Care222 and Dose

1. Introduction

Ushio America is offering Care222 modules as well as, support and guidance to calculate the irradiance distribution of 222nm light in various fixture configurations and on various objects. The result is typically an irradiance map in µW/cm^2.

Since many customers are fairly unfamiliar with anti-microbial applications, they are not sure how to interpret these results or how to draw conclusions about the expected microbial reduction from the simulations provided. This paper explains some of the basic concepts of this.

2. What is Dose

One fundamental term when calculating microbial reduction is the term Dose. Dose (in units of milli Joule per cm2 [mJ/cm^2]; or Joule per m2 [J/m^2]) is calculated by multiplying the irradiance (calculated or measured in mW/cm2 or W/m^2) with the seconds of exposure (1 Joule= 1 Watt *1 second)

Dose= Irradiance x time

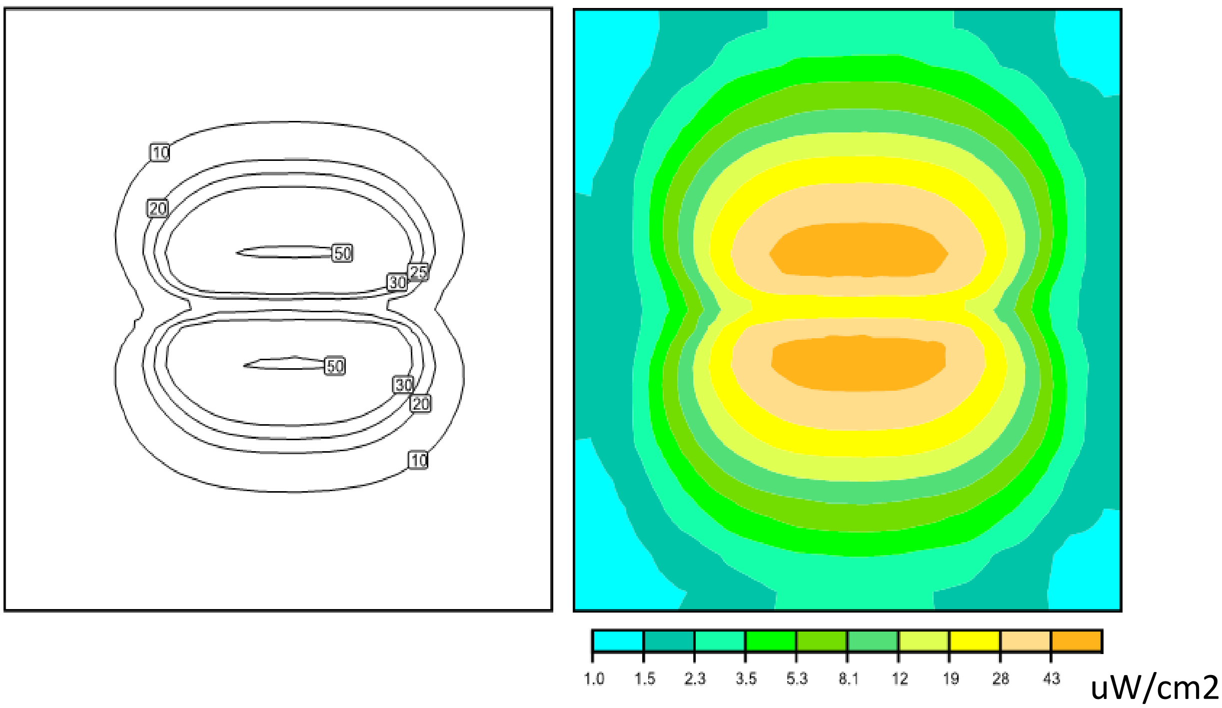
The required dose to reduce pathogens by a certain amount depends very strongly on the pathogen. Some examples from scientific literature are given below

