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RESEARCH **Chromaticity Shifts, Thermal, Phosphors**

TECHNOLOGIES **Micro-LED Displays, UV-C Light**

APPLICATIONS **Lighting Standards, Green Walls**

# Characterization of UV Radiation Sources

Since the beginning of this unfortunate situation caused by the COVID-19 virus, many companies, research centers and lighting designers have adopted UV radiation as a new tool in their projects and research. For a reasonable prediction on the amount of potentially germicidal energy, we have to guarantee proper measurements and especially, spatial distribution. Marc Ballbè, Technical Director at Asselum Luminotecnics, S.L. will explain the complexity of this task and show how to use it correctly for meaningful and reproducible results.

**A**pplications in the disinfection of pathogens with UVC radiation sources have proven effective in multiple activities. Frequently, the chosen radiation sources have been low pressure mercury lamps thanks to their spectral emission at 253.7 nm, very close to the maximum sensitivity peak of DNA and RNA [1]. UV LED technology has not yet entered with force due to its low efficiency, but it is expected that in the next few years its performance will increase considerably and may become the choice when designing UV radiation disinfection equipment. The article will not just explain what else to consider, but also give hints on the requirements of equipment and how to transform the knowledge from visible light measurement to the UV domain.

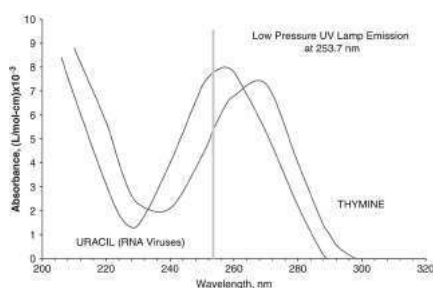


Figure 1: Uracil absorption spectrum compared to that of thymine and the wavelength peak of low pressure mercury [1]

## UV Radiation Source Tests

Since before the global pandemic, the characterization of UV radiation equipment for disinfection was very simple. Most of the time, one-off measurements were made in the equipment facility itself at its usual location, rather than in a laboratory.

The data that we can find in a commercial data sheet of a UV lamp or UV complete equipment is the radiant flux (W) (the radiant flux is the amount of electromagnetic energy per unit of time, not to be confused with the power consumed). In some cases, some irradiance values are also included (They are expressed in  $W/m^2$  or  $mJ/cm^2s$ ) indicated at a specific distance.

The value of the radiant flux (W) of a UV lamp can be interesting to indicate the amount of potentially germicidal energy that we will have for our project. But it does not help us to calculate elimination times for a given pathogen if we have the dose values in  $mJ/cm^2$ . It is as if we were trying to calculate the lighting project of an office to obtain 500 lux and U0 of 0.6 with only the value of 3000 lm of a standard LED screen. The Irradiance values ( $W/m^2$ ) are useful as long as they indicate the distance that this UV lamp / system emits said irradiance. However, we can only know with precision our germicidal potential and calculate the levels of elimination at the

distance presented in the technical sheet. These calculations are only accurate in the same direction that the manufacturer has performed the measurement, we cannot expect irradiance levels to be maintained over the entire surface that the lamp is radiating.

In the case of lamps, the point of maximum intensity is usually obtained on the perpendicular axis of the lamp, so that the intensity values will decrease as we move away from the perpendicularity of the lamp. This is why a spatial characterization for UV radiation sources is necessary in order to perform more reliable calculations in projects for disinfection facilities with UV sources.

## Spatial Characterization of UV Equipment

The systems for measuring and characterizing UV radiation lamps and equipment are very similar to those used in photometry measurement (380–780 nm). The big difference is that they have to be prepared to have a special sensitivity to short wavelengths between 100 nm and 400 nm. Radiometers are photometers with sensors sensitive to specific wavelengths. However, it is not possible to obtain an extensive sensitivity that can cover the entire UV range.

