Ultraviolet Radiation Safety

WARNING: Do not attempt operation until you are familiar with all warnings, precautions, and procedures outlined within this instruction sheet.

OPERATION PRECAUTIONS

- **UV LIGHT WARNING:** UV-C light can cause temporary or permanent loss of vision, and temporary acute redness or ulceration (mild to severe sunburn) to exposed skin. To prevent exposure, do not operate the device in any application that allows UV-C light to be visible during operation.
- **UV LIGHT CAUTION:** UV light may degrade plastic and rubber components after longterm exposure.
- Currently, there are no work place related rules and regulations that are set by OSHA (Occupational Safety and Health Association) in regard to UVC environmental health and safety.
- **NEVER LOOK DIRECTLY AT THE BULB OR DISINFECTING TARGET ZONE**

OPERATION SAFETY

- People and animals are forbidden from being exposed to the light output of this cart for extended periods of time. Long term exposure will case damage to the eyes and skin.
- This product produces UV radiation in a 180° direction. Anything in front of the unit will be exposed to UV radiation. Operators positioning the cart while not illuminated will not be exposed. Radiation is only emitted while the cart is turned on. Radiation will not linger in the environment when the lamps have been powered off. Safety equipment is only required when the device is in-use.
- Wear eye protective gear when operating the equipment. Polycarbonate safety glasses at minimum are required during all operations. Full frontal polycarbonate or UV-preventative face masks are recommended.
- Wear long sleeves and gloves when operating the equipment. Tyvek personal protective gear is required for long term exposure.

OPERATION SAFETY STRATEGIES

- Instruct service personnel to never look directly at UV-C light without adequate eye protection.
- Make it a policy to never enter areas being disinfected with UV lighting systems without powering the system down first. Methods of powering down depends on the options of the device purchased and may include unplugging the light source, operating the power switch to power the lamps off, or turning the system off via a wireless remote control or wireless application.
- Place warning labels near all openings/entrances to areas being disinfected with UV lighting systems. When possible, lock access doors to prevent unexpected guests from entering the area.
- Close blinds/curtains of areas being disinfected with UV lighting systems if available. If not available, block off direct access to windows/doorways to prevent access to the area. If you cannot fully block off all access (hallways with visible windows, etc) place exterior warnings in areas prior to the exposed windows (hall pedestals, banners, posters) explaining what areas are being disinfected and to not look into the room.
- Educate non service personnel about the intended operations for UV disinfecting and what signage will be posted. Instruct non service personnel to never look directly at UV-C light.
- Instruct service personnel to always wear personal protective gear (as outlined above) when they must operate in an area that has UV-C exposure, for short or long term work.

These safety precautions will help ensure service personnel are protected from accidental exposure while maintaining the effectiveness of UV-C to eradicate biological contaminants.

In the event of UV exposure, the following actions are recommended.

- See an ophthalmologist if eye damage is suspected.
- Treat skin lesions immediately.
- For severe skin lesions, seek local medical treatment and follow their recommendations for treatment.
- Follow your organization’s incident reporting procedure. These often require documentation of the date and time of the incident, persons involved, equipment involved and type of injury.

Ultraviolet Radiation Safety

WARNING: Do not attempt operation until you are familiar with all warnings, precautions, and procedures outlined within this instruction sheet.

OPERATION PRECAUTIONS

- **UV LIGHT WARNING:** Far UV-C has been shown in studies to be less harmful to eyes and skin compared to standard 254nm germicidal lamps. 254nm UV-C light can cause temporary or permanent loss of vision, and temporary acute redness or ulceration (mild to severe sunburn) to exposed skin.
  - In a comparison of UVC-induced premutagenic skin lesions CPD (cyclobutane pyrimidine dimers) and 6-4PP (photoproducts) in the dorsal epidermis of mice, Far UV-C light was shown to not cause skin lesions in the tests. A UV dose of 157 mJ/cm2 was used for both 254 and 222 nm.[1]
  - In a study of the effects of Far-UV light on the eye, Far UV-C (222nm) light was shown to be absorbed in the outer surface of the Cornea and is much less likely to cause cataracts.
- **UV LIGHT SAFETY:** Independent studies have shown that Far UV-C light is less likely to be harmful to eyes and skin. As of 2020, the FDA has not approved Far UV-C light sources for use in occupied areas in medical facilities. This is something to be voted on in the near future for medical applications. At this time, the FDA has not ruled on the safety. Independent studies have been done. Please see the following whitepaper for more information on eye and skin safety over 254nm UV-C.
- **UV LIGHT CAUTION:** UV light may degrade plastic and rubber components after longterm exposure.
- Currently, there are no work place related rules and regulations that are set by OSHA (Occupational Safety and Health Association) in regard to UVC environmental health and safety.
- **<u>NEVER LOOK DIRECTLY AT THE BULB OR DISINFECTING TARGET ZONE</u>**

