Influence of the light spectral distribution used in the radiometers calibration

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Abstract. The use of radiometers is common as a form of control in tests that engage exposure to natural or artificial electromagnetic radiation. The photodiode is a very much used device, capable of converting the incident radiation into electrical current, which is transformed in irradiance by a duly calibrated meter. The calibration of radiometers is made by comparing it with a spectroradiometer and a calibration factor is obtained. Considering that the photodiodes responsiveness is not constant for all wavelengths, the spectral distribution of the light source is a great influence factor in the calibration. Thus, the objective of this work was to evaluate the variation in the calibration factor of the radiometers resulting from the spectral distribution variation of the light source used. The results showed a variation of up to 16% in the calibration factor, reinforcing the importance of calibrating the radiometers with the same light source type used daily, in order to assure the accuracy of the measurements made with this type of equipment.

1. Introduction
The use of radiometers is common as a form of control in tests that engage exposure to natural or artificial electromagnetic radiation. There are several types of radiometers available in the market, with different principles of working. The photodiode is the most used device, capable of converting the incident radiation into electrical current, which is transformed in irradiance by a duly calibrated meter. Associated to optical filters that filter part of the radiation, more specific sensors are obtained for specific spectral ranges.

Radiometers manufacturers usually provide a spectral response curve, better known as responsiveness, which represents the sensor response over its spectral range. The responsiveness of the photodiodes is not the same for all wavelengths, meaning, it is more sensitive for certain wavelengths and less sensitive for other ones, it can even record different irradiance values for different wavelengths, even when they have the same intensity.

Thus, as other pieces of equipment, it is necessary to calibrate it with defined intervals, in order to assure the accuracy of the radiometers. The calibration of the radiometers is made by following the ASTM G130 standard, comparing its response with the response of a spectroradiometer, which measures the spectral irradiance, obtaining a calibration factor to correct the radiometer reading.

Considering that the spectral responsiveness of the photodiodes is not constant, the distribution of the light source is a factor with great influence in the calibration and measurements made with this type of equipment. Therefore, it is necessary to calibrate it with the same light source measured daily with the radiometer.
2. **Objective**
Evaluating the variation on the calibration factor of the radiometers resulting from the spectral distribution variation of the light source used, to reinforce the necessity of calibration with the same light source used daily.

3. **Methods**
The calibration factor of the radiometer was obtained according to ASTM G-130 standard. Different light sources were used to calibrate the radiometer and the variation in the calibration factor was analyzed.

3.1. **Equipment used**
Two UVA radiometers manufactured by Solar Light, model PMA 2110, with datalogger PMA 2100.
Spectroradiometer manufactured by Optronic OL756, calibrated against a spectral irradiance standard with NIST traceability, following the ASTM G-138 standard, with specified bandwidth of 0.8nm, wavelength interval of 1nm, integrating sphere of 5cm diameter, with 5mm-opening and optical fiber.
The light sources used in the radiometer calibration were: xenon, xenon + UV filter, xenon + UVA filter, sunlight and mercury.

3.2. **Radiometer Calibration**
The radiometer calibration was performed according to ASTM G-130 standard. The radiometer was positioned in a way its entrance port was at the same level as the input of the integrating sphere relative to the source of light used, with ±1mm of tolerance.
After the light source was stabilized, the radiometer reading was recorded (n≥5) and then the integration sphere was positioned on its place. Three (n=3) measurements of spectral irradiance were taken, using the reading range of the radiometer – (320-400) nm – in 1nm intervals.
After the measurements with the spectroradiometer were completed, there was a 10-minute wait before repeating this procedure, until a total of 3 replicates were obtained.
The spectral irradiance in the range of (320-400)nm was integrated using the trapezium method and converted to the reading unit of the radiometer (mW/cm²). The integrated irradiance was divided by the average irradiance obtained by the radiometer, and an F calibration factor was obtained (Equation 1).

\[
Calibration\ Factor\ (F) = \frac{\text{Integrated\ Irradiance\ (Spectroradiometer)}}{\text{Obtained\ Irradiance\ (Radiometer)}}
\]

The calibration factor can be used to correct the spectroradiometer reading to obtain the corrected value, corresponding to the real value obtained by the standard (Spectroradiometer).
The calibration was repeated by using 5 types of light sources:
- Xenon + UV filter
- Xenon + UVA filter
- Sunlight
- Mercury

4. **Results**
Figure 1 shows the responsiveness of the UVA radiometer used, as declared by the manufacturer Solar Light. It is noticeable that the radiometer is more sensitive between 360 nm and 370 nm and the responsiveness is reduced at the extremes of the spectral range analyzed.
Figure 2 shows the spectral distribution of different light sources used for the calibration of the radiometer.