## Radiometers

UV radiometers measure incident radiation or irradiance normally in  $W/m^2$ . The photoreceptor is usually a silicon (Si) photodiode that improves its responsiveness to UV rays with a spectral sensitivity between 190 nm and 1100 nm. The drawback is that it is not possible to obtain an extensive sensitivity that can cover the entire UV range. Most radiometers are only sensitive to a narrow range of wavelengths. Normally, a different calibration is necessary for each spectral distribution that needs to be measured with the radiometer. This results in a fairly high measurement uncertainty if appropriate correction factors are not applied (Figure 2).

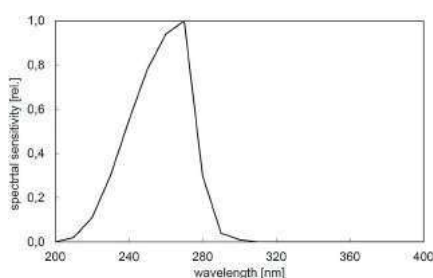


Figure 2: Sensitivity curve of a UVC radiometer. The point of maximum sensitivity corresponds to the wavelength of 270 nm. Instead, its sensitivity to other wavelengths drops dramatically [2]

## Spectroradiometer

Another type of sensor to measure irradiance values are spectroradiometers. The main difference between a spectroradiometer and a radiometer is the sensor that performs the measurement. In a radiometer, it is usually a photodiode with a certain spectral sensitivity, while in a spectroradiometer the sensor is a monochromator. The main advantage of the spectroradiometer is the ability to accurately measure the irradiance ( $W/m^2$ ) of any radiation source regardless of its spectral power distribution (Figure 3).

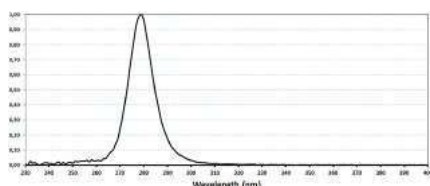


Figure 3: Irradiance measurement using a UV spectroradiometer. It allows a complete analysis for each wavelength of the source under test

## Gonio-Spectroradiometer

The equipment previously mentioned only allows the measurement of point values at a specific distance from the radiation source. To characterize a UV

lamp or equipment spatially, a gonio-spectroradiometer can be used. This equipment has the advantage of the automatic gonio-photometer system and the measurement capacity of a spectroradiometer.

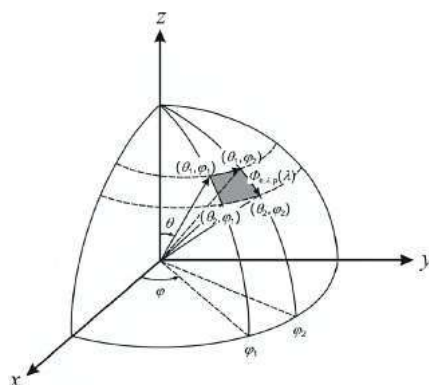


Figure 4: Scan of a point source defined in CIE 239 [4]

With this system, you can scan the entire source and characterize the spatial shape of the radiation. It is also possible to achieve the spectral distribution in the range of the necessary wavelengths. With this information, we can know both the radiant flux (W) and the way to distribute the radiation in space. In this way, calculations and projects of the irradiance levels that would be obtained by installing UV radiation disinfection lamps or equipment can be carried out more accurately and much faster (Figure 4, Figure 5).

## Why Can't We Use a Conventional Goniophotometer?

Humans are not capable of perceiving ultraviolet radiation. Our eyes, like the radiometers explained above, have a defined spectral sensitivity. In the case of humans, our sensors have sensitivity in the area that we know as the visible range of the electromagnetic spectrum. This can be better understood by analyzing the sensitivity curve of the human eye defined by the CIE. The curve  $V(\lambda)$  defines the sensitivity of humans to electromagnetic radiation in the range of 380–780 nm (Figure 6).

