



UNIVERSITY OF  
**PATRAS**  
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ



## TECHNICAL REPORT

Tests, measurements, and verification of good performance of unit:  
'Ultraviolet sterilizer of surfaces and air UVC TROLLEY PHILIPS  
LAMP type SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-  
30Y, Foshan Shengma Technology Co. LTD'

SUBMITTED TO  
THE RIGHT CHOICE IKE  
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PATRAS, GREECE  
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TERMINOLOGY / ΟΡΟΛΟΓΙΑ			
IRRADIANCE	RADIATION INTENSITY	ΕΝΤΑΣΗ ΑΚΤΙΝΟΒΟΛΙΑΣ	W/m <sup>2</sup>
UV	ULTRAVIOLET	ΥΠΕΡΙΩΔΕΣ	10nm<400nm *
UVA	ULTRAVIOLET A-BAND	ΥΠΕΡΙΩΔΕΣ Α	315nm-400 nm
UVB	ULTRAVIOLET B-BAND	ΥΠΕΡΙΩΔΕΣ Β	280nm-315nm
UVC	ULTRAVIOLET C-BAND	ΥΠΕΡΙΩΔΕΣ C	200nm-280nm
VUV	VACUUM UV	ΥΠΕΡΙΩΔΕΣ ΚΕΝΟΥ	100nm-200nm
EUV	EXTREME UV	ΑΚΡΑΙΟ ΥΠΕΡΙΩΔΕΣ	10nm-100nm
NUV	NEAR ULTRAVIOLET	ΕΓΓΥΣ ΥΠΕΡΙΩΔΕΣ	300nm-400nm
VIS	VISIBLE	ΟΡΑΤΟ	400nm-700nm
IR	INFRARED	ΥΠΕΡΥΘΡΟ	0.7 μm -200μm
NIR	NEAR-INFRARED	ΕΓΓΥΣ ΥΠΕΡΥΘΡΟ	0.7 μm -3.0μm
EXPOSURE TIME		ΧΡΟΝΟΣ ΕΚΘΕΣΗΣ	(sec)
EXPOSURE DOSE	DOSE	ΔΟΣΗ ΕΚΘΕΣΗΣ	J/m <sup>2</sup>
*NOTE /ΣΗΜΕΙΩΣΗ:	ALL SPECTRAL RANGE LIMITS ARE SET BY CONVENTION	ΟΛΑ ΤΑ ΟΡΙΑ ΦΑΣΜΑΤΙΚΩΝ ΠΕΡΙΟΧΩΝ ΟΡΙΖΟΝΤΑΙ ΚΑΤΑ ΣΥΜΒΑΣΗ	

## SYNOPSIS

This Technical Report presents the results of the project 'Tests, measurements and verification of good performance of unit: 'Ultraviolet sterilizer of surfaces and air UVC TROLLEY PHILIPS LAMP type SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-30Y, Foshan Shengma Technology Co., LTD, performed in June 2022 on the initiative and for the purposes of THE RIGHT CHOICE IKE, by the Photonics Nanotechnology Research Laboratory (PNRL) of the Department of Materials Science (Prof. N. A. Vainos) in collaboration with the Laboratory of Biological Chemistry of the Department of Medicine (Prof. C. Stathopoulos) of the University of Patras, Greece.

The work comprises the tasks:

1. **Pilot Use** of UVC sterilizer SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-30Y
2. **Absolute radiation measurements** (a) Irradiance [ $\text{W}/\text{m}^2$ ] of UVC radiation emitted in the range of  $\lambda=200\text{nm}-300\text{nm}$  by use of (a) quantum and (b) bolometric detectors calibrated under NIST. Measurements were performed in free space as a function of distance R and polar coordinates in azimuth and height ( $\varphi-\theta$ ) for the radiation emission of the sterilizer machine. (b) Spectral analysis of the emitted radiation (c) Analysis of results and determination of sterilization conditions according to the international standards in the near field ( $R<50\text{cm}$ ) and the far-field ( $R\sim 50\text{cm}-500\text{cm}$ ).
3. **Sterilization study** by use of (a) e-coli and staphylococcus cultures (more than 15 samples each) (b) UVC exposure of samples at a range of radiation doses [ $\text{J}/\text{m}^2$ ] at spatially distributed points in laboratory environment (c) cultivation and cell population growth – no growth estimation.
4. **Analysis of Results- Technical Reporting**

Radiation measurements show very high irradiance levels in the range of 200nm-300nm recorded mainly at Hg Line  $\lambda=253.7\text{nm}$  emitted by the low-pressure mercury lamps. Biological experiments proved the strong sterilization effect of the UVC radiation on Staphylococcus aureus and e-coli cultures even at distances greater than 6m from the source. It is noted that the tolerance of viruses (e.g. SARS, Covid-19, hepatitis, etc.) is negligible as compared to the bacteria used here. According to the international standards, the estimated survival probability at the irradiance levels recorded is zero.