![Figure 1](image1.png)

**Figure 1.** Responsiveness of the UVA radiometer used, as declared by the manufacturer Solar Light.

![Figure 2](image2.png)

**Figure 2.** Spectral distribution of the light sources used.

A great difference between the spectral distributions is observed. The mercury lamps contain emission peaks that are characteristic of the atomic emission of mercury, the reason why it is called spectral source. As for the sunlight and the tungsten lamp, they are continuous light sources, characterized by emitting continuous radiation throughout the wavelengths, similar to the emission of a blackbody.

The xenon lamp has its spectral distribution modified according to the combination of filters used. It is observed that the UVA+ID65 filters block a part of the UVA radiation between 320 nm to 370 nm when compared to the UV filter.

Table 1 shows the results obtained when comparing the calibration using the tungsten lamp and the xenon lamp + UV filter, both continuous light sources, but with slight differences in the spectral distribution between 360 nm and 400 nm.
Table 1. Results obtained in the UVA radiometer calibration with 1.10 scale for the tungsten and xenon lamps with UV filter.

<table>
<thead>
<tr>
<th></th>
<th>Xenon with UV Filter</th>
<th>Tungsten</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiance - Radiometer (mW/cm²)</td>
<td>8.19</td>
<td>0.10</td>
</tr>
<tr>
<td>Irradiance - Spectroradiometer (mW/cm²)</td>
<td>7.61</td>
<td>0.09</td>
</tr>
<tr>
<td>Calibration Factor (F) (s/u)</td>
<td>0.93</td>
<td>0.89</td>
</tr>
</tbody>
</table>

A difference of 3.8% in the calibration factor of the radiometer when calibrated with the tungsten lamp was observed in relation to the calibration carried with the xenon lamp with UV filter.

As the relative intensity of the tungsten lamp in the range of the radiometer greater responsiveness is similar to that of the xenon lamp, the calibration factors resulted in very close values.

Table 2 shows the results obtained when comparing the calibration using the mercury lamp, the xenon + UVA + ID65 filter and the xenon lamp + UV filter.

Table 2. Results obtained in the UVA radiometer calibration with 0.96 scale for the tungsten and xenon lamps with UV filter.

<table>
<thead>
<tr>
<th></th>
<th>Mercury</th>
<th>Xenon with UVA+ID65 filter</th>
<th>Xenon with UV Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiance - Radiometer (mW/cm²)</td>
<td>1.94</td>
<td>4.62</td>
<td>6.54</td>
</tr>
<tr>
<td>Irradiance - Spectroradiometer (mW/cm²)</td>
<td>1.35</td>
<td>4.77</td>
<td>6.56</td>
</tr>
<tr>
<td>Calibration factor (F) (s/u)</td>
<td>0.70</td>
<td>1.03</td>
<td>1.00</td>
</tr>
</tbody>
</table>

A difference of 30.5% in the calibration factor of the radiometer when calibrated with the mercury lamp and a difference of 3.1% when calibrated with the xenon lamp with UVA+ID65 filter were observed, both in relation to the calibration carried with the xenon lamp with UV filter.

Table 3 shows the results obtained when comparing the calibration using sunlight and xenon lamp + UV filter.

Table 3. Results obtained in the UVA radiometer calibration with 1.10 scale for the tungsten and xenon lamps with UV filter.

<table>
<thead>
<tr>
<th></th>
<th>Sunlight</th>
<th>Xenon with UV Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irradiance - Radiometer (mW/cm²)</td>
<td>0.87</td>
<td>1.37</td>
</tr>
<tr>
<td>Irradiance - Spectroradiometer (mW/cm²)</td>
<td>5.62</td>
<td>7.61</td>
</tr>
<tr>
<td>Calibration factor (F) (s/u)</td>
<td>6.43</td>
<td>5.55</td>
</tr>
</tbody>
</table>

A difference of 16.0% in the calibration factor of the radiometer was observed when calibrated with sunlight, in relation to the calibration carried with the xenon lamp with UV filter.

5. Conclusion
The international standard ASTM G-130 which describes the method of broadband radiometer calibration using a reference spectroradiometer requires that the light source used is the same as the one used daily with the radiometer, and even specifies methods of assurance that the positioning is also the same.
Taking into consideration the 30 % difference found in the calibration factors, the importance of calibrating the radiometers with the same light source type used daily is reinforced, in order to assure the accuracy of the measurements taken with this type of equipment.

References