

# Round Robin Test of the IUVA UV Lamp Efficiency Testing Protocol (Revised)

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## Introduction

Over the past several years, the Manufacturers' Council of the International Ultraviolet Association (IUVA) has developed a protocol for testing of the UV efficiency of low-pressure and low-pressure high-output UV lamps. The first version of this protocol was adopted in 2008 (Lawal et al., 2008). A round-robin test of this protocol was conducted in 2009, but the results were not satisfactory. In reviewing the 2008 protocol, there was no flaw in the requirements but rather the practice. Such factors as adherence to protocol, reflectance and measurement methods led to high sources of error.

Hence, in 2013, The Manufacturers' Council adopted a revised protocol (see Appendix A on page 15) that further refined the requirements of the 2008 protocol. Before finalizing this new protocol, it was decided to conduct a second Round Robin. This paper presents the results of this new Round Robin.

The Round Robin was initiated by testing at Light Sources Inc. (Orange, CT) of 15 Light Sources 320 W (model GPHHA1554T6L/4P) low-pressure high-output (spot amalgam) UV lamps (arc length 1.475 m) according to the revised Protocol using an electronic power supply (Philips Electronic Ballast – Model TUV 325W XPT) and a recently calibrated radiometer (International Light model ILT 1700 with an SED240 detector with an NS254/NS254 filter and a W diffuser). After the tests were completed, the lamps, power supply and radiometer were shipped sequentially to nine other manufacturers where similar tests were conducted.

## Procedures

The testing procedures followed the protocol given in Appendix A. Some centers used method 1 to minimize reflection, and some used method 2, as shown in Appendix B on page 18.

## Results

Table 1 gives the average lamp efficiencies under four conditions as obtained from the tests conducted by the participating manufacturers, which were (in random order): Hanovia, Trojan, Xylem, Light Sources, Calgon Carbon, Heraeus, Philips, Foshan-Comwin, LightTech and Ozonia. Table 2 gives the average lamp voltages, lamp powers, optical powers, lamp current and the ambient and surface temperatures.

Detailed tables of results for individual lamps are in Supplementary Files.

The four conditions were:

1. Steady-state efficiency after a period of at least 10 min
  - a. Input to the lamp
  - b. Input to the ballast
2. Efficiency at time of peak output (usually about 2-5 min)
  - a. Input to the lamp
  - b. Input to the ballast

## Discussion

The following observations can be made:

1. The results are generally highly reproducible among the various test centers.
2. There was a 2-3% drop in efficiency between measurements across the lamp vs. those from the wall. This indicates that the power supply consumes about 7-12% of the input power with the rest going to the lamp.
3. One would expect that the efficiency at peak output should be more reproducible among the various labs; however, there is not much difference in the reproducibility between the data for steady state and the data for peak output.
4. There does not appear to be any significant correlation between lamp efficiencies and the ambient temperature, although the temperature range is quite small.
5. One test center (C) failed to make reliable measurements of the output across the lamp.
6. Some centers (e.g., C and H) reported electrical values that were well outside the norm. Perhaps there was a problem with the calibration of their power analyzers.
7. The distance from the center of the lamp to the radiometer detector varied from 2.88 to 4.00 m. There did not appear to be any correlation in the results vs. this distance. This confirms the recommendation that this distance be at least twice the arc length.
8. When the lamps, ballasts and radiometer were returned to Light Sources and again tested in October 2014, the results were almost the same as when the lamps were originally tested in September 2013.

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**Table 1.** Average lamp efficiencies (%) for the conditions: (1) Steady-state for the “input to the lamp,” (2) Steady-state for the “input to the ballast,” (3) Time of peak output for the “input to the lamp” and (4) Time of peak output for the “input to the ballast.”

Condition	Manufacturer											Average	2 x Std. Dev. of Mean
	A(1)	B	C	D	E	F	G	H	I	J	A(2)		
Steady-state (input to lamp)	34.9%	34.5%		34.3%	35.1%	34.0%	33.9%	32.1%	33.1%	30.4%	34.4%	33.9%	1.0%
Steady-state (input to ballast)	32.3%	31.6%	31.4%	31.5%	32.8%	32.0%	32.4%	29.2%	30.7%	30.0%	32.7%	31.7%	0.7%
Time of peak output (input to lamp)	34.4%	34.3%		33.8%	35.3%	33.8%	33.9%	31.1%	32.6%	32.3%	34.3%	33.8%	0.8%
Time of peak output (input to ballast)	32.1%	31.4%	31.2%	31.1%	33.0%	31.8%	32.3%	28.4%	30.2%	29.8%	32.5%	31.6%	0.8%

**Table 2.** Average lamp voltage, current and optical power for the “input to the lamp” condition and the average ambient and surface temperatures.