## 1 Description of the sterilizer

The machine UVC TROLLEY PHILIPS LAMP type SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-30Y, Foshan Shengma Technology Co. LTD, comprises two units of 900X25mm Hg lamps mounted in series along a reclining arm. The retractable bracket is mounted inside a rectangular metal frame. The machine has a timer, ON / OFF switch and

photoelectric motion detection sensor. The photoelectric motion sensor provides safety to the operator, as the machine turns off, when they detect motion the machine. The SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-30Y sterilizer after activation (switch ON) provides the user the necessary time of a few seconds (~ 30sec) to leave the area to be sterilized.

## 2 Emission spectra

The emitted radiation spectra was recorded by a Theta-metrisis / Ocean optics spectrum analyzer and presented in Fig. 1. The spectrum was recorded at several operation time intervals. Strong emission at UVC Hg-line  $\lambda=253.7\text{nm}$  (~254nm) was evidenced with minute power levels found between 254 and 300nm. The emission stability of the hot lamp is evidenced by insignificant power variation.

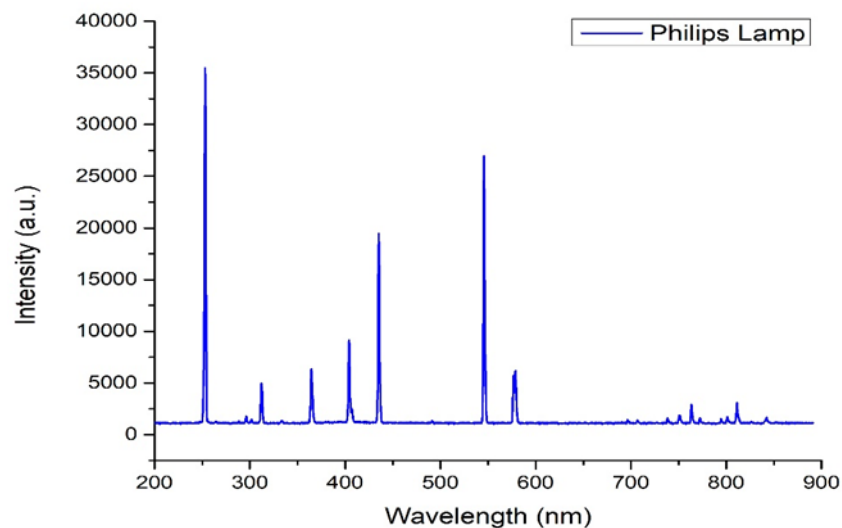


Fig. 1 Emission spectrum of SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-30Y sterilizer.

The recorded spectrum fully agrees with the typical emission spectra of low-pressure Hg lamps. Emission at 270nm is negligible. However, radiation at 270nm shows higher sterilization due to higher penetration in the cells. Radiation 254nm has ~50% the efficiency of radiation at 270nm but it is safer for the user.

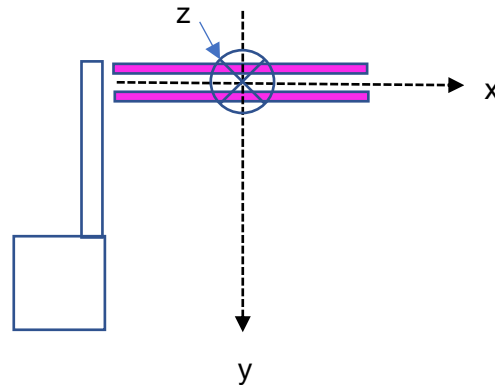
## 3 Irradiance measurements

Irradiance levels were recorded using Newport 2832C NIST validated power meter having two detector heads recording from the ultraviolet to the near infrared (200nm-1100nm) A bolometric Gentec power meter was used for cross reference. Total radiation (200nm-

1100nm) and NUV-NIR (300nm-1100nm) radiation measurements were performed and the respective Irradiance levels  $I$  ( $\mu\text{W}/\text{cm}^2$ ) were recorded and presented in the following sections.

### 3.1 Vertical field

Fig. 2 presents the relevant geometry of the emission device in horizontal setting of the arm, Fig. 3 tabulates the irradiance over the area of the exit window as described by the respective coordinates



(a)

VERTICAL DISTANCE FROM LAMP $y(\text{cm})$	$I(200-1100\text{nm}) \mu\text{W}/\text{cm}^2$	$I(300-1100\text{nm}) \mu\text{W}/\text{cm}^2$	$I(\text{UVC}) \mu\text{W}/\text{cm}^2$
0	1800	120.6	1679.4
100	112.6	14.2	98.4
170	43.7	3.9	39.8

(b)

Fig. 2 (a) Schematic of the lamps and coordinates (b) Table of measurement  $I(y)$ .

