EVALUATION OF SPECTRORADIOMETER PERFORMANCE FOR APPLICATION OF PHOTOBIOLOGICAL SAFETY ASSESSMENT OF LIGHTING PRODUCTS

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1. Background

Currently, tungsten filament lamps, gas-discharge lamps, and LED light sources are typically applied in general lighting. Besides the visible light, these sources may emit a small quantity of ultraviolet and infrared radiation. The optical radiation safety has been considered in these products. The emission limits and classification for the safety assessment are in IEC 62471/CIE S009 [1]. However, the infrared radiation levels in common use lighting sources are generally low and not notable to cause optical radiation hazard. Therefore, actinic UV hazard, near UV hazard and blue light hazard should be considered as potential photobiological effects relating to the optical radiation safety of lighting sources. For the assessment of optical radiation hazards of above products, actinic UV weighted irradiance, near UV irradiance and retinal blue light weighted radiance need to be measured, but It is difficult for broadband detectors to match well with the spectral response as action functions of photobiological effects. Optical radiation for the safety classification of lighting sources is measured via many types of spectroradiometers including scanning monochromator spectroradiometers and CCD array spectroradiometers[2][3].

Because of a large difference of the characteristics in current commercial spectroradiometers, such as low cost CCD spectrometers, well-designed array spectroradiometers, single or double monochromator spectroradiometers, it is difficult to select in compare of the performance and cost in the practical applications for correct safety classification.

2. Evaluation conditions

The scanning monochromator spectroradiometer can positively provide broad spectral range, various slit bandwidth and good linearity. It is still widely used in many applications nowadays. With the improvement of CCD array detectors and multi-chromators, the CCD array spectroradiometer is more and more suitable in various applications.

In the spectral irradiance and radiance measurements, the width of both the entrance slit and the exit slit should be the same so that the spectral response function of the spectroradiometer has a isosceles triangle function, which is very important for gas discharge lamps with narrow spectral lines. Double monochromator spectroradiometer possess very low stray light that is excellent in the UV spectrum for the measurement of lighting sources.

In compact array spectroradiometers, the spectrum diffracted by concave holographic grating focuses on an array detector, and the elimination of high order spectrum and stray light are a practical bugbear in the measurement for photobiological safety. The entrance slit width of the array spectroradiometer shall be between the sensitivity and wavelength resolution.

For evaluating the effects on photobiological safety assessment of lighting sources from the spectroradiometer performance, the five lighting sources of above three types which include HID (MH), FL, cool white LED, warm white LED and quartz tungsten lamps are as shown in

Figure 1. However, it is mainly considered for the effects in the measurements of actinic UV weighted irradiance, near UV irradiance and retinal blue light weighted radiance.

The risk group of the photobiological safety might be changed under the different application conditions (i.e. viewing conditions) for a certain lighting source. According to the specifications in IEC62471 for GLS sources, the risk should be evaluated at the position where produces 500lx illumination. Therefore, here actinic UV weighted irradiance and near UV irradiance will be in this condition, and the retinal blue light weighted radiance will be under the condition of 10000cd/m2.

