et al (2005), etc. The objective of this work is the study of UV-B data with the purpose of developing a standard climatology of the region that it is necessary to establish its seasonal and geographical distribution and its values and oscillations. In this way, its evolution is determined with the purpose of detecting changes that can take place in short periods of time. And finally the study serves us as to evaluate processes that affect to the amount of radiation of this kind that it reaches the terrestrial surface and that it comes determined by the thickness from the ozone layer, aerosols, etc.

Instrumentation and Measurements

The data for this work have been registered in C.I.B.A. Laboratory, University of Valladolid, Spain, located at 35km of the city in NW direction, in a place of geographical coordinates: 42º 1' North latitude, 4º 32' West longitude and 832 m beyond the sea level. The sensors are located so that the obstructions of the horizon are null. The data for this work correspond to a period between the 16th June 2002 and the 30th December 2005. The solar radiation components recorded continuously at the measurement station are the following: solar global radiation on horizontal and vertical surfaces facing south, west, north and east, using Kipp-Zonen CM6B sensors; total ultraviolet solar radiation UVT(295-385nm) and UV-B(280-315nm) using TUVR Eppley and YES UVB-1 sensors, respectively. (Miguel et al 2005). Meteorological variables like temperature, relative humidity and pressure are also registered. The average measured values are stored in a Campell data logger every 10 minutes and after a data quality control, hourly and daily values are obtained. From hourly and daily values, the most important statistical index, the monthly average hourly and daily values and the accumulated UV-B solar radiation have been evaluated.

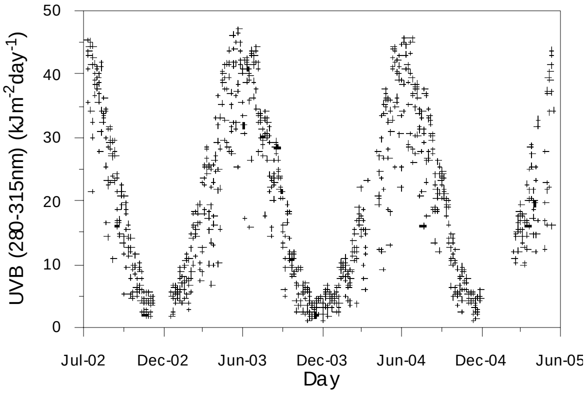

Figure 1. Evolution of daily values of UV-B on horizontal surface (kJ m^{-2} day^{-1}).

Results

The evolution of daily values during the measurement period is shown in Figure 1. It can be seen that maximum values are obtained in summer time and minimum ones in winter. The daily maximum value of UV-B is reached in June, 45 kJ m^{-2} and the minimum is reached in December, 2 kJ m^{-2}. Figure 2 shows the comparison of UV-B and UVT (UV total) solar radiation values, the 30 July 2003 at the measurement station. From the results, it can be said that UV-B is the 4% of the UVT.

1. Analysis of UV-B irradiation hourly values

A statistical study of the most representative indices of hourly values of UVT for each month of the year has been carried out. These indices are:

arithmetic mean (M), median (Md), standard deviation (SD), maximum (Mx), minimum (Mn), first and third quartiles (Q_1 and Q_3 respectively), percentiles 5 and 95 (P_5 and P_{95} respectively), inter-quartile range (Q_1 - Q_3) and coefficient of quartile variation (V) which is defined by the following expression: $V = 100\,(Q_3 - Q_1)/(Q_3 + Q_1)$ (Martinez-Lozano et al., 1996).

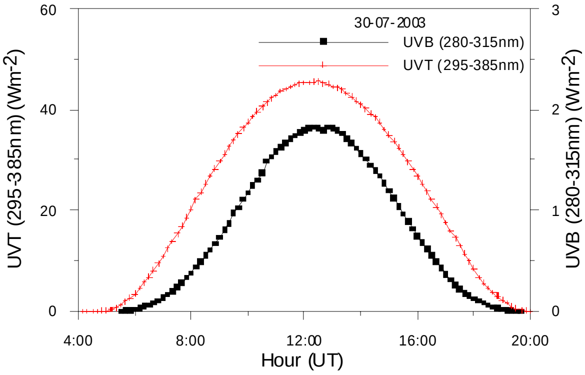

Figure 2. Comparison of UVT and UV-B horizontal solar irradiance.