Two lamps are positioned horizontally as in Fig.1 and power measurements are taken in vertical  $y$ -axis, on contact  $I(0) \sim 1.67\text{mW}/\text{cm}^2$  to  $\sim 30 \mu\text{W}/\text{cm}^2$  near the ground floor.

### 3.2 Horizontal field

Measurements were performed along the central  $z$ -axis of propagation and are presented in Fig. 2(a)

Fig 3 presents the irradiance variation  $I(0,0,z)$  along the  $z$ -axis.

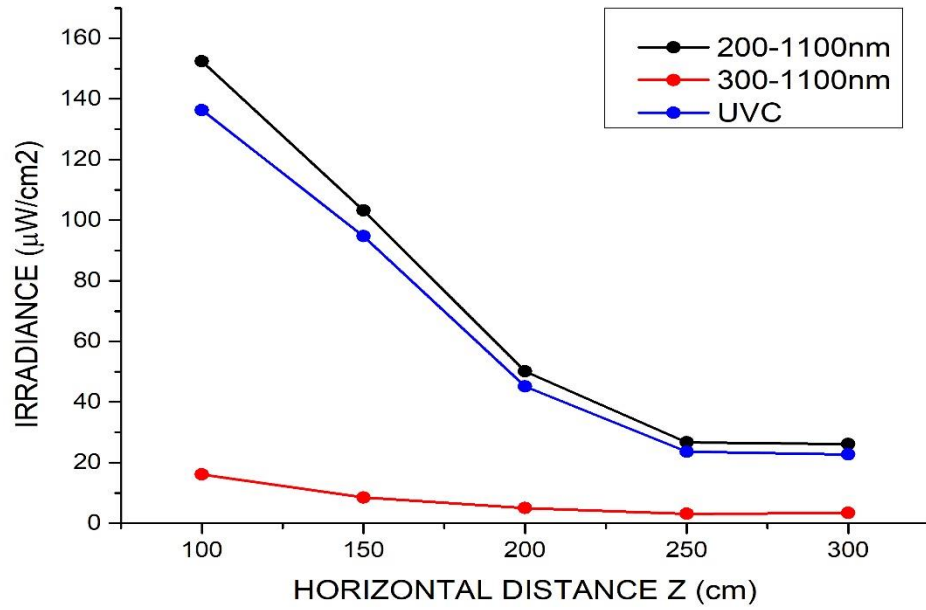


Fig. 3 Irradiance along the radiation propagation z-axis;  $(x,y,z) \rightarrow (0,0,z)$ .

The fitting function  $y = 663552x^{-1.816}$  is a good first order approximations at correlation  $R^2 = 0.9347$ .

Estimation beyond 300cm is made as above.

### 3.3 Far field

Fig. 4 presents the geometry with reference to cartesian and polar coordinates  $(R,\varphi,\theta)$  of the detection point '●'.

