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Methodology and Uncertainty Budget for UV Radiometer Calibration

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ABSTRACT

Calibration of ultraviolet irradiance meters are depending on many parameters. This work demonstrates the most important parameters affecting the uncertainty calculation of ultraviolet irradiance meters and a general methodology for calibration of ultraviolet (UVA) radiometers. The calibration procedure discussed in this paper is based on comparison method between effective irradiance responsivity. In the same time an example of calibration set-up and uncertainty budget is presented.

Key words: Radiometry, Radiometer calibration, Irradiance measurements, UVA radiometer.

1. INTRODUCTION

The international commission on illumination (CIE) defined the Ultraviolet radiation (UVR) as any radiant energy with a wavelength between 100 nm - 400 nm. Ultraviolet (UV) is a portion of the electromagnetic spectrum and the radiation within this wavelength range is produced by the sun and by man-made sources.

Photobiologists often use the division of the ultraviolet spectrum as given by the CIE: UV-A, 315 nm - 400 nm; UV-B, 280 nm - 315 nm; UV-C, 100 nm - 280 nm.[1,2]. The natural UVA irradiance level is affected by the region and time where it is measured. Also the irradiance of artificial UVA sources (Lamps) is affected by lamp aging and the measuring condition.

For their low cost and ease of use, ultraviolet (UVA) meters (scientifically: ultraviolet radiometers, and in industry black light meters) are widely used for measuring UVA radiation in various industrial, medical, environmental, health and other applications.

UVA radiometers usually consist of a detector head, a signal converter and a display unit. The detector head consists of a photo-detector, a spectral filter, a beam-limiting aperture and a diffuser .The spectral filter is used to shape the spectral response of the detector head to match a spectrum of the application. For example, to study the effect of solar radiation on human skin, the spectral response of the UV meter should match the action spectrum of the erythemal function. While for measurement of UVA, the spectral response required is a square function from 315nm to 400nm. Therefore, a UV meter is usually designed to measure the effective irradiance generated by a source defined as the irradiance spectrally weighted by the action spectrum of the phenomenon of concern.

Previous work provide the theoretical basis for the calibration of broadband UV meters

$$E_c = \int_0^\infty E_{\lambda,c} s(\lambda)_{act} \, d\lambda \qquad (1)$$

Where, $E_{\lambda,c}$ is the spectral irradiance produced by a source *c* at the position of measurement.
And $s(\lambda)_{act}$ is the action spectrum with peak value of unity.

The calibration of a UV irradiance meter is the ratio of its output and the actual value of the effective irradiance produced by the calibration source at the meter head:

$$R_c = \frac{i}{E_c} = \frac{i}{\int_0^\infty E_{\lambda,c} s(\lambda)_{act} \, d\lambda} \qquad (2)$$

Or

$$R_c = \frac{i}{E_c} = \frac{A s_0 \int_0^\infty S_{\lambda,c} s(\lambda)_{rel} \, d\lambda}{\int_0^\infty S_{\lambda,c} s(\lambda)_{act} \, d\lambda} \qquad (3)$$

Where *i*, A are the output and receiving area of the meter head,

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$s(\lambda)_{rel}$ is the relative spectral responsivity, normalized to its peak value s_0.
and, $S_{\lambda,c}$ is the spectral radiant power of the source received by the detector.
The detector head should be overfilled by the radiation flux. [3,4].
There are two major measure UVA radiometers, the narrow band UV (365±5nm) radiometer (S365) and the broad band UVA (315-400nm) (SUVA) according to their definitions their responsivities are calculated using equations (5) and (6) respectively.

$$S_{365} = \frac{i_{365}}{E_{365}} = \frac{i_{365}}{\int_0^\infty E(\lambda)T(\lambda)d\lambda} \qquad (AW^{-1}cm^2) \qquad (5)$$

$$S_{UVA} = \frac{i_{UVA}}{E_{UVA}} = \frac{i_{UVA}}{\int_{315}^{400} E(\lambda)T(\lambda)d\lambda} \qquad (AW^{-1}cm^2) \qquad (6)$$

Where:
i_{365} Is the photocurrent of a detector under the narrow band (centre wavelength: 365nm, bandwidth: ±5nm FWHM) UV irradiance (E_{365}) produced by the UV source through a 365nm interference filter.
i_{UVA} Is the photocurrent of a detector under the broad band radiation from the UV source and E_{UVA} is the UVA irradiance produced by the UV source at the detector surface
E(λ) is the spectral irradiance of the UV source and *T(λ)* is the spectral transmittance of the filter. [5]

2- Calibration method:

This method is carried out for the calibration of UVA radiometers with the spectral responsivity range 315-400 nm peaked at 365nm.

The procedure is directed to calibrate the radiometers that measure the UVA irradiation in Watt/meter^2 and its multiplications. These devices mainly are considered as one unit (sensor and read out unit). Also these devices can be with digital or analog outputs.

2.1- Apparatus and equipment:

The set up of this calibration includes the following apparatus:

1- UV light source.
2- Reference Radiometer, calibrated at the range of UVA radiation.
3- UVA filter.
4- Variable diaphragm.
5- Computerized linear translation stage if available, it can be substitute by linear manual stage.
6- Alignment laser.
7- Light enclosure.
8- Optical bench if available otherwise can be substituted by flat rugged table.
9- Optical accessories (bases, holders,…..atc).