The instruments that allow us to quantify the lighting levels (we understand lighting as the energy that we perceive and can detect with our eyes) also have to have the same 380–780 nm measurement range and have a sensitivity similar to the  $V$  luminous function ( $\lambda$ ). Precisely, the most important quality parameter of a lux meter is the difference between the spectral response of the sensor compared to the sensitivity curve of the human eye. This pa-

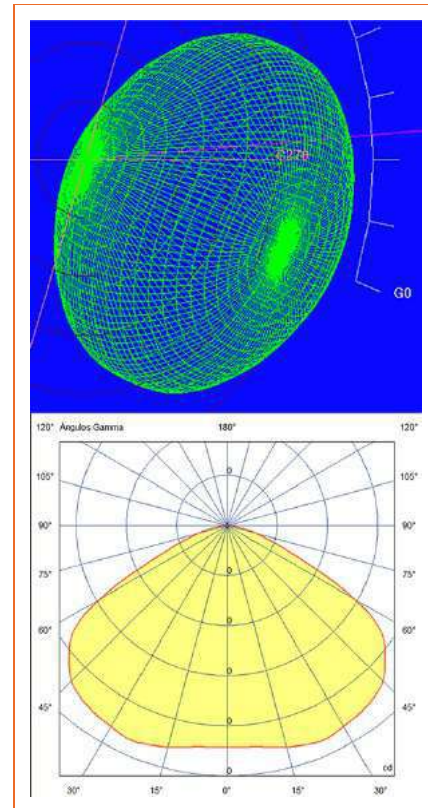


Figure 5: The top figure shows the radiometric solid of a UVC LED made using a gonio-spectroradiometer. On the bottom, the polar representation of radiant intensities ( $W/sr$ ) of the same UVC LED (Source: Asselum Laboratory)

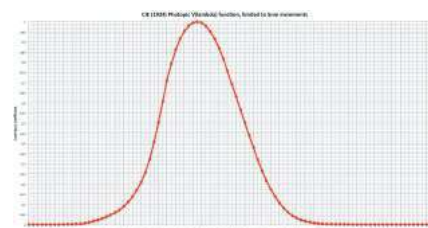


Figure 6: The human eye sensitivity ( $V(\lambda)$ ) curve is one reason why a conventional goniophotometer is not suitable

rameter is known as the spectral response  $f_1'$  [4].

It is for this reason that it is not suitable to measure UV sources with light meters, color meters or spectroradiometers in the visible range. In many cases the equipment would not only fail to detect any signal but it could generate an aberrant signal caused by UVA radiation in the instrument's sensor. Another reason not to characterize UV sources with gonio-photometers is the different reflection property of materials to UVC short-wave reflection. Very short wavelengths (200–280 nm) are reflected much less than visible radiation.

The polar distribution of radiant intensities ( $W/sr$ ) of a luminaire with aluminum reflec-

tors and a low pressure mercury lamp is shown in **Figure 7**.

The visible waves are reflected in the aluminum reflector causing the typical lateral opening in fluorescence luminaires with reflectors. While UVC short wavelength radiation is not reflected and absorbed by the reflector material. Many of the UVC LED technology disinfection equipment also have color LEDs built in for safety measures that indicate if the equipment is on.

This can also lead to poor characterization if visible radiation is not adequately suppressed in the overall characterization of the system. The following figure shows the polar distribution in the range of 200 nm to 800 nm. As can be seen, an asymmetric distribution appears despite the fact that the UVC LEDs are centered on the reflector. This happens by having the LED visible on the side (**Figure 8**).

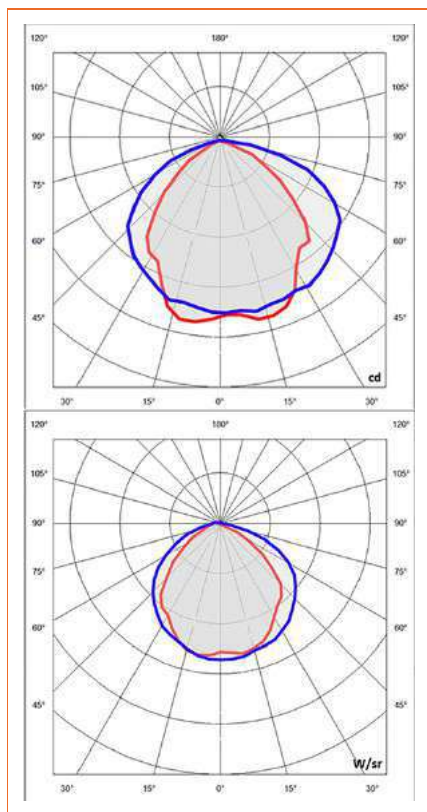


Figure 7: On the top, the polar distribution of intensities in the visible range (380–780 nm) On the bottom, the polar distribution of radiant intensities in the UVC range (200–280 nm)

Not only is it a problem of spatial characterization, but including the visible radiation values in the germicidal radiation levels can cause a calculation error both in irradiance levels ( $W/m^2$ ) and in pathogen elimination times (**Figure 9**).