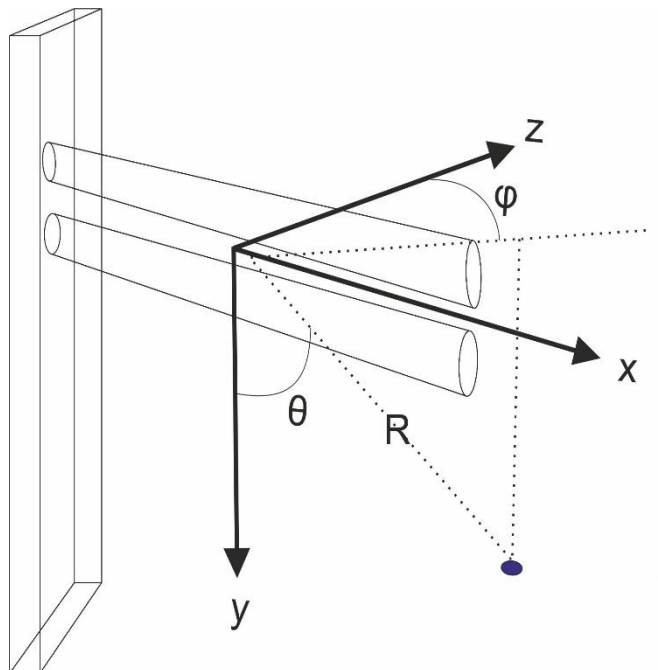


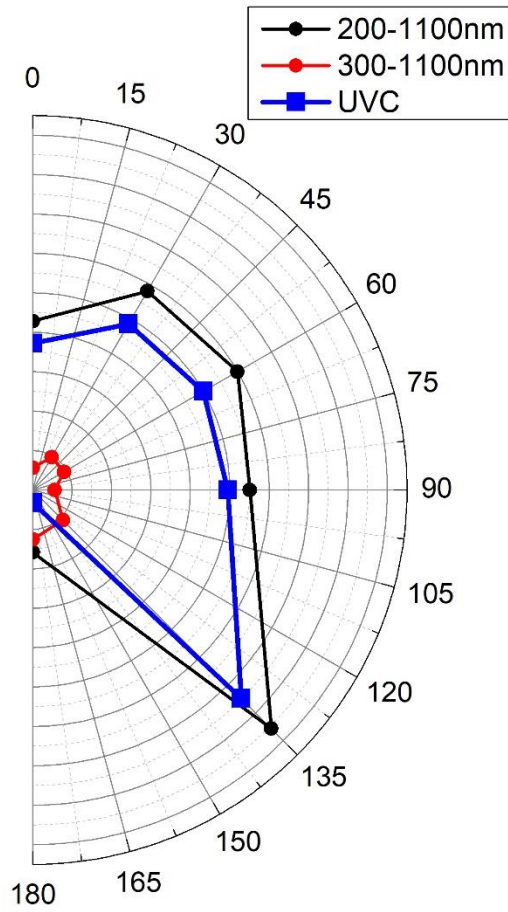
Fig. 4 Detection geometry

Fig. 5 presents the polar diagrams of irradiance at the spectral ranges 200nm-1100nm, 300nm-1100nm και UVC 200nm-300nm.

It is important to note that the safety motion sensor impedes full range of measurements as it interrupts operation.

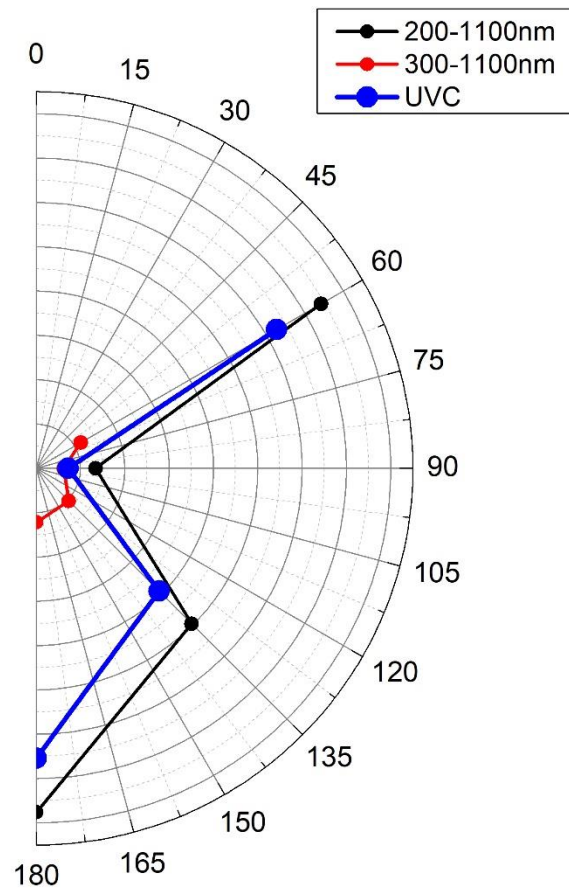
IRRADIANCE ( $\mu\text{W}/\text{cm}^2$ )

$I(\phi)$   
 $\theta=90\text{deg}$   
 $R=100\text{cm}$

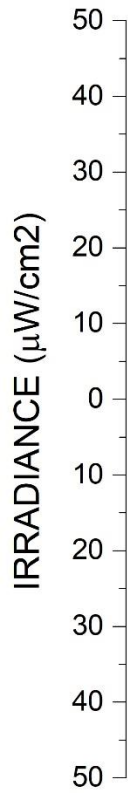


IRRADIANCE ( $\mu\text{W}/\text{cm}^2$ )