Data for each month were arranged in upward order and the statistical characteristics were evaluated and for June the following results were obtained: the difference between the values of the absolute minimum and the P_5 is always great. From this result it is possible to conclude that the minimum absolute is not a representative value of UV-B in Valladolid, and these values correspond with atypical days and not with a tendency. The differences between the absolute maximum and P_{95}, are very small every month. These results do not agree with (Martinez Lozano et al. 1996), perhaps due to the number of data. The median values are higher but quite similar to the arithmetic mean. The differences between them are variable and do not seem to follow any defined seasonal pattern. The coefficient of quartile variation is considered as a stability index and it reaches the minimum values in summer. That means that these months show a high stability.

The monthly average values of hourly radiation UV-B have been evaluated and Figure 3 shows the evolution from February to June. It can be seen that the average hourly values recorded at solar noon range between 0.4 Wm^{-2} in February and 1.6 Wm^{-2} in June. These average hourly irradiance values in the central hours of the day shows a considerable symmetric evolution.

2. Analysis of ultraviolet solar irradiation daily values

Daily UV-B values have been evaluated and the statistical indices have the following characteristics: the difference between the absolute minimum and the percentile P_s is not high enough; the monthly median values are higher than the arithmetic mean ones; minimum values of the variation quartile coefficient, V, are obtained in July and August.

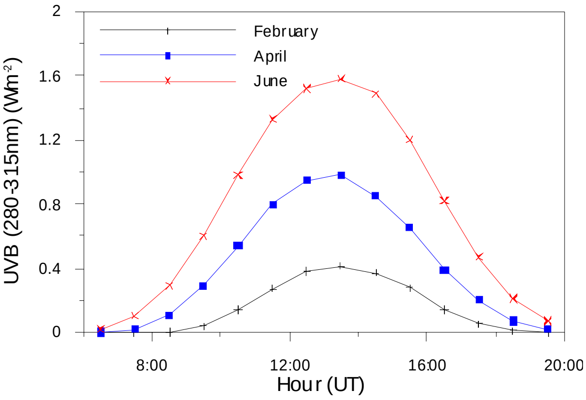

Figure 3. Monthly mean hourly UV-B irradianc .

Conclusions

Hourly and daily values of solar UV-B irradiation (280-315nm) have been evaluated from 10-minute-measured values at the C.I.B.A. site station, in Valladolid (Spain), during the period June 2002 to December 2004. From data series the elemental statistical characteristics have been evaluated and the hourly value analysis shows that the maximum values can be considered representative of UV-B in Valladolid, but the minimum values are not representative, especially in summer. The indices of stability (V) show that the most stable months correspond to summer time, especially July. The results of the daily value analysis show a high stability for summer months and an appreciable symmetrically evolution of the UV-B. Finally the study on accumulated UV-B shows a yearly value of $7MJm^{-2}$.

Acknowledgments The authors gratefully acknowledge the financial support extended by the Spanish Science and Technology Ministry under the Project: REN2003-04522/CLI.

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UV-B and UVI measured and calculated in Valladolid, Spain

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Abstract. Broadband ultraviolet–B solar irradiance (UV-B, 280-315 nm) and ultraviolet index (UVI) measurements, and model evaluations have been carried out in Valladolid, Spain, at C.I.B.A (Low Atmosphere Research Center), between July 2002 and May 2005. UV-B measurements were recorded with a YES UVB-1 sensor and model evaluations were performed by the radiative transfer: CIBA_1.2 and SMARTS_2.9.2 models. Total daily ozone column values were obtained y from NASA, United States (web) an the results show that the maximum ozone values were obtained five month before than the maximum of UVB, approximatelly. Maximum UVI values range between 10 and 11.2. The comparison between measured and model evaluation of UV-B hourly values for clear days show a good agreement at the solar noon and in the afternoon, and the differences increase near the sunrise hours.

Introduction

The ozone plays a role of shield around the Earth protecting us from ultraviolet radiation. A diminution in the amount of ozone will carry an increase in the UVB that reach the Earth's surface. The UVB radiation only represent a 0.5% of the solar radiation (Leun, 1993) but that range of wavelength is very important to human because it can produce skin diseases, skin cancer, cataracts and many others illnesses (Tevini 1993). The UVI is an index that represents the danger of an exposure of that kind of radiation. There are different models to predict the solar radiation that reaches the surface of Earth. These models work with different methods to solve the equation of radiative transfer. These models can consider the atmosphere like one only or multiple layer and in this work we use two models: Both of them are spectral, the first is a mono-layer and the SMARTS is a multiple-layer and it uses the standard atmospheres. In this study the atmospheres chosen were the mid latitude summer and mid latitude winter. The aim of this work is to give a description of the variation of UVB and UVI in Valladolid, Spain.