	Manufacturer										
	A(1)	B	C	D	E	F	G	H	I	J	A(2)
Lamp Voltage / V	155.2	156.5	146.9	157.6	154.3	157.1	155.5	155.7	156.1	156.3	155.9
Lamp Current / A	1.922	1.934	1.750	1.885	1.923	1.898	1.998	2.244	1.928	1.900	1.929
Lamp Power / W	297.0	301.7	257.1	296.0	293.2	297.0	309.4	294.9	299.8	296.8	299.6
Optical Power / W	102.2	103.5	104.5	99.9	103.5	100.4	104.8	91.8	97.7	95.6	102.6
Ambient Temp. / °C	25.9	23.0	20.8	25.4	18.1	22.0	21.3		22.7	20.5	23.5
Surface Temp. / °C	123.6	117.2				130.7				120	125

**Conclusion**

These results provide strong verification that the IUVA Test Procedure is effective and valid.

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**References**

Lawal, O., B. Dussert, C. Howarth, K. Platzer, M. Sasges, J. Muller, E. Whitby, R. Stowe, V. Adam, D. Witham, S. Engel, P. Posy, A. van de Pol. 2008. *Proposed Method for measurement of the output of monochromatic (254 nm) low pressure UV lamps*, *IUVA News*, 10(1), 14–17.

# Round Robin Test Appendix A: Proposed Method for Measurement of the Output of Monochromatic (254nm) Low-Pressure UV Lamps (Revised)

Prepared by Oliver Lawal (Wedeco), Bertrand Dussert (Siemens), Craig Howarth (Hanovia), Karl Platzer (Light Sources), Mike Sasges (Trojan), Jennifer Muller (Trojan), Elliott Whitby (Calgon Carbon), Richard Stowe (Fusion UV), Volker Adam (Heraeus), Dave Witham (UVDI), Stuart Engel (Sanuvox), Phyllis Posy (Atiantium) and Argan van de Pol (Phillips) – contributing authors on the IUVA Manufacturer’s Council

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Note that this is the testing protocol that was used for the Round Robin tests. This protocol is currently under consideration by the IUVA Manufacturers’ Council and further revisions may be made to the protocol.

## 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, nonsymmetrical or other special lamps (e.g., excilamps – also called excimer lamps).

In this revision, suggestions are given concerning minimizing the effect of reflected UV.

## 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 ( $\text{W m}^{-2}$ )

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

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

$\alpha$  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.

## Necessary conditions

1. Measurements shall be conducted in still room air, not in a moving air stream.
2. The lamp orientation shall be horizontal.

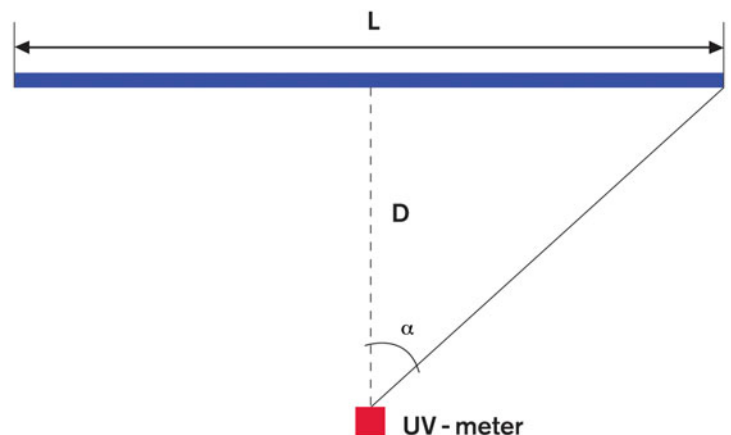


Figure 1. Geometry of the Measurement System.

3. Reflected light must be avoided (e.g. through use of baffles, differential measurement with beam stops). See Appendix B for two possible methods of accounting for or minimizing reflection.
4. The UV sensor must have an adequate cosine response for the lamp length and distance used. See Validation.

### 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 Figure 2, denoted as a “slightly over-heated 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.

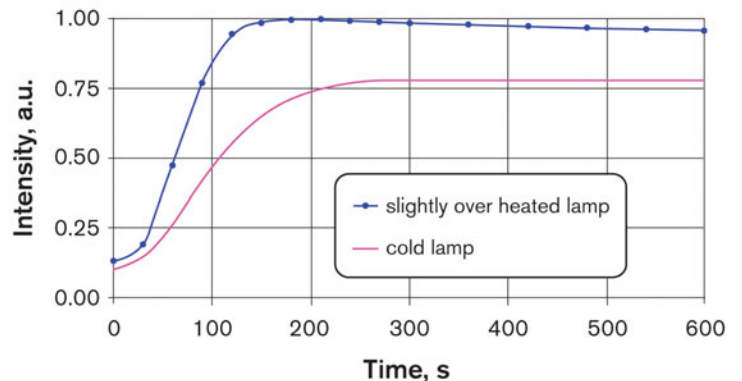
The entire warm-up curve of irradiance vs. time shall be reported, including the maximum peak. Room temperature shall be documented and included in the report. There is a question as to where on the growth curve the efficiency should be determined. Some like to use the “steady-state” plateau after long warm-up, but others prefer to use the peak efficiency because this may better represent the operating conditions of a UV lamp in a quartz sleeve with water flowing outside the sleeve, where the lamp temperature will be controlled. The final report should state where on the growth curve the efficiency is determined.

### Measurements

The lamp output reported shall be measured after a new-lamp 100h 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.