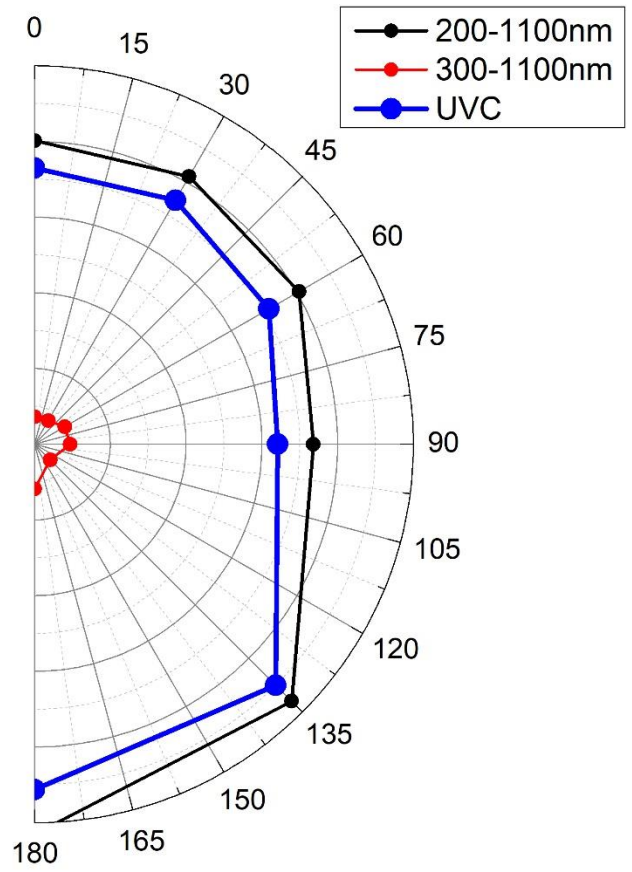
$I(\phi)$   
 $\theta=90\text{deg}$   
 $R=200\text{cm}$