Data

The measurements were recorded by a Yankee UVB-1 sensor mounted on a wide-open area in the C.I.B.A. Laboratory (Low Atmosphere Research Center), University of Valladolid (Spain), located 35km from the city in NW direction. The geographical coordinates of the place are: 42º 1' North latitude, 4º 32' West longitude and 832 m above sea level. The measurements have been converted into UVE (erythemal ultraviolet irradiance) by means the conversion factors, provided by the manufacturer (SIRSA 1998). The UVI (ultraviolet index) was evaluated from UVE values at different hours (WMO 1994). Daily UVI values were also evaluted by two spectral models, CIBA_1.2 and SMARTS_2.9.2, taking into account the erythematic action spectra (as a weighting function). The CIBA_1.2 model has been developed by our research group and it is based on the work for Bird (Bird 1984). The SMARTS_2.9.2 model has been developed by Gueymard (Gueymard 2001). We have compared the models evaluations and measured values in order to validate and select the most appropriate model. The input parameters: surface pressure, humidity and air temperature at ground level have been measured and recording at CIBA station and ozone daily column values were obtained from TOMS by NASA.

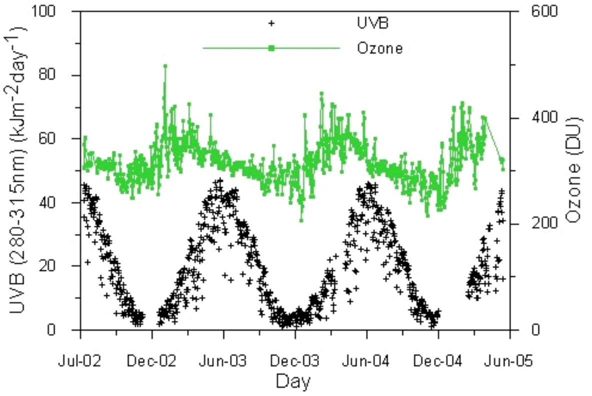

Figure 1. Daily values of UVB (280-315nm) and ozone between 2002 and 2005.

Results

The evolution of daily values of ozone and UV-B solar irradiance during the measurement period are shown in Figure 1. Maximum values UV-B values were recorded in summer and maximum ozone column daily values were obtained at the end of the winter. The results of the analysis have been the following:

- The maximum of ozone measured with the spectrometer TOMS by the NASA is reached in January (496 DU) (Figure 1) and the maximum of UVB in July (2.04 Wm^{-2}). This difference is due to the wind of the stratosphere. This winds travel from the pole in summer hemisphere to the pole in winter hemisphere where the temperatures are minimum because of the winter night. This flow is the responsible of the maximum of ozone at the end of winter (Vilaplana 2004).
- The maximum values of UVB oscillate near 2 Wm^{-2} at solar noon in June-July and near 0.3 Wm^{-2} in December-January at solar noon too.

- The greater stability in UVB have been found around solar noon specially in summer.
- The maximum UVI, at solar noon, reaches high values, 10, in summer time, as it can be seen in Figure 2.
- The models CIBA_1.2 and SMARTS_2.9.2 have been used to evalute the UVB solar radiation and UVI and the results have been compared with the measured ones. The agreement between measured and model evaluations is more important in the afternoon and in the solar noon.

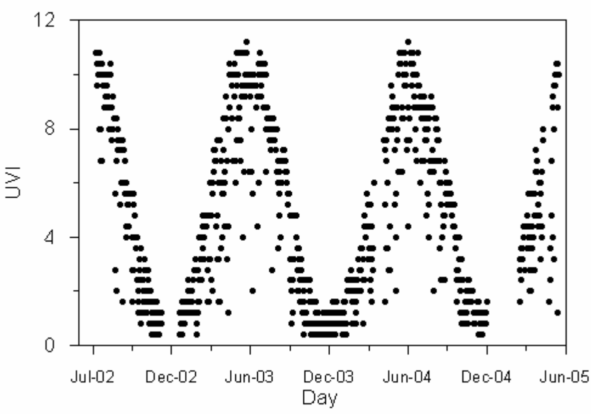

Figure 2. UVI measured values in CIBA at solar noon during the period 2002 to2005.

Figure 3 shows the evolution of the UVB (280-315nm) hourly values, in Wm^{-2} during a cloudless day in July 2002 and the results given by the CIBA_1.2 and the SMARTS_2.9.2 models. That day, the ozone amount is 307.4 DU, the surface pressure 923 mb and the precipitable water vapour is 2.98 cm. The SMARTS model ran with a standard atmosphere corresponding to a mid latitude summer and a rural aerosol model. The results of both are closed to the measurements. At first hours of the day we can find the biggest errors around the 40%, but at solar noon and in the afternoon the errors are smaller than the 7% for both models, nulls in some cases as we can see in Figure 4. We can use these models to predict the amount of solar radiation at least in cloudless days and near the solar noon. The accuracy of these models is based on the input parameters. In this case the input parameters (except ozone) and UVB have been measured in the same place, but if we use this models in other place and we do not know the input parameters, we would have to use standard atmospheres and probably the results would not be so good due to the variability of these parameters.