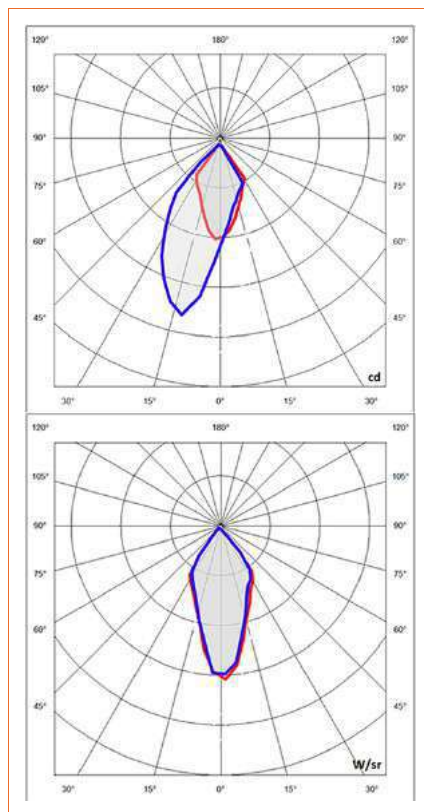


Figure 8: On the top, the distribution of radiant intensities ( $W/sr$ ) 200–280 nm. On the bottom, the same test filtering the radiation at 200–350 nm

## IES TM 33 and OXL Files

All the measurements in the goniometer have to be inserted in a format that allows the exchange of data between platforms and to be able to manage, analyze and calculate these results. For the photometry data, we use the IES and EULUMDAT photometric files. These formats are basically a matrix of the light intensities (Candela or Candela per Kilolumen) measured by a goniophotometer. However, these formats were designed in the last century and are not prepared to incorporate the information of the spectral power distribution.

The new XML formats [5] that have emerged in the United States with the IES TM33, and in Italy with the UNI XML and OXL from the company Oxytech, allow the storage of photometric and radiometric information and, above all, the spectral power distribution, in addition to other technical information. With these files you can perform calculations in commercial lighting calculation programs such as Litestar 4D and Relux among others **Figure 10**.

## Conclusions

This pandemic has caused the entire chain in the general lighting sector to adapt to the new needs that have arisen. Manufacturers, component testers, manufacturers of measuring instruments and laboratories that were used to working in the visible range of radiation have had to learn and adapt their procedures and increase their commercial catalogues. The industry has had to get used to working with spectral distributions, new measurement systems, such as goni-spectroradiometers and, finally, the limitation of the photometric files of the past century such as the eulumat and IES files has been demonstrated. I hope that all this knowledge can also be applied in areas such as HCL, lighting for horticulture and much more, once we have defeated the virus. ■



### AUTHOR: Marc BALLBÈ

Marc Ballbè is CEO of Asselum, an accredited ISO 17025 lighting laboratory with more than 15 years of experience performing photometric and radiometric tests. He has received his electrical engineering degree from the Polytechnic University of Catalonia (UPC) and a Master's Degree on Industrial Automation and Domotics from La Salle University. He is member of the technical committees for tests, calibrations and management of photometric files at CIE and IESNA. Marc Ballbè manages the group for technical seminars and scientific dissemination in the CICAT Lighting Cluster. He has co-authored the technical guide for the use and installation of UV radiation carried out by CICAT.

