Source Based Discrepancies in UV Meter Calibrations

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The errors associated with the calibration of broad band UV meters based on the light source used during calibration are well documented but appear to not be very well known. With the proliferation of UV meters used for several industry applications ranging from everything including tanning booths, semiconductor photolithography, solar radiation measurements, and UV curing, it is becoming increasingly important to understand the design, correct application, and calibration of these instruments.

Depending on the design of the instrument and the light source used, discrepancies in UV meter calibration can range as high as 10%-300%. In order to understand why such a dramatic difference can occur, it is necessary to understand the fundamentals of irradiance measurement, the design of a typical UV meter, and the relative spectral distribution of different sources.

Irradiance is a radiometric term for the power of electromagnetic radiation at a surface, per unit area, with SI units of $W \cdot m^{-2}$. More specifically irradiance refers to light that is incident on a surface. Irradiance quantifies the combined amount of radiation present, within a designated interval of wavelengths. Sometimes it is also necessary to determine the radiation incident on a surface at each individual wavelength. When this is done the radiation is quantified as spectral irradiance, with SI units of either $W \cdot m^{-3}$ or the more common $W \cdot m^{-2} \cdot nm^{-1}$.

The typical UV meter is often designed to measure irradiance of an action spectrum, whether it is the internationally accepted definition of UV-A (315nm-400nm), UV-B (280nm-315nm), or the erythemal action spectra. An action spectrum is the effectiveness of different wavelengths of light to cause a photobiological or photochemical action or reaction.

The term f'_1 is used to describe how well the responsivity of a meter matches the "designated action spectrum." This is a term primarily used in photometric measurements to determine the mismatch of a meter's responsivity to the CIE photometric defined area. Whereas in photometry we would commonly see a few percentage points difference between the responsivity and the CIE photometric defined area, a UV-A meter may have an f'_1 value of near 50%.

The typical UV irradiance meter contains a number of elements, including a diffusing surface, a filter designed to approximate an action spectrum, an aperture and optical radiation detector. The combination of these items contribute to the signal (i) as the diffuser, filter and detector affect the sensors sensitivity (s(λ)), and may have an aperture (A) that defines the area of flux collection. However these are not the only pieces which determine the signal of the detector, as it should be clear that the spectral irradiance of the lamp also affect the signal. The simple equation is given below which defines the signal of the detector, with the irradiance of the lamp given in the equation by E(λ) , λ being the common representation for wavelength.

$$i = A\int_{\lambda} E(\lambda)S(\lambda)d\lambda$$

The discrepancies and errors occur from a mismatch of the action spectrum with the sensitivity of the filter-detector combination over the designated area. The ideal UV-A meter would have a square function from 315 nm to 400 nm. However a simple commercial UV-A meter can not match this function exactly. The typical UV-A meter has a function similar to the one shown in Figure 1. As can be seen, the UV meter covers only a portion of the CIE designated UV-A spectrum. This can create discrepancies in the measurement process when the meter is calibrated against one type of source and then used to measure UV of a completely different spectrum.

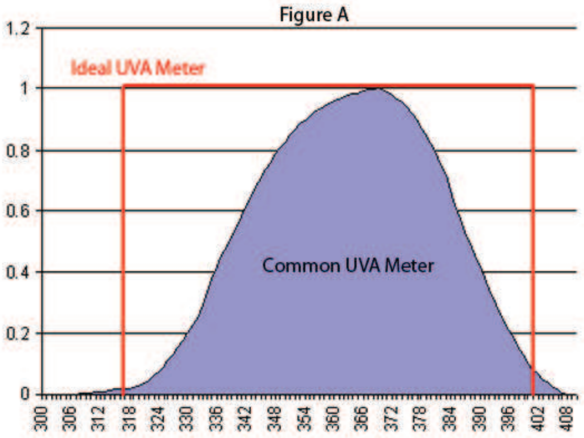

Figure 1. Typical UV-A meter capability.