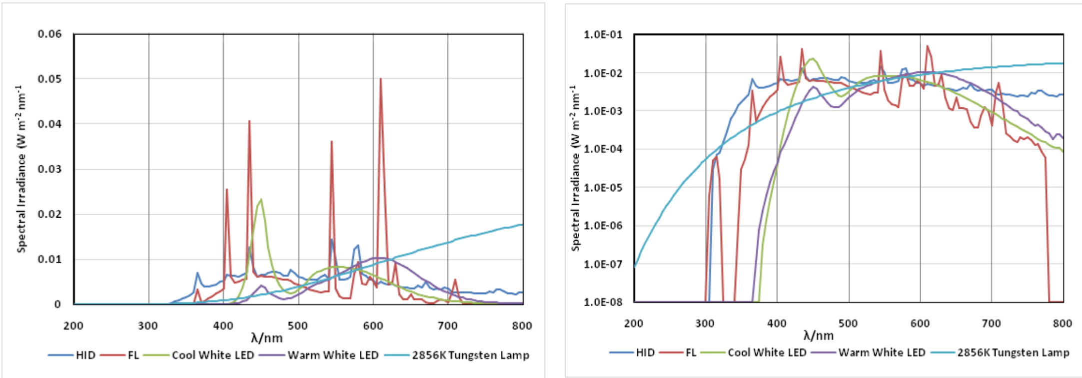
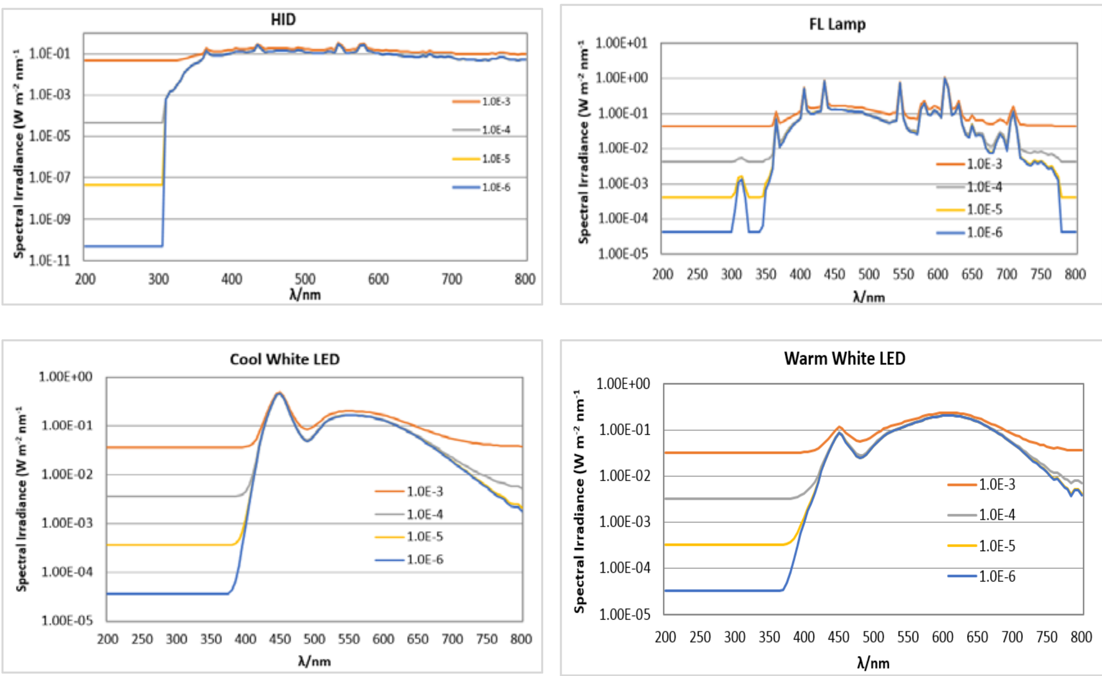


Figure 1. Spectral irradiance distributions of typical lighting sources

3. Effects of the main performances



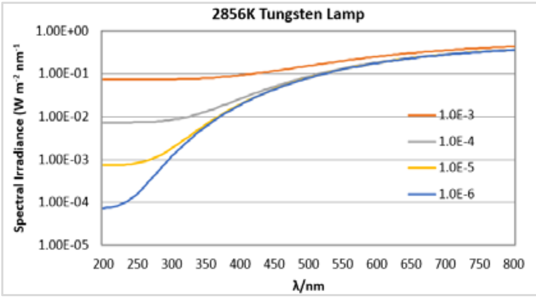


Figure 2. Spectral irradiance distribution including stray light

Stray light, wavelength accuracy and photoelectrical linearity are three main factors in the spectroradiometer performance. The stray light of scanning double monochromators can be better than 10-6; whereas the stray light of small CCD spectroradiometer with short focus length only reaches to 10-3 to 10-4. Therefore, the levels of stray light between 10-6 and 10-5 are to evaluate the effects on the measurement of these photobiological quantities. In Figure 2, it shows the spectral data of the light source with different levels of stray light; the corresponding photobiological quantities are in Table 1, in which the UV actinic weighted irradiance is very sensitive with stray light. If the stray light magnitude of the spectroradiometer were more than 10-4, it would cause the RG0 to be assigned to RG1. Therefore, for the light source with some UV radiation like the 2856 K tungsten lamp in Table1, the stray light should be requested to be not more than 10-6. However, for the measurement of the retinal blue light hazard radiance, the stray light needs to be less than 10-4 for the quantity change of 5%.