## References

- [1] Ultraviolet germicidal irradiation handbook. Wladyslaw Kowalski.
- [2] Technical sheet radiometer model RMD of the company Opsytec Dr. Groebe
- [3] CIE 239:2020 Goniopspectroradiometry of Optical Radiation Sources
- [4] Definition of a Spectral Mismatch Index for Spectral power Distributions
- [5] <https://www.led-professional.com/resources-1/articles/rethinking-the-photometric-data-file-format>

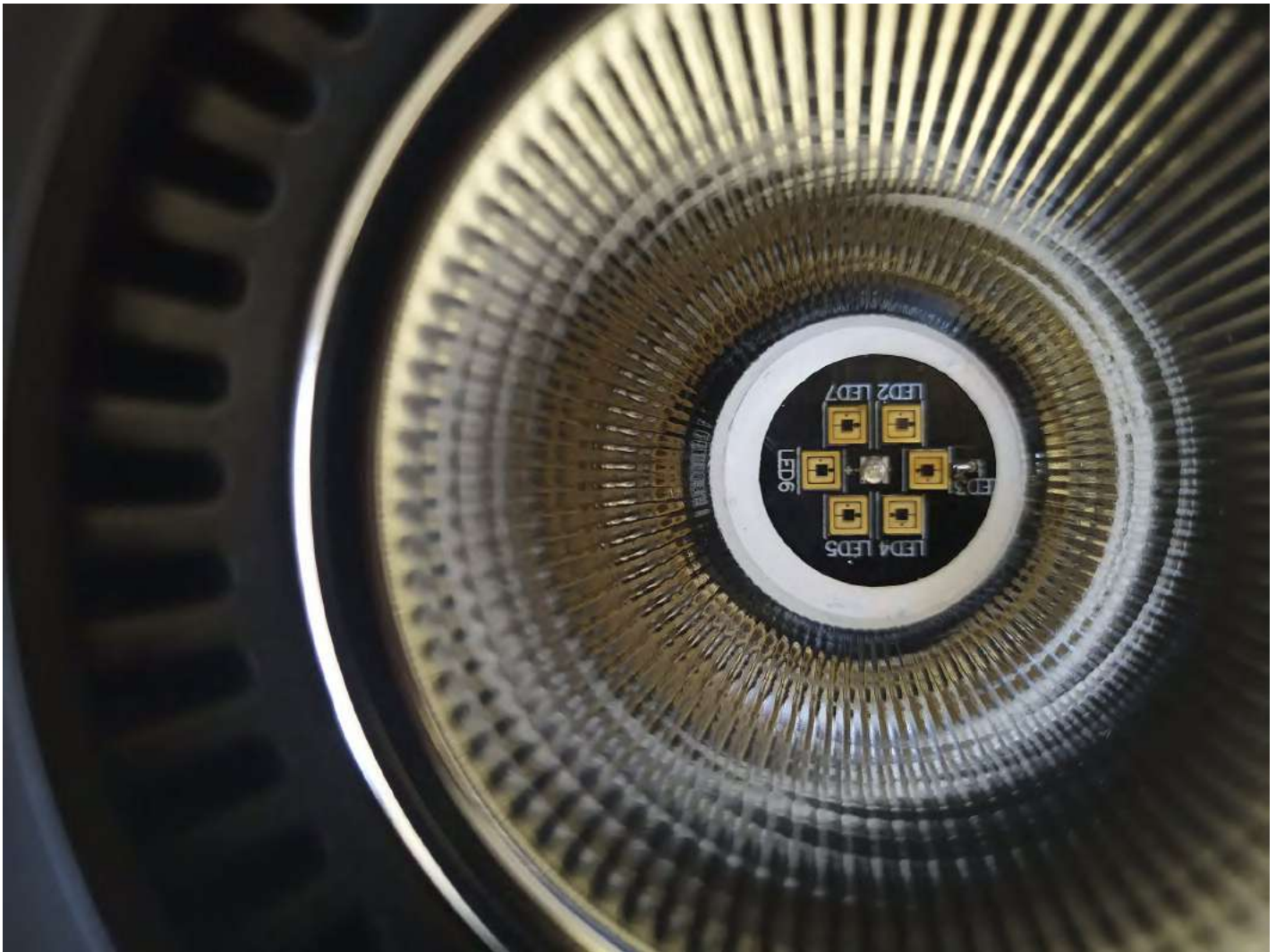


Figure 9: Example of inserting the color safety LED in the center of the optical system to have the same intensity distribution in the visible and UVC bands (Image Credit: Lamp Lighting and JVV Grup)