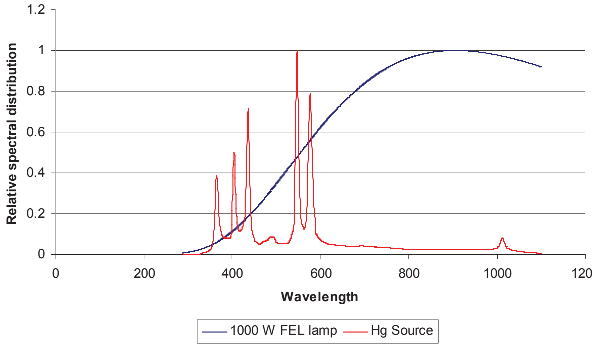

Figure 2. Spectral distribution of common light sources.

Consider the spectral distribution of a few common light sources, shown in Figure 2. As can be seen, the portion of each light source which would be designated as part of the UV-A spectrum varies considerably. With portions of each light source outside of the filtered responsivity, an accurate reading from the meter is very difficult to achieve, unless prior knowledge of the spectral distribution of the source is already known, as well as the responsivity of the detector. However this is often beyond the scope of most users as it requires the use of a spectroradiometer system.

Figure 2 shows the differences in spectral distribution between a common FEL lamp at 3200K, and a mercury source. The combination of the source and the mismatched responsivity function of the meter lead to erroneous errors that the user may not be aware of.

This problem is exasperated by the dramatic differences in UV spectral distribution of different light sources, as well as the glass filters used by a simple UV meter often having out-of-band leakage. This information is often goes unreported by the product literature. The out-of-band responsivity is a combination of filter transmittance and the responsivity of the silicon photodiode peaking in the infrared region.

A commercially available filter was measured for transmittance from 290-1100nm, for Figure 3. The manufacturer's stated information only noted spectral transmittance up to 450 nm. However as can be clearly seen, there is still significant transmittance above 680nm. By taking a look at the ratio's of the out-of-band energy and the in-band energy, we can estimate the expected difference in measurement readings.

For example a 1000 W lamp, ANSI designation, FEL, will have a much greater reading since as can be seen from Figure 2, the peak of the lamp's radiation occurs near the same region as the out-of-band energy. This can lead to measurement errors as much as 300%, and the user may not be aware that a problem even exists in the measurement. The problem is much less significant when used to measure a mercury source, as the light source has very little out-of-band radiation. However, if the same meter was used to measure the UV radiation of both the 1000 W lamp and the mercury source, the user would naturally assume the 1000 W lamp to have as much if not greater UV energy as the mercury source.

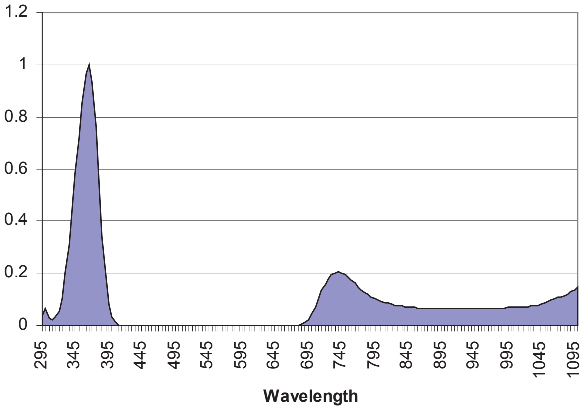

Figure 3. Irradiance measurement of a filter showing significant transmittance above the manufacturer's specifications.

If the desired application was the measurement of the UVA irradiance of a solar or 1000 W source, then there would be a significant over-estimation. It is therefore necessary to explore the properties of the individual broadband meter if a non-monochromatic source is to be measured. If the measurement involves the broadband measurement of an action spectrum, it will be essential to find a meter that matches the desired action spectrum as closely as possible. It is also necessary to have the instrument calibrated against a similar source as the measurement is to be made. If the desired application is to measure monochromatic irradiance, then even a broad band meter calibrated at the desired wavelength should be sufficient.

The calibration of a direct read meter may require a considerable amount of effort, depending on the measurement application and desired uncertainty. The user often will be unaware of the essential factors required for the correct calibration of direct reading UV meters. It is necessary for the calibration facility or laboratory and the user to discuss the issues listed above as well as any other contributing factors. It is also necessary to match the radiometer to the application of its use, then to make sure to match calibration source to the application source as well. This will help to reduce the uncertainty involved in the measurement process.

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Angstrom Metrology, LLC. is an independently owned and operated calibration facility for light measurement equipment.