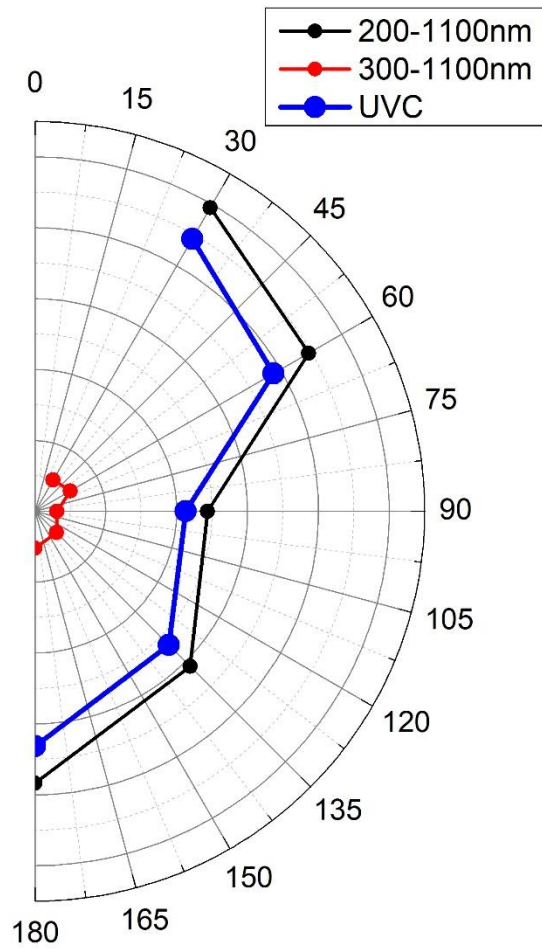




$I(\phi)$   
 $\theta=30\text{deg}$   
 $R=200\text{cm}$



$I(\phi)$   
 $\theta=45\text{deg}$   
 $R=140\text{cm}$



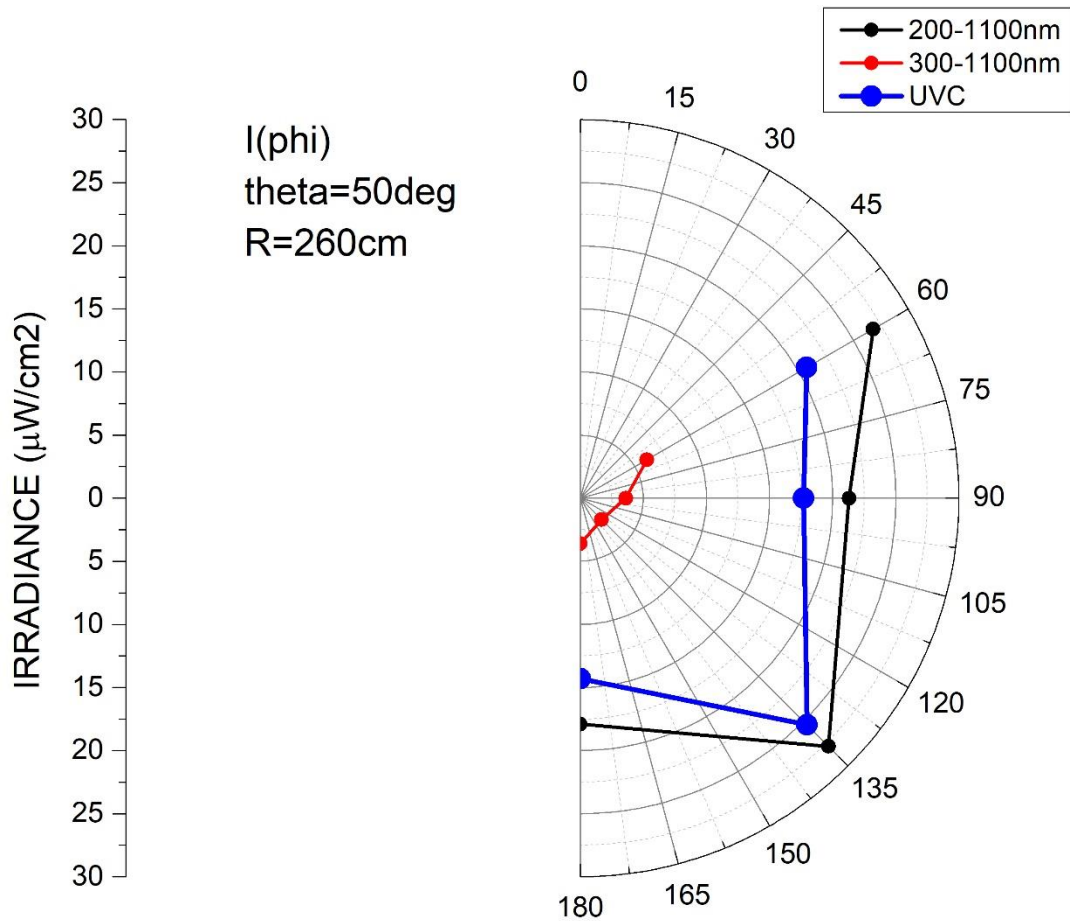


Fig 5 Radiation emission diagrams  $\phi$ -I[mW/cm<sup>2</sup>]

#### 4 Sterilization experiments

Sterilization experiments were performed to assess the effectiveness of the machine. Staphylococcus aureus and e-coli cultures in Petri dishes were exposed to UVC radiation produced by the machine respectively for (a) various intensity levels  $I$  [ $\mu\text{W}/\text{cm}^2$ ] and (b) various exposure times [sec] and respective Exposure Dose levels [ $\mu\text{J}/\text{cm}^2$ ].

For the measurement of the degree of bacteria survival there was performed a comparative assessment of optical density (OD) of the exposed and not exposed cultures by means of laser scattering using a HeNe laser beam at 633nm.

The original culture has cell density of

- Staphylococcus :  $2.4 \times 10^9$  cell/ml
- e-coli :  $1.76 \times 10^9$  cell/ml

and they were disposed on Petri dishes on suspension at thickness for

- Staphylococcus: 220  $\mu\text{m}$
- e-coli: 70 $\mu\text{m}$

Laser power was measured at 11mW.

The mean value of non-scattered power over the laser aperture was of the order of ~7mW for all samples. This value corresponds to OD~0.2 and relates to the total loss caused by microbial population, gel suspension, and dish surfaces.

It is noted that Staphylococcus produces larger scattering and variable response among samples.

The graphs in the following sections present the microbial survival results in reference to the O.D. of exposed vs. unexposed samples.

High sterilization efficiency is found even at distances of 5m from the source at 30min exposure.

It is underlined that the measurements of optical density were performed here in the cultures disposed in Petri dishes as described above and not as usually in liquid cultures disposed in cuvette of 10mm optical path.