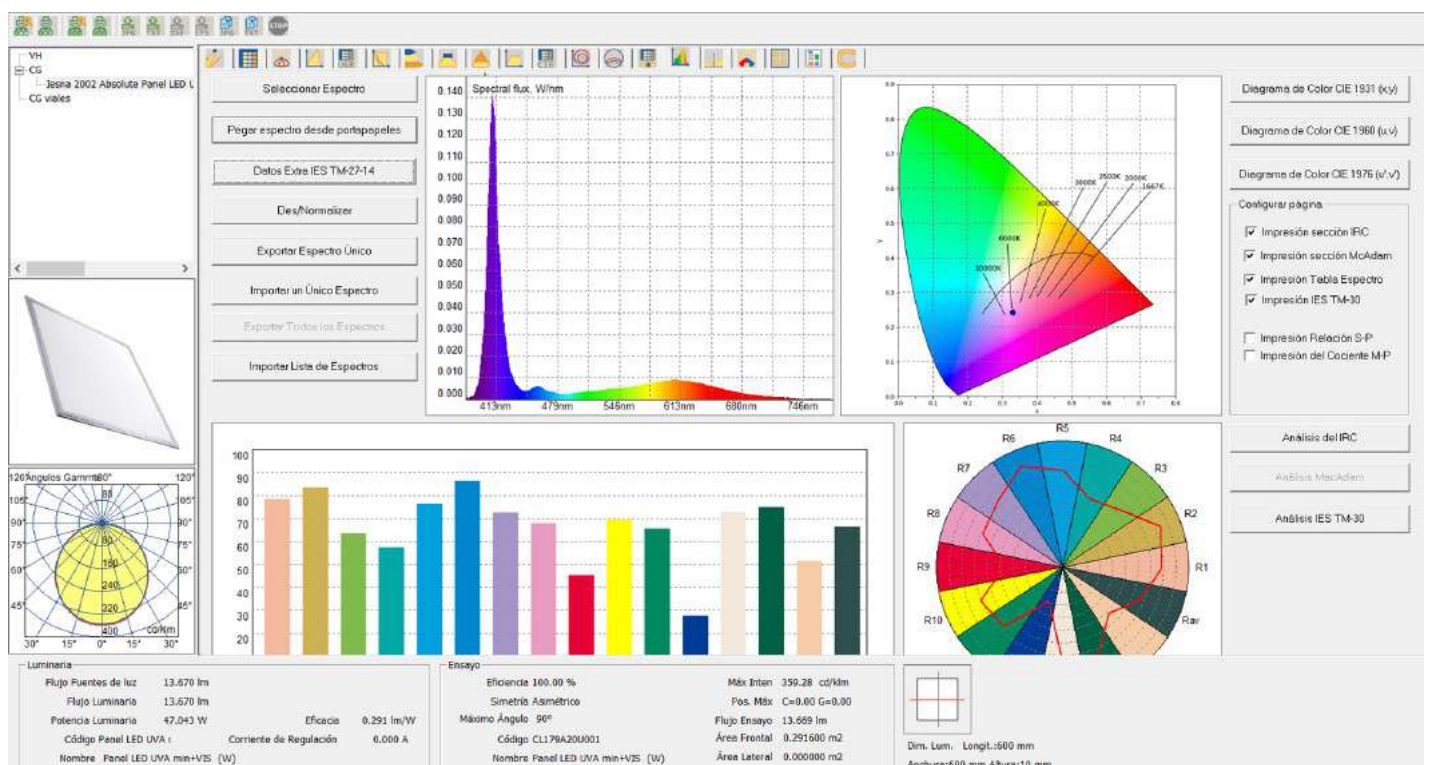


Figure 10: Photometric and radiometric file in OXL format - photometry, radiometer and image