Table 1. The impacts of the stray light

E_{UV}					
Stray Light	HID	FL	Cool White LED	Warm White LED	2856k
0	2.64E-05	1.18E-05	1.03E-08	1.62E-08	8.30E-04
1.0E-6	2.64E-05	1.08E-04	8.35E-05	7.41E-05	9.98E-04
1.0E-5	2.65E-05	9.73E-04	8.34E-04	7.41E-04	2.52E-03
1.0E-4	1.34E-04	9.62E-03	8.34E-03	7.41E-03	1.77E-02
1.0E-3	1.07E-01	9.61E-02	8.34E-02	7.41E-02	1.69E-01
E_{UVA}					
Stray Light	HID	FL	Cool White LED	Warm White LED	2856k
0	2.43E-01	8.48E-02	3.20E-04	1.61E-03	3.75E-02
1.0E-6	2.43E-01	8.44E-02	4.74E-04	5.77E-04	3.79E-02
1.0E-5	2.43E-01	8.61E-02	1.94E-03	1.88E-03	4.08E-02
1.0E-4	2.43E-01	1.03E-01	1.67E-02	1.49E-02	7.06E-02
1.0E-3	4.53E-01	2.72E-01	1.64E-01	1.46E-01	3.68E-01
L_B					
Stray Light	HID	FL	Cool White LED	Warm White LED	2856k
0	9.80	11.77	12.81	2.61	2.96
1.0E-6	9.80	11.77	12.82	2.61	2.97
1.0E-5	9.80	11.80	12.84	2.63	3.01
1.0E-4	9.80	12.06	13.07	2.83	3.47

1.0E-3	13.02	14.65	15.32	4.83	8.02

For general lighting service, the light sources emit radiation mainly in the visible range, and very little in UV range, which is mostly less than 1%. Therefore, the stray light from visible radiation to be spread on UV range should be considered seriously. An alternative method to eliminate the effects of stray light can be used by the combination of a visible blind PMT detector whose response is active only in the SUV(λ) effective range of 200nm~320nm and another visible sensitive PMT. In Table 2, it shows that the stray light effect on UV actinic weighted irradiance is reduced significantly after using the visible blind PMT. In Figure 3, its results (dash line) are with common (solid line) spectroradiometer. E_{uv}(th) is the emission limit of the UV actinic hazard irradiance relating to RG0. Here, the safety classification of these five typical lighting sources would not be affected.

Table 2. Stray light effects to UV actinic weighted irradiance (with visible blind PMT)

Stray Light	HID	FL	Cool White LED	Warm White LED	2856K
0	2.64E-05	1.18E-05	1.03E-08	1.62E-08	8.30E-04
1.0E-6	2.64E-05	1.69E-05	3.54E-08	3.85E-08	8.30E-04
1.0E-5	2.64E-05	1.71E-05	2.62E-07	2.39E-07	8.30E-04
1.0E-4	2.65E-05	1.97E-05	2.52E-06	2.25E-06	8.35E-04
1.0E-3	5.87E-05	3.40E-05	2.51E-05	2.23E-05	8.81E-04