#### 4.1 Staphylococcus aureus

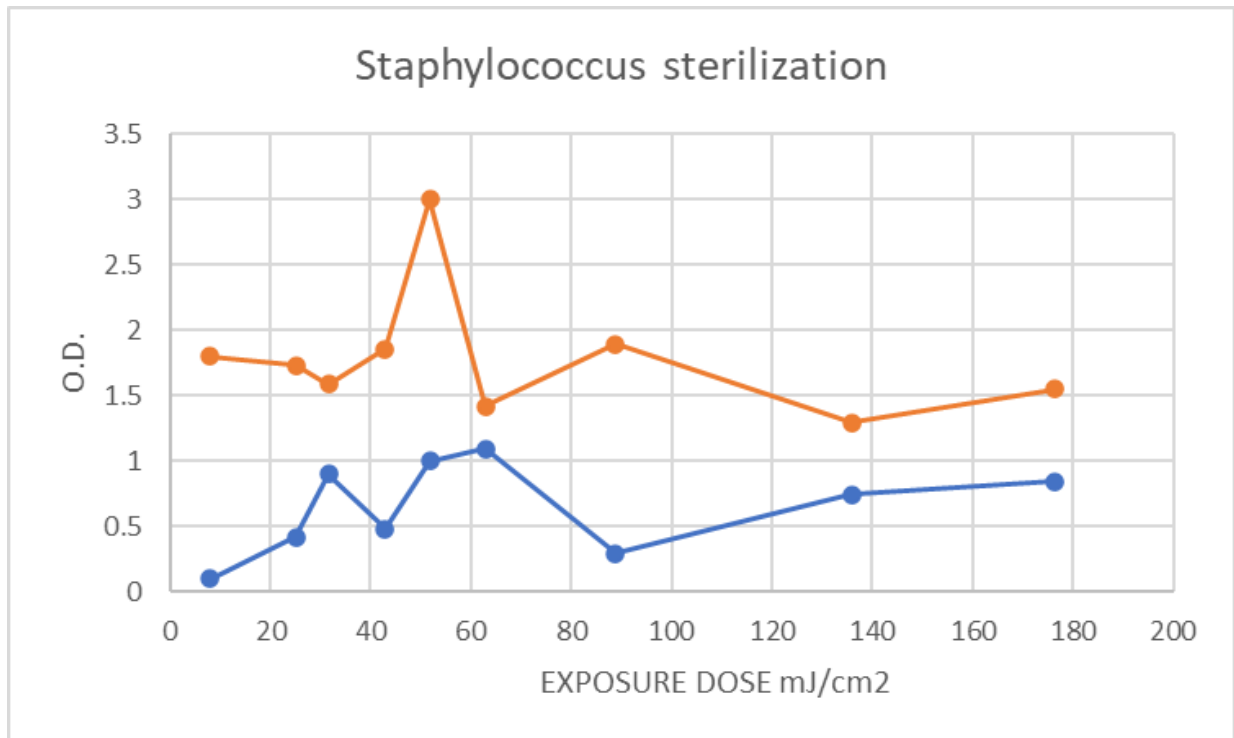


Fig 6 Sterilization of staphylococcus aureus vs. dose

#### 4.2 E-coli

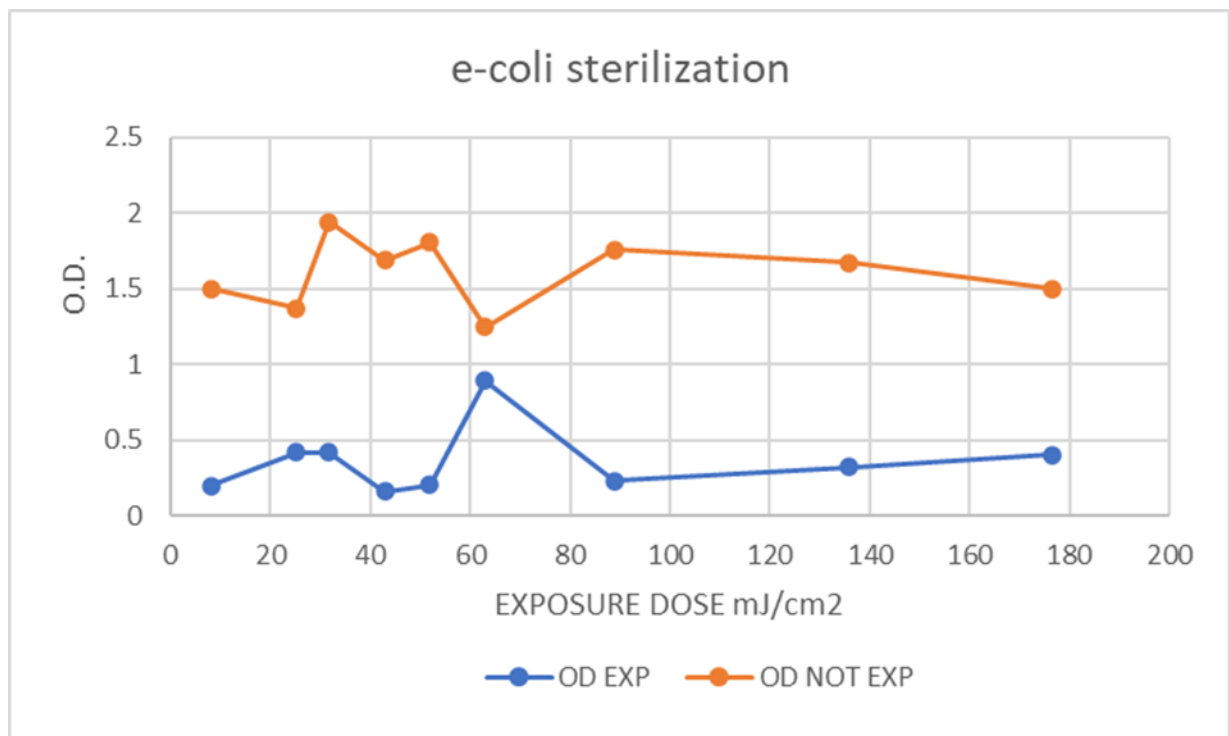


Fig 7 Sterilization of e-coli vs. dose

## 5 Concluding Remarks

This report presents the results of radiation intensity measurements and sterilization experiments performed for testing the efficiency and good operating performance of the air and surface sterilization machine unit UVC TROLLEY PHILIPS LAMP type SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-30Y, Foshan Shengma Technology Co. LTD.