Domain	**Species**		**Dose for 3 log reduction** (mJ/cm^2)	
			222 nm	**254 nm**
Bacteria	MRSA (Methicillin-Resistant *Staphylococcus aureus*)		15	10
	Pseudomonas aeruginosa Pseudomonas aeruginosa		8	4
	Escherichia. coli O-157		9	5
	Salmonella Typhimurium		10	4
	Campylobacter jejuni		4	4
	Bacillus subtilis	Vegetative cell	7	8
	Bacillus cereus	Spore	44	90
	Clostridium difficile	Spore JCMI1296	30	60
		Spore JIR8094	32*	>86*
	MS2	23	50	
	Feline calicivirus	24	24	
Virus	*Influenza A* H1N1, pdm09 strain A/Michigan/45/2015		<6	<6
	H1N1, A/PR/8/34 ATCC VR-1469		3 **	-
	H1N1, A/PR/8/34		2***	-
	Alphacoronavirus Feline enteric coronavirus WSU 79-1683		2 **	-
	Human coronavirus 229E VR-740		1.7 ****	-
	Betacoronavirus Human coronavirus OC43 VR-1558		1.3 ****	-
	SARS-CoV-2 2019-nCov/Japan/AI/I-004/2020		3.2 *****	-

The table notes the necessary dose for a 3 log reduction. What that means is that, as an example, after applying 9mJ/cm2 of 222nm radiation to Escheria coli, 99.9% of the initial bacteria will be killed (or 0.1% $=10^{-3}$ survive, which is -3 $\log_{10}$). For calculations it is advantageous to calculate the dose for 1log (in this case 9/3(log)=3mJ/cm^2). If one would only try to achieve 99% reduction (aka 2log) 2*3 of the dose =6mJ/cm2 and for 90% (1log) 3mJ/cm^2 would be required.

It should be mentioned, that in most practical cases the dose is not dependent on the irradiance. What that means is, that the same reduction will be achieved if for instance 0.1mW/cm^2 for 90 seconds (=9mJ/cm2), or 1mW/cm^2 for 9 seconds (=9mJ/cm^2) is applied.

As an example for how to use this information with an irradiance map, let's look at below modeled picture (this was done by using 2 groups of several Care222 B1 modules at a distance of 1 meter).



As can be seen, the irradiance values vary quite substantially from the center to the edges. In order to evaluate the setup one has to fix one of the remaining variables: reduction rate (aka log) OR time of exposure. Usually one will start with reduction rate of a specific pathogen. So, if we choose the Escheria coli and want a 99% reduction in the center, we calculate the necessary time:

Exposure Time = Needed Dose/ Irradiance

Needed Dose for 99% = 6mJ/cm^2; chosen irradiance (we choose an average from above graph) 30µW/cm2 (=0.030 mW/cm^2 – Note that irradiance maps are usually shown in µW/cm^2!!)

Exposure time = 6mJ/cm2/0.030 mW/cm^2 = 200 seconds =3.3 minutes

It should be noted that in practical applications it is advantageous to split this total time in several shorter chunks of exposure (e.g. spreading the exposure over 1 hour, turning the lamp on 5 times for 40 seconds)

Assuming exposure time will be set to 200 seconds, we can now calculate the reduction in other areas.

Center: irradiance =50µW/cm^2 Dose=0.05*200= 10mJ/cm^2 which should lead to a 10/3=3.33log reduction = 99.95%

Outside edge: irradiance 10µW/cm^2 Dose=0.01*200=2mJ/cm^2 which should lead to a 2/3=0.66log reduction = 78%

3. Human safety and dose

Unfortunately UVC light is not only killing bacteria, but can also severely hurt humans. Fortunately it has been found that filtered 222nm light is almost entirely absorbed by the tear layer of the eyes, and the outermost layers of human skin, which are not living cells and the underlying living cells will not be damaged by the 222nm radiation (note, that longer UV wavelengths like 254nm penetrate much deeper and will reach and damage living cells).

National (ACGIH and many others) and international organizations (IEC) have published and standardized limits of permitted UV exposure for humans. The 8 hour exposure limit for 222nm to a human is currently (2020) set to approximately 22mJ/cm^2 (this value is currently being reviewed, and will likely be raised in a foreseeable future). Although all recent scientific evidence indicates that 500mJ/cm^2 does not cause skin or eye inflammation, it is highly recommended to design 222nm applications to stay within the current recommended limits (22mJ/cm^2).

