PROPOSED METHOD FOR MEASUREMENT OF THE OUTPUT OF MONOCHROMATIC (254 nm) LOW PRESSURE UV LAMPS

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CONTEXT

This paper has been developed to present a consistent methodology for the determination and benchmarking of UV lamp output from monochromatic (254 nm) lamps operated by a corresponding power supply (ballast). The protocol can be used for testing and comparing different lamp and ballast combinations, to compare test results from different laboratories and to compare operation under different ambient conditions. The protocol is not intended for general manufacturing quality control or quality assurance testing.

Monochromatic lamps include tubular low pressure and low pressure high output (e.g. amalgam) lamps that are typically used in water and air disinfection applications. The protocol described herein is not recommended for medium pressure, pulsed, folded, non-symmetrical or other special lamps (e.g., *excilamps* – also called *excimer lamps*).

FORMULA

Based on the work of Keitz (1971), the following formula is recommended for calculating the total UV output from a UV lamp with a monochromatic (e.g., 254 nm) output. The lamp output power P can be calculated from Equation 1 (the Keitz formula):

$$P = \frac{E 2\pi^2 D L}{2\alpha + \sin 2\alpha} \quad [1]$$

where (see Figure 1)

E is measured irradiance (W m^{-2}).

D is distance (m) from lamp center to the UV sensor.

L is lamp length (m) from electrode tip to electrode tip.

α is the half angle (radians) subtended by the lamp at the sensor position. That is, $\tan \alpha = L/(2D)$

This expression has been tested by comparing with goniometric measurements of lamp output, and by comparing results from laboratories in different countries (Sasges et al. 2007). The results are considered accurate within 5% and have shown good agreement between laboratories.

Depending on how the lamp output data are to be used, it may be advised that UV companies undertaking lamp testing under this Protocol engage a qualified 'third party' consultant to oversee the testing and write a 'third party' independent Report.

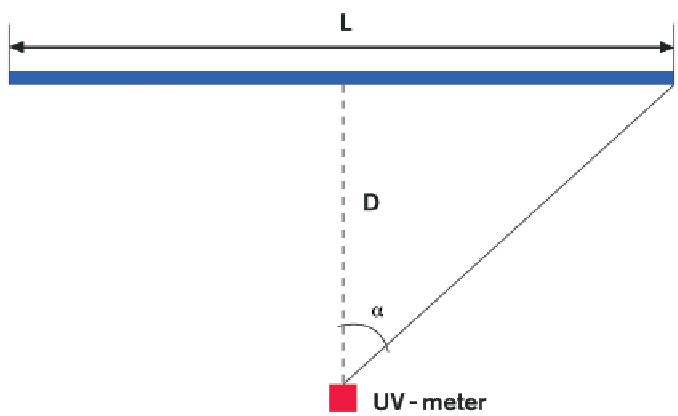

Figure 1. *Geometry of the Measurement System*

NECESSARY CONDITIONS

1. Measurements shall be conducted in still room air, not in a moving air stream.
2. The lamp orientation shall be horizontal.
3. Reflected light must be avoided (e.g. though use of baffles, differential measurement with beam stops)
4. The UV sensor must have an adequate cosine response

for the lamp length and distance used. This may require a distance $D \geq 2L$, measured from lamp's axis (per Equation 1).

Temperature Conditions

Low pressure and amalgam lamps are affected by their operating temperature, which is in turn affected by their surroundings, air temperature, etc. These lamps will generally exhibit increasing UV output with increasing temperature after ignition until an optimum temperature is reached, and then a decreasing output with further increases in lamp temperature. This behavior is shown in the figure below, denoted as a 'slightly overheated lamp'. It is desirable to measure a lamp under these slightly overheated conditions, so that the maximum output can be measured. Lamps shall be measured at a stable and constant air temperature. The entire warm-up curve of irradiance vs. time shall be reported including the maximum peak. Room temperature shall be documented and included in the Report.

