Spectral Mismatch Correction for the Calibration of UVA Radiometers

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Using examples of the calibration of UVA radiometers, the influence of spectral mismatch will be discussed. As the spectral responsivity of so-called UVA radiometers is never spectrally flat, it will be shown that this can lead to significant differences between measurement results even of narrow-band UVA sources typically used for calibrations. This should be taken into account both for routine calibrations of UVA radiometers and for carrying out intercomparisons.

INTRODUCTION

The ideal UVA radiometer does not exist because no device can simulate the "UVA" interval. In practice, the term "UVA radiometer" usually refers to measuring devices that provide values for irradiance in a defined spectral (sub-)range between 315 nm and 400 nm.

A frequent application is the non-destructive testing of materials using UVA radiation according to DIN EN ISO 3059 [1]. Here, a defined irradiance in the UVA spectral range is required (1 W/m² - 50 W/m²). The irradiation source should have a spectral distribution with maximum value at 365 nm ± 5 nm and a full-width at half-maximum (FWHM) of 30 nm. For this application, the UVA radiometers should be calibrated using a narrowband radiation at 365 nm.

The required calibration is, thus, a comparatively simple measurement task in which the radiometer to be calibrated is compared under narrowband radiation at 365 nm against a calibrated reference detector. A respective correction factor is calculated for the display readout of the UVA radiometer and a simple measurement uncertainty estimate is obtained:

$$k_{dut,UVA} = \frac{E_{UVA}}{Y_{dut}} = \frac{1}{s_{0,r}} \cdot \frac{Y_r(365\text{ nm})}{Y_{dut}},$$

$$u^2\left(k_{dut,UVA}\right) = u^2(s_r) + u^2(Y_r) + u^2(Y_{dut}). \quad (1)$$

Here $s_{0,r}$ is the spectral irradiance responsivity of the calibrated reference detector at 365 nm, $Y_r(365\,nm)$ is it's photosignal and Y_{dut} is the readout value of the UVA radiometer. A standard measurement uncertainty typically in the range of 1 % can be estimated for the correction factor.

However, this simple estimation of the calibration uncertainty does not consider substantial contributions. This becomes apparent in particular if the application on site runs under different conditions or calibration results of different origins are compared, which has also been observed during different intercomparisons. Obviously, some other elements can contribute significantly to the measurement uncertainty making it considerably higher.

The EURAMET comparison EURAMET.PR-S4 [2] included a comparison of the calibrations of two UVA radiometers at 365 nm between ten participants. After spectral characterizations of the radiometers it became clear that the relative spectral responsivity of the UVA radiometers will have a huge impact on the results and must be taken into account even though narrow-band irradiation sources were used during the calibrations.

SPECTRAL MISMATCH

The (relative) spectral responsivity of a UVA radiometer is not, as demanded, spectrally flat. Therefore, even if a narrow-band source is selected for the calibration, a strong local change in the spectral responsivity may cause a displacement of the measurement result. In general, the weighted spectral deviation of a radiometer depends on the relative spectral irradiance distribution of the calibration source "C", $E_{\lambda,C,rel}(\lambda)$, and the relative spectral responsivity of the radiometer, $s_{rel}(\lambda)$,

$$m_{UVA,C} = \frac{\int E_{\lambda,C,rel}(\lambda)d\lambda}{\int E_{\lambda,C,rel}(\lambda)\, s_{rel}(\lambda)d\lambda}. \quad (2)$$

In addition to the correction of the weighted spectral deviation, further corrections must be considered for the calibration. This is achieved by extending the calibration equation by means of adjustment factors a_j and the calibration equation (1) extends to

$$k_{dut,\text{UVA,C}} = \frac{1}{s_{0,r}} \cdot m_{r,UVA,C} \cdot \frac{Y_{r,C}}{Y_{dut,C}} \cdot \prod_{j=1}^{n} a_j, (3)$$

with $m_{UVA,r,C}$ being the weighted spectral deviation of the reference detector responsivity. At this point, for the calibration source "C", the weighted deviation of the device under test needs not to be considered. Only the reference detector responsivity around 365 nm needs to be considered. Knowledge of the weighted spectral deviation of the device under test is required if a source with a different spectral distribution is used for the application or for other calibration being compared with. Then the weighted spectral deviations with respect to the calibration source “C” and the reference source “R” must be considered and the so-called spectral mismatch is obtained [3],

$$a^*_{dut,\mathrm{UVA,R},C} = \frac{k_{dut,\mathrm{UVA},R}}{k_{dut,\mathrm{UVA},C}} = \frac{m_{\mathrm{dut,UVA},R}}{m_{dut,\mathrm{UVA},C}}. \qquad (4)$$