For the design, it is important to determine the likely position (distance) of a human to the 222nm light source, and the time of exposure to the human. Since the head of the person is usually closer to the light source than the target surface for pathogen reduction (e.g. a table), a separate lighting simulation for that distance has to be done. In this case there is no variable left. The dose is given (22mJ/cm^2 max.) and the irradiance is calculated. So, the maximum exposure time of the person is calculated:

Exposure time = 22mJ/cm^2 / irradiance (at head height)

As example, if the maximum irradiance time at head height would be calculated (and measured in the installation!) as 80uW/cm^2, and it is estimated that one person would potentially stand still under the lamp for 8 hours, the maximum on time of the 222nm lamp would be:

Maximum ON time = 22mJ/cm^2 / 0.08mW/cm2 = 275 seconds

It should be noted that this maximum time can be split in smaller chunks over 8 hours, for instance

275 seconds per 8 hours = 35 seconds per hour ON time (or 5 times 7 seconds ON per hour)

(Note: it is not recommended to turn lamps on for less than 10 seconds)

Once the maximum ON time has been determined we can go back and calculate the estimated pathogen reduction (in 8 hours). Following the examples above the reduction for Escheria coli (3mJ/cm2 needed for 1 log reduction) we calculate:

Center dose = 0.05 *275= 13.7mJ/cm^2 which should lead to a 13.7/3=4.6log reduction =99.998%

Outside edge= 0.01 *275 =2.75mJ/cm^2 which should lead to a 0.91 log reduction = 88%

It should be emphasized that these limitations only apply in occupied spaces. If an occupancy sensor is coupled with a 222nm fixture and no humans are detected in the light beam, the fixture could be turned on for extended times (or until the desired pathogen reduction is achieved). It should also be considered what the likelihood is that the same person spends 8 hours, standing still, in the same position.

If it would be determined that the maximum dose for a person in a still position within 8 hours(!) is less than the total on time per hour, based on the desired pathogen reduction, then the maximum ON time for pathogen reduction could be used.

4. Caution!!!

The above calculations follow established common, agreed calculations. The results should be considered as best case scenarios, however in practice there will certainly be deviations from the expected results. There are many reasons for that.

The reduction rates have been established under lab conditions that will not likely happen in practice, especially not when disinfecting surfaces. So, actual reduction rates will be smaller than calculated.

The irradiation distribution may have errors since it cannot take many unknown factors of reality into account, like shadowing or reflections in the room. It is therefore absolutely necessary to take actual measurements of the radiation after installation with a highly accurate and sensitive and solar blind measurement instrument, calibrated at 222nm!

It must also be emphasized that the safety limits (22mJ/cm^2) and calculations ONLY apply to filtered Care222 radiation. Competitor lamps that use unfiltered KrCl lamps have different, significantly lower safety limits and have to be individually investigated.

On the positive side, it should be mentioned that the 222nm "light" traveling through the air will certainly cause a reduction of airborne pathogens. However, as of today, unfortunately the calculation and prediction of such effects is not possible with simple means.

5. Summary

Through lighting calculations the irradiance distribution of Ushio's filtered Care222 B1 modules can be calculated. With that information designs and exposure times can be established that predict the maximum dose levels for safe human exposure and can predict the expected dose for pathogen reductions on surfaces.

Additional explanations regarding pathogen reduction data

Data without a note were obtained from studies conducted at Hirosaki University (1) (2) (3)
* : Data cited from Figures in Taylor, *et al.* (2020). The study was conducted at the Dept. of Molecular Biology and Biophysics, UConn Health. (4)
** : Data obtained from studies conducted at the Kitasato Research Center for Environmental Science in 2019 and 2020. (5)
*** : Welch, *et al.* (2018) indicate a very low dose of 2 mJ/cm^2 of 222-nm light inactivates >95% of aerosolized Influenza A H1N1 virus in a particle size distribution similar to the natural distribution from human coughing and breathing. (6)
**** : Data cited from Figure 1 in Buonanno, *et al*. (2020). The data show the dose of 222-nm light to inactivate aerosolized human coronaviruses. (7)
***** : Data calculated from a reduction rete of "0.94 log reduction at 1mJ/cm^2" in Kitagawa, *et al*. (2020). (8)

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