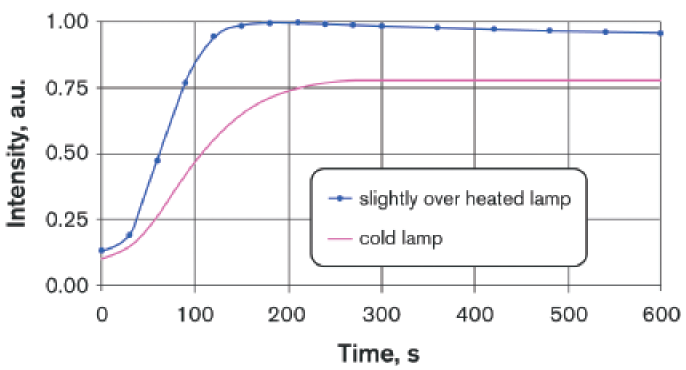

Figure 2. ***Lamp output vs. time after ignition for a slightly overheated lamp and for a lamp that does not reach its optimum temperature.***

MEASUREMENTS

The lamp output reported shall be measured after a *new-lamp* 100 h burn-in period. The lamp output reported shall be based on lamps operating under air conditions, in which the lamp has reached a maximum output and then decreases to steady state, indicating that the lamp has passed through an optimum into an overheated condition. This will generate a UV irradiance curve as a function of time, which will illustrate the maximum and steady state output values. Figure 3 shows a typical test setup.

Lamp and Ballast Efficiency

Lamp Output Power is generally compared with the electrical (line) power consumed in order to calculate the efficiency of the lamp/ballast system. It is recommended that the input power to the ballast be accurately measured as *true RMS*, so that the efficiency may be calculated. This electrical power measurement must be done accurately, using calibrated instruments for power (e.g., a power analyzer suitable for the operating frequency of the power supply). In particular, it is <u>not</u> sufficient to measure the ballast voltage and current to obtain the lamp power by multiplication.

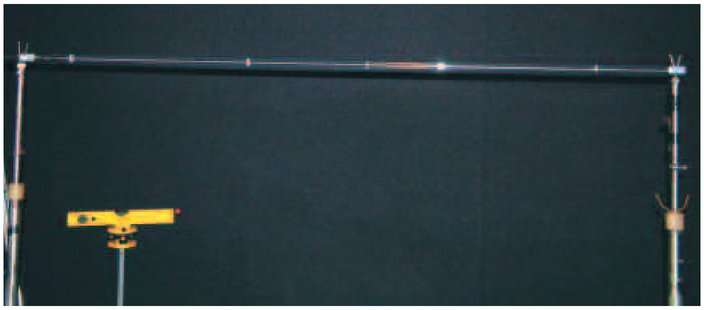

Figure 3. ***Typical test setup. The UV lamp is mounted about 1 m off the floor. The UV detector is mounted at the same height as the lamp (photo courtesy of Trojan Technologies).***

Calibrations

The following traceability of calibration, standard method must be confirmed, showing calibration within one year:

1. Radiometer with a detector traceable to a National Laboratory (e.g. NIST, PTB, NPL, NRC etc.). The calibration for the UV radiometer used must be valid and traceable for calibration in the UVC range, and it must include a wavelength of 254 nm. If a spectroradiometer is used, then only the output between 250 and 260 nm shall be included in the calculated output.
2. The radiometer or spectroradiometer calibration to be validated by a qualified third party and/or accredited facility.
3. Confirmation for calibration of the Power Analyzer.

DETAILED METHOD

General Remarks

Avoid reflected light during the measurement of the UV light.

1. Use non reflecting materials for walls, floor, baffles.
2. Be aware that the UV reflectance may be different from reflectance in the visible range. Wood and black cloth have very low UV reflectance.
3. Use baffles, beam stops, light traps as appropriate.
4. If possible, take geometry of the lab into account (the bigger the better) thereby reducing reflected or stray light.
5. Test: to check the amount of reflected light, compare the sensor signal to that measured when direct irradiation is blocked out. Report the corrected result.

Safety

1. Do not expose uncovered skin or eyes to UV radiation
2. Use adequate protective equipment such as a UV safety shield, gloves and UV goggles. Almost all plastic or glass safety glasses do not transmit UV below 300 nm.

Equipment

1. Adjust the lamp and detector at a suitable height over the ground (e.g., about 1 m).
2. Check validity of calibration for all devices that influence results:
   a. Radiometer
   b. Spectroradiometer
   c. Electrical equipment (power analyzer, multimeter, etc.)
   d. Thermometer
   e. Warm up all devices.
   f. Make sure that the measurement equipment is appropriate.