### 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



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

supply). In particular, it is not sufficient to measure the ballast voltage and current to obtain the lamp power by multiplication.

### 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 measurement of UV light.

- a. Use nonreflecting materials or flat black paint for walls, floor and baffles.
- b. Be aware that the UV reflectance may be different from reflectance in the visible range.
- c. Choose a method to reduce reflected light. Two possible methods are described in Appendix B.
- d. 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 lamp and detector at suitable height over the ground.
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 the measurement equipment is appropriate.

## Validation

1. The cosine correction for radiometers and spectroradiometers is critical to proper measurement of the UV irradiance. The cosine correction must be confirmed by the following method for each lamp and ballast combination, so 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 ( $\pm 1^\circ\text{C}$  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 change of the UV intensity readings.
5. Rate of  $\sim 1$  reading every 10s is often sufficient to mark the maximum.
6. Record the ambient temperature again.
7. 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.

8. Calculate lamp efficiency based on lamp power (Equation 2a; top) or power from the wall (Equation 2b; bottom; optional) as:

$$\text{Efficiency (based on lamp power)}(\%) = 100 \times \frac{\text{Total UV Output (W)}}{\text{Power across the lamp (W)}}$$

$$\text{Efficiency (based on wall power)}(\%) = 100 \times \frac{\text{Total UV Output (W)}}{\text{Power from the wall (W)}}$$

## 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” of the radiometer detector.
6. Room temperature ( $^\circ\text{C}$ ).
7. Give an estimate of the fraction of reflected light in the total irradiance reading.
8. 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.
9. Valid, traceable radiometer or spectroradiometer calibration documentation.
10. Plot of irradiance vs. time after ignition, with an indication of the peak irradiance values and the point on the curve where the efficiency calculations were made.
11. Calculated peak UV power, with uncertainty.
12. 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.
13. Measured voltage and current into the ballast.
14. Measured electrical power across the lamp and “from the wall” with uncertainty.
15. Calculated lamp efficiency (%) both with respect to the electrical power consumed by the lamp and the “from-the-wall” (optional) electrical power. ■

## References

- Keitz, H.A.E. 1971. *Light Calculations and Measurements*, Macmillan and Co. Ltd., London, UK.
- Sasges, M.R., A. van der Pol, A. Voronov, and J.A. Robinson. 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.

# Round Robin Test Appendix B: Two Suggested Methods to Minimize the Effects of Reflected UV

## 1. Detector mask method

In this method, a black cardboard or wooden mask is placed at a distance about  $D/2$  from the lamp, where the size and the positioning of the mask casts a complete shadow over the detector. The mask should be of a size that completely blocks the direct rays from the lamp, but not much larger.

In this case the irradiance reading  $E_{refl}$  from the detector represents only UV reflected from the floor, ceiling and walls.  $E_{refl}$  should be subtracted from the overall irradiance reading and should represent less than 1% of the total irradiance at the detector.

## 2. Two-chamber method

UV can reach the UV sensor by reflection from walls, the floor and the ceiling. This reflected UV must be avoided or subtracted from the detector signal in order to get proper irradiance values. A two-sector approach can be used for this purpose.

In this method, the test chamber is divided into two light-tight sectors, with the divider between the two sectors at least 35 cm from the center of the UV lamp. The lamp and detector should be mounted at least 25 cm (preferably about 1 m) from the floor and preferably about 1 m from the wall behind the lamp.

A rectangular hole 3 cm longer than the arc length and 2 cm wider than the width of the lamp should be cut in the divider,

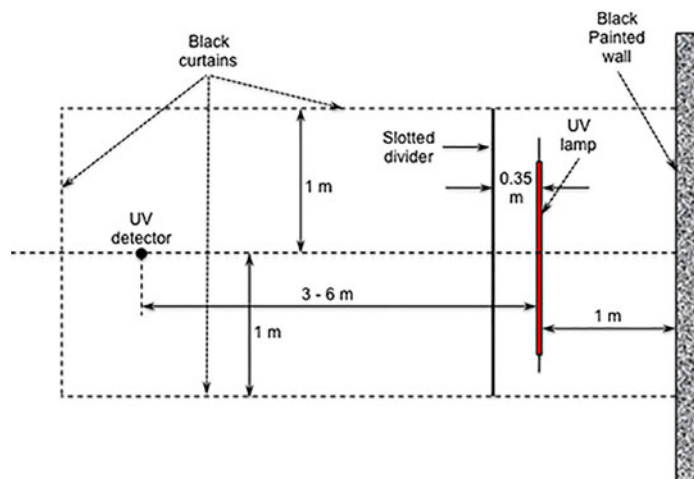


Figure 3. Diagram of a setup that minimizes reflected UV.

so the UV sensor can “see” the entire arc length of the lamp through the hole. See Figure 3 for a possible setup.

## Irradiance measurement procedure that minimizes the effect of reflection

When the two-sector chamber approach is used, the procedure is the same as that described in the main body of this protocol. In addition, a measurement should be made with the hole between the two chambers covered with black cardboard. The radiometer signal in that case should be virtually zero. ■

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