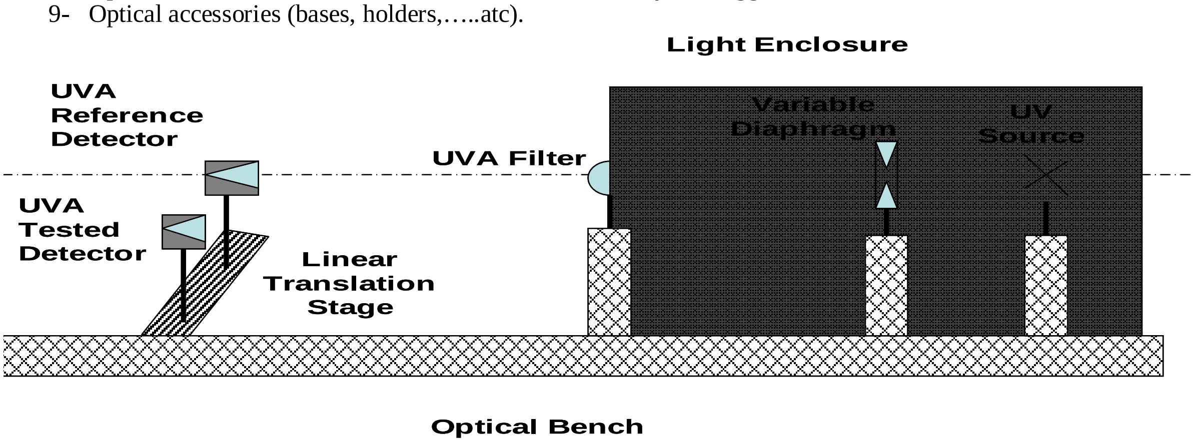

Fig. 1: Sketch of the used experimental apparatus.

2.2- Reference standards and reference materials required

Calibration methods of these kinds of instruments are detector based or source based method. This work presents a detector based calibration procedure for UVA meters using substitution method following the requirements of ISO 17025. In this method the readings of the test radiometer are compared with the readings of the standard radiometers when both are exposed to the same irradiance level from a given source.

2.3- Detailed calibration procedure:

1- The test radiometer should be checked for battery level, and irradiance range.
2- Use the alignment laser to align radiometers head so that the irradiance is normal to its geometrical center.
3- Adjust the plane of the tested radiometer to be at the same plane position with the standard radiometer.
4- Check each radiometer before starting calibration to indicate zero with no irradiance on its head.
5- Steps to be followed to record data:
  - 5.1- The UV lamp should be turned on for 30 minutes until it becomes stable.
  - 5.2- Check the environmental condition to be matched with that obtained on the standard radiometer when it was calibrated, otherwise temperature correction should apply.
  - 5.3- Place the reference radiometer in front of the source.
  - 5.4- Record the irradiance value given by the standard radiometer. Replace the standard radiometer head with the head of the tested radiometer and record its reading.
  - 5.5- Reading of both radiometers at different irradiance levels which cover the range of the tested radiometer can be tabulated by a way that clearly show readings of standard radiometer, reading of tested radiometer, and the repetition of measurements at each irradiance level.

Notes:
1- Special precautions should be considered to prevent stray irradiance, i.e. irradiance which does not come directly from the source but scattered from the surrounded walls.
2- Cover the radiometer head between each recorded measurements.
3- At each successive point of calibration expose the heads to the source for sufficient time for the reading to settle before recording the reading.
4- Stabilization of environmental condition is common in calibration procedures. In this procedure the environmental condition is not critical but the calibration temperature at which the reference radiometer was calibrated should be followed otherwise temperature correction must be applied.
5- Safety precautions of UV exposure should be considered. [6-7-8]

3- Sources of Uncertainty:

The sources of uncertainty depend on the method used for calibration and it can be slight different from calibration laboratory to anther. The following are the most important uncertainty sources at many laboratories
- Calibration uncertainty of the standard meter including values of spectral responsivity or band responsivity.
- Non-linearity of the standard meter.
- Instability of the standard radiometer head due to changes of filter transmittance, detector spectral responsivity and its electronic circuit.
- Measurement uncertainty of electrical quantities (e.g. current measurement from photodiode) in the standard meter if they are measured separately using a current or voltmeter.
- Stability of irradiation from the UV source.
- Stray irradiation falling on the detector during calibration.
- Uncertainty caused by alignment of detector heads.
- Spatial non-uniformity of irradiating beam.
- Uncertainty caused by low resolution of some industrial UV meters.[8]

In our laboratory, the uncertainty budget is quoted according to international Comparison of radiance responsivity of UVA Detectors [9] and other similar laboratory as listed in table 1

Table 1: The uncertainty budget

	Uncertainty Source	Type
1	Calibration of reference standard detector	B
2	Reading repeatability of standard detector	A
3	Reading repeatability of transfer detector	A
4	Alignment and positioning of standard detector	A
5	Alignment and positioning of transfer detector	A
6	Uncertainty due to uniformity of UV beam	A
7	Stability of irradiation from the UV source	A

CONCLOSION

UVA radiometers mentioned in this paper are basically instruments with law- accuracy. To calibrate such radiometers two main methods are commonly used. In this work the theoretical bases of calibration and the uncertainty budget assisted with the calibration procedure are demonstrated. The detector based method discussed here is completely independent on the source of UV, but highly dependent on the calibrated UV radiometer. It is clear that for calibration of UVA radiometers using detector based method scientists may follow steps discussed before to achieve applicable procedure with high accuracy of measurement and acceptable uncertainty level.

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