The reciprocal value of this spectral mismatch $F^*_{\mathrm{r,UVA,R,C}} = 1/a^*_{\mathrm{r,UVA,R},C}$ is called the spectral mismatch correction factor and so the correction factor for the reference source “R” can be calculated:

$$k_{dut,UVA,R} = k_{dut,UVA,C} \cdot F^*_{dut,UVA,R,C} = k_{dut,UVA,C} \cdot \frac{m_{dut,\mathrm{UVA},C}}{m_{dut,\mathrm{UVA},R}} \qquad (5)$$

PRACTICLE EXAMPLES

For the Euramet.PR-S4 intercomparison, two different UVA radiometers were measured. In contrast to the manufacturers' specifications, the radiometers showed a significant change in relative spectral responsivity around 365 nm. Figure 1 shows that one detector (DUT1) has a local slope of 3 %/nm, and the other one (DUT2) shows -13%/nm. The reference standard detector (REF) based on a Si

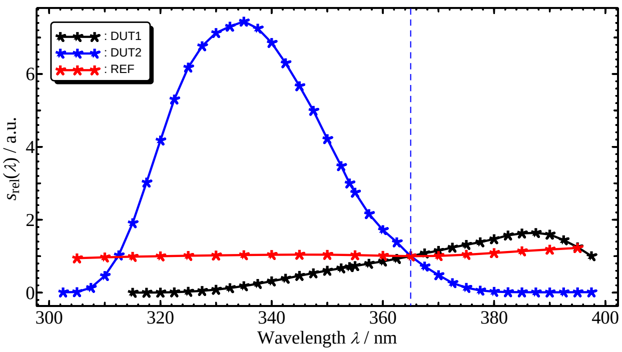

Figure 1. Relative spectral responsivity of two UVA radiometers (DUT1, DUT2) and a Si reference photodiode (REF).

photodiode features a minor local minimum symmetric around 365 nm.

The calibration source “C” used at PTB is a filtered HgXe high-pressure lamp. The relative spectral irradiance distribution has a centroid wavelength of 365.3 nm and a bandwidth (FWHM) of 2.2 nm (Figure 2). For the intercomparison, a reference spectrum “R” with a centroid wavelength of 365.7 nm and FWHM of 5 nm was provided by the pilot and is shown in Figure2 as well. The resulting weighted deviations related to the reference spectrum are up to $m_{\mathrm{DUT2,UVA},R}$ = 7 % for DUT2 and its resulting spectral correction factor is in the range of $F^*_{\mathrm{DUT2,UVA,R,C}}$ = 4 % (Table 1). For the evaluation of the intercomparison results, appropriate spectral corrections are therefore indispensable.

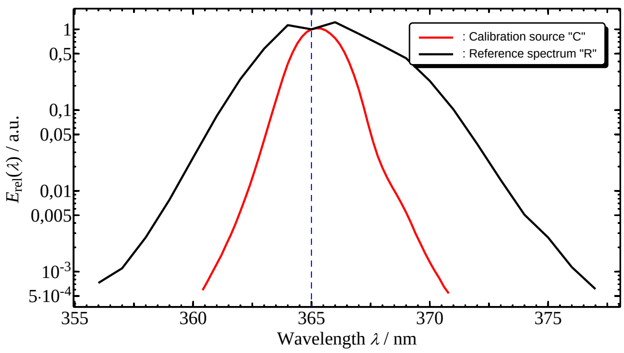

Figure 2. Relative spectral irradiance distribution of the calibration source “C” used for calibration and the reference spectrum “R” for the intercomparison.

Table 1. Weighted spectral deviation and mismatch correction factor for three different radiometers.

Radiometer	$m_{x,UVA,C}$	$m_{x,UVA,R}$	$F^*_{x,UVA,R,C}$
DUT1	0.989	0.974	1.016
DUT 2	1.025	1.066	0.962
REF	0.999	0.996	1.003

CONCLUSION

Even if sources with narrow-band spectral distributions are used for calibrations, it is necessary to perform a spectral mismatch correction of radiometers. This is the only way to achieve comparability between measurement results by different radiometers and institutes. The corrections require knowledge of the relative spectral responsivity of radiometers and the spectral distribution of the relevant emitters. However, such measurements are often not included in routine calibrations. Nevertheless, even if no spectral characterization can be made, a conservative estimate of the contribution to measurement uncertainty should be made.

REFERENCES

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