The intensity of UVC radiation emitted was found at very high levels with microbe killing effectiveness at distances >6m and exposure time as low as 10min.

The polar distribution of radiation is very satisfactory, giving UVC intensity of 0.5mW/cm<sup>2</sup> 5-fold greater than the total solar radiation intensity on clear summer midday.

According to international literature\* the percentage level of cell survival, S, exposed to UVC for one stage sterilization is given by:

$$S=\exp(-k D)$$

k=rate of exposure constant (cm<sup>2</sup>/mJ)

D=exposure dose (mJ/cm<sup>2</sup>)

TABLE 3 presents the survival results according to the bibliographical data by using specific experimental conditions and test data reported here for the minimum exposure time 10min (600sec) at the maximum z-axis site of 500cm corresponding to D=8mJ/cm<sup>2</sup>.

**TABLE 3 BACTERIA SURVIVAL**

### E-coli

k (cm <sup>2</sup> /mJ)	D (mJ/cm <sup>2</sup> )	Επιβίωση %	ΜΕΣΟ	Reference	
1.09E+00	8	1.63E-02	W	Zelle	1955
0.432	8	3.16E+00	W	Tyrrell	1972
1.151	8	1.00E-02	W	Oguma	2001
0.494	8	1.92E+00	W	Kim	2002
0.53	8	1.44E+00	W	Hofemeister	1975
1.8	8	5.57E-05	W	Harris	1987
1.15	8	1.01E-02	W	Harm	1968
0.96	8	4.62E-02	W	David	1973
0.2832	8	1.04E+01	W	Abshire	1981
0.9398	8	5.43E-02	S	Sharp	1939
1.2	8	6.77E-03	S	Rentschler	1942
1.93	8	1.97E-05	S	Rentschler	1942

## Staphylococcus aureus

4.40E-01	8	2.96E+00	W	Dolman	1989
8.53E-01	8	1.09E-01	W	Chang	1985
4.13E-01	8	3.66E+00	W	Abshire	1981
7.70E-01	8	2.11E-01	S	Sturm	1932
4.65E-01	8	2.42E+00	S	Hollaender	1955
3.50E-01	8	6.08E+00	S	Gates	1934
8.86E-01	8	8.35E-02	S	Sharp	1939
6.24E-01	8	6.79E-01	S	Luckiesh	1949
1.18E+00	8	7.70E-03	S	Gates	1929
1.13E+00	8	1.19E-02	Air	Nakamura	1987
3.48E+00	8	8.38E-11	Air	Sharp	1940
9.60E+00	8	4.36E-32	Air	Luckiesh	1949
9.62E+00	8	3.77E-32	Air	Luckiesh	1946

The above estimations yield zero survival levels at the given conditions verifying the very strong sterilization efficiency of the SM-II intelligent Control UV Disinfection Lamp / SM-SJD-2-30Y machine. We may further underline that even at the lowest exposure rate constant  $k \sim 0.3 \text{cm}^2/\text{mJ}$ , 200sec exposure is enough to provide 99% sterilization. Alternatively, a 600sec exposure is capable to sterilize to 99% level at a 30m distance.

### SAFETY NOTE

The American Conference of Governmental Industrial Hygienists (ACGIHR)\*\* references UVC radiation at 254 nm to have half the biological effects of radiation at 270 nm. The allowable eye-exposure at 254nm defined as the Threshold Limit Value (TLV) is  $0.2 \mu\text{W}/\text{cm}^2$  for 8hr continuous irradiation to reach the total dose of  $6.0 \text{mJ}/\text{cm}^2$ .

It is recommended to use the machine with extreme care, wearing full protective clothing, gloves, and full-face mask with at least OD3 UV protective glasses. The presence of people and animals in space during irradiation is forbidden.

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\*\* Melvin W. First, Robert A. Weker, Shojiro Yasui, and Edward A. Nardell, Monitoring Human Exposures to Upper-Room Germicidal Ultraviolet Irradiation, J Occup Environ Hyg, 2: 285–292(2005)

The Scientific Responsible  
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