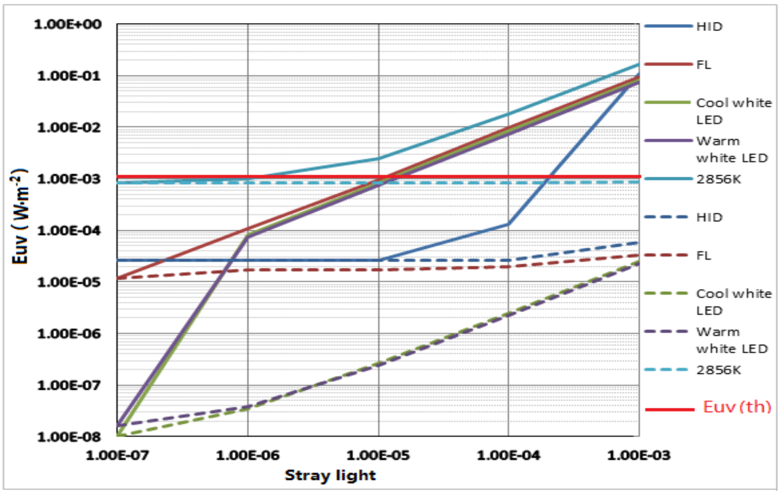


Figure 3. Compare of UV actinic weighted irradiance variations

Table 3 shows the effects of wavelength shifts in spectroradiometers to the quantities for the radiation safety classification. Since the weighting function SUV(λ) changes rapidly in the range of 300nm~320nm, which varies 300 times in 20nm range, the effect on UV actinic weighted irradiance of FL is greatest because of the sensitive wavelength at 313nm for FL radiation spectrum. If less than 10% uncertainty is, the wavelength shift should be no more than 0.2nm, and for the light sources with a continuous spectrum should be no more than 0.3nm. Considering the effects of retinal blue light radiance from wavelength shift, the weighting function variation shall be twice as much at each 5nm in sensitive wavelength ranges of 390nm to 415nm and 480nm to 500nm. Therefore, the wavelength accuracy should be better than 0.5nm.

Table 3. Effects of wavelength shifts in the spectroradiometer

E_{uv}					
Wavelength shift	HID	FL	Cool White LED	Warm White LED	2856K
0	2.64E-05	1.18E-05	1.03E-08	1.62E-08	8.30E-04
-0.1	2.68E-05	1.24E-05	1.07E-08	1.79E-08	8.34E-04
-0.2	2.71E-05	1.29E-05	1.11E-08	1.82E-08	8.38E-04
-0.3	2.75E-05	1.35E-05	1.15E-08	1.85E-08	8.43E-04
-0.5	2.82E-05	1.46E-05	1.23E-08	1.92E-08	8.51E-04
+0.1	2.64E-05	1.18E-05	1.03E-08	1.75E-08	8.30E-04
+0.2	2.63E-05	1.17E-05	1.02E-08	1.74E-08	8.26E-04
+0.3	2.61E-05	1.16E-05	1E-08	1.72E-08	8.23E-04
+0.5	2.60E-05	1.14E-05	9.9E-09	1.7E-08	8.19E-04
L_B					
Wavelength shift	HID	FL	Cool White LED	Warm White LED	2856K
0	9.80	11.77	12.81	2.61	2.96
-0.1	9.80	11.77	12.81	2.61	2.96
-0.2	9.80	11.78	12.80	2.61	2.96
-0.3	9.80	11.79	12.78	2.60	2.95
-0.5	9.80	11.79	12.77	2.60	2.95
+0.1	9.80	11.77	12.83	2.61	2.97
+0.2	9.80	11.76	12.84	2.62	2.97
+0.3	9.80	11.76	12.85	2.62	2.97
+0.5	9.81	11.75	12.87	2.63	2.98

4. Conclusion

In photobiological safety assessment, the spectroradiometer is key equipment. Its performance will directly affect the classification of the safety. The results show that stray light of the spectroradiometer will obviously affect the measurement of UV actinic weighted irradiance by considering five typical lighting sources. Double-monochromators system and the single monochromator system with visible blind PMT can be well applied in the classification of the UV risk of general lighting sources. Besides, the wavelength accuracy of the spectroradiometer should be required within 0.2nm in UV range and 0.5nm in the visible range.

Reference:

[1] IEC 62471-2006/CIE S009 Photobiological Safety of Lamps and Lamp Systems Photobiological Safety of Lamps and Lamp Systems.

[2] TONGSHENG, M, 2010. The measurement of weighted LED radiance related to photobiological safety based on the spectroradiometry and imaging methods, CIE Tutorial and Expert Symposium ”Spectral and Imaging Methods for Photometry and Radiometry”, 30- 31 August 2010, Bern, Switzerland.

[3] TERESA GOODMAN, 2011. Methods of Characterizing Spectrophotometers, CIE 197:2011, Proceedings of the 27th Session of the CIE -- Sun City, South Africa, 9-16 July 2011.