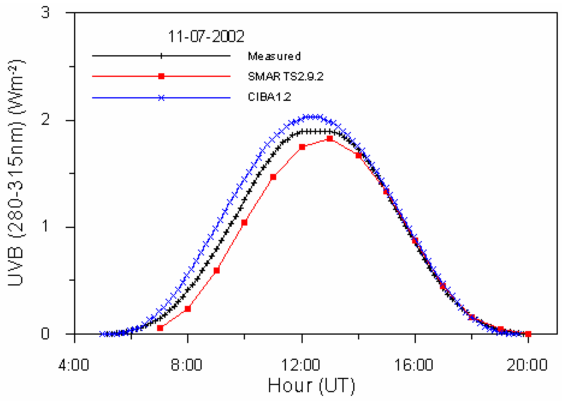

Figure 3. Comparison of measured and calculated UVB (280-315nm) hourly values, during a day in July 2002.

Conclusion

The spectral models used in this work show a very good accuracy for calculating UVB solar irradiation when input parameter measured values are used. The possible errors al solar noon are lower than 7% and bigger near the sunrise.

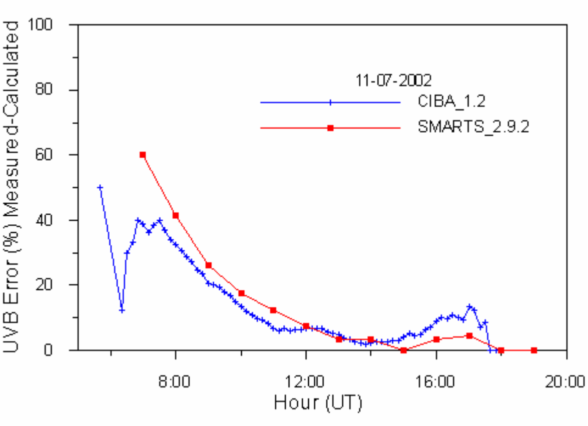

Figure 4. Percentage of error between the measured and calculated UVB .

Acknowledgments The authors gratefully acknowledge the financial support extended by the Spanish Science and Technology Ministry under the Project: REN2003-04522/CLI.

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A natural UV human exposure model - Preliminary comparison with dosimetry data -

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The link between skin cancer incidence and exposure to UV radiation is one of the reasons often invoked to monitor natural UV radiation. However, these environmental data do not directly represent the exposure, which is very much dependent on the people's behaviour. This poster presents a concept for developing a model that would combine environmental and behavioural data for estimating human exposure. One input is the location in space and time of the person. The surface erythemal UV radiance field is then computed where and when the person is, by means of a radiative transfer (RT) code. The RT model takes into account the solar zenith angle, the total column ozone, the cloud optical thickness, the aerosol load, the surface reflectivity and the altitude. The values given to these influencing parameters can be obtained from databases or can be set according to a scenario. In this paper, a satellite-derived data set is used, which provides ozone, cloudiness, surface reflectivity and aerosol load anywhere in Europe and over the period from January 1st 1984 to present. Once the radiance field is computed, the exposure of an arbitrarily oriented surface can be evaluated. It is thus possible to estimate separately the exposure of various part of the body. The scheme described above has been applied to estimate the daily exposure, during 2001, of two office workers living in Düsselldorf and Palermo. Very simple occupational schedules have been defined. The persons are exposed when going to work in the morning, when jogging around lunchtime and when returning home in the evening. They have outdoor activities in the afternoon during the weekend. Additionally, they take ski holidays (1week) in the beginning of March and summer holidays in a sunny sea resort (2 weeks). The modelled daily exposure shows i) that the daily dose almost never exceeds 1 MED out of the holiday periods, ii) that the maximum daily exposure is comparable during the ski and summer holidays, iii) that the holiday periods (3 weeks) account for more than 50% of the total yearly exposure. In order to perform a preliminary assessment of the modelled exposure, dosimetry measurements were performed by means of polysulphone films attached on mannequins exposed outdoors for various periods and in variable meteorological conditions. Although, as expected, the model is not able to reproduce the measurements, it does catch the essential variability in the experimental data set.