Validation

1. The cosine correction for radiometers and spectroradiometers is critical to the proper measurement of the UV irradiance. The cosine correction must be confirmed by the following method for each lamp and ballast combination so that the lamp measurements are consistent within and between laboratories.
2. Validation of cosine response and the resulting minimum distance D_{min} where measurements for a given combination of lamp and detector can be performed as follows:
   a. Take readings of the UVC Detector for different distances (detector position perpendicular to lamp axis), recommended range from $D = L/2$ to $4L$.
   b. Take several readings of the UVC irradiance. For example, moving the detector from the closest point to the most remote point and then back again.
   c. Average the irradiance readings for each distance.
   d. Calculate the UVC power from the measured irradiances using Equation 1 (the Keitz formula) for each distance.
   e. Plot calculated UVC power versus distance.
   f. At a certain distance (D_{min}) the UV output should become independent of distance.
   g. Measure at least at one distance greater than D_{min}.
3. The distance derived by this method is valid for the combination of this lamp length and this individual detector.

Measurement Procedure

1. Record or monitor ambient temperature (±1°C tolerance).
2. Determine that the distances for radiometer readings are valid.
3. Start recording the readings (UVC irradiance, electrical measurements, etc.) after the lamp is turned on.
4. Sampling rate: should be matched to the rate of changing of the UV intensity readings.
5. Rate of ~1 reading / 10 s is often sufficient to mark the maximum.
6. Record the irradiance until a steady state is achieved; record the steady state value of the irradiance.
7. Record the ambient temperature again.
8. Calculate Peak and Steady State UV-Power using the Keitz formula. The peak UV Power value is the value where the influence of temperature is reduced to a minimum and which can be compared to results of other laboratories.
9. Calculate the lamp efficiency either based on lamp power (Equation 2a) (optional) or power from the wall (Equation 2b) as:

$$[2a]\ \text{Efficiency (based on lamp power)(\%)} = 100\text{x}\ \frac{\text{Total UV Output (W)}}{\text{Power across the lamp (W)}}$$

$$[2a]\ \text{Efficiency (based on wall power)(\%)} = 100\text{x}\ \frac{\text{Total UV Output (W)}}{\text{Power from the wall (W)}}$$

REPORT CONTENT

Measurement report to include:

1. Full and detailed information about the lamp (e.g., manufacturer, identification etc.).
2. Full and detailed information about the ballast (e.g., manufacturer, identification etc.).
3. Lamp orientation during testing (horizontal required).
4. Active arc length L (between the ends of the filaments for 'linear' lamps).
5. Measurement of the distance D from lamp center (with tolerance) to the *calibration plane*[1] of the radiometer detector.
6. Room Temperature (°C).

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[1] The 'calibration plane' shall be specified in the 'calibration certificate' from the company manufacturing and calibrating the radiometer and detector. In many cases, the 'calibration plane' is not the surface of the detector.

7. Sensor and radiometer brand, model number and serial numbers for the radiometer, detector and any filters or other optical elements (e.g., diffuser) on the detector.

8. Valid, traceable radiometer or spectroradiometer calibration documentation.

9. Plot of Irradiance vs. time after ignition, with an indication of the maximum and steady-state irradiance values.

10. Calculated Peak and Steady State UV Power, with uncertainty.

11. Electrical power meter (e.g., brand, model number and serial numbers for the power meter). Confirmation of Calibration or Calibration Certificate for the electrical power meter.

12. Measured Voltage and Current into the ballast.

13. Measured Electrical Power across the lamp and 'from the wall',[2] with uncertainty

14. Calculated Lamp Efficiency (%) both with respect to the electrical power consumed by the lamp and the 'from-the-wall' electrical power.

REFERENCES

Keitz. H.A.E. 1971. Light Calculations and Measurements, Macmillan and Co Ltd, London, UK.

Sasges, M.R., van der Pol, A., Voronov, A. and Robinson, J. A. 2007. Standard Method for Quantifying the Output of UV lamps, Proc. International Congress on Ozone and Ultraviolet Technologies, Los Angeles, CA, August, International Ultraviolet Association, PO Box 28154, Scottsdale, AZ, 85255.

[2] The 'from-the-wall' power includes power consumption in the ballast or power supply.