References:

1 Buonanno, Manuela; Ponnaiya, Brian; Welch, David; Stanislauskas, Milda; Randers-Pehrson, Gerhard; Smilenov, Lubomir; Lowy, Franklin D.; Owens, David M.; Brenner, David J..
Germicidal Efficacy and Mammalian Skin Safety of 222nm UV Light. Radiation Research. 2017 April; 187(4): 483-491.

2 Kolozsvári, Lajos; Nógrádi, Antal; Hopp, Béla; Bor, Zsolt.
UV Absorbance of the Human Cornea in the 240- to 400-nm Range. Investigative Ophthalmology & Visual Science July 2002, Vol.43, 2165-2168

Far-UV 222 nm vs 254 nm: Safety and Germicidal Effectiveness

LARSON ELECTRONICS LLC • 9419 E US HWY 175 • KEMP, TX 75143
p: 1-800-369-6671 • intl: 903-498-3363 • f: 903-498-3364 • sales@larsonelectronics.com

Table of Contents

1.0 Executive Summary

This white paper compares the safety and germicidal effectiveness of 222 nm and 254 nm ultraviolet (UV) wavelengths when applied to sanitation. An overview UV-C sanitation is provided to establish the mechanisms of disinfection with UV light. Next, the properties of both UV-C bands are showcased in order to highlight their unique characteristics and various associated safety precautions. Artificial light sources capable of emitting these types of UV-C light are carefully assessed to determine the practicality of deployment based on technological limitations and environmental factors (temperature, humidity, etc.). The white paper concludes with recommendations on how to best leverage far-UV 222 nm and 254 nm for sanitation purposes in industrial and commercial sites.

Larson Electronics is a manufacturer of industrial lighting systems, explosion proof devices and power distribution products. The company has more than 40 years of experience in the industrial sector, serving a wide range of organizations and businesses. This paper supports the use and effectiveness of 222 nm and 254 nm UV lights for germicidal applications.

2.0 Introduction

According to data from the International Ultraviolet Association (IUVA)[1], UV treatment has been around for more than 40 years. As a tried-and-tested solution, UV disinfection is prevalent in hospitals, medical or healthcare centers, laboratories, food processing, wastewater facilities, HVAC system management and more. At 2018, the UV disinfection equipment market was valued at $1.1 billion by Allied Market Research. This industry is forecasted to reach $3.4 billion by 2026 (or at a compound annual rate of 15 percent from 2019 to 2026).

UV light contains several unique properties and characteristics, which can be used to disinfect up to 99.9% of viruses, bacteria, mold, spores and other harmful microbes. According to experts from University of British Columbia, University of Alberta, University of Colorado-Boulder and Trojan Technologies[2], UV-C light is capable of killing tuberculosis, *e.coli*, *methicillin-resistant S. aureus* (MRSA) and more. Initially, this sanitation method relied on the UV-C spectrum, i.e. UV-C rays within the range of 200 nm to 280 nm (traditionally optimized at 254 nm), to deactivate the cellular ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), as well as the reproductive capabilities of microorganisms. Although highly effective in eliminating microbes on surfaces and in the air, the 254 nm UV-C band is dangerous to humans. Extended exposure to this UV-C wavelength, typically using fluorescent UV lamps, can cause mild to severe sunburns and temporary to permanent vision loss without proper safety gear.

Advancements in UV light technology addresses the drawbacks and limitations of traditional UV-C sanitation using 254 nm bands by introducing far-UV sanitation lights to the market. This type of germicidal lamp utilizes 222 nm UV rays to eliminate bacteria, viruses, mold, spores, fungi and other deadly microbes. Moreover, far-UV light is considered to be eye and skin safe for humans, as 222 nm UV rays cannot penetrate the skin to levels that cause burns or severe damage. A 2018 study published in the US National Library of Medicine National Institutes of Health[3] has proven that chronic irradiation with 222 nm far-UV lamps does not cause epidermal lesions often associated with exposure to traditional 254 nm UV-C rays. This finding, among others, revolutionizes the application of UV-C disinfection, allowing the lights to be deployed safely in busy locations, occupied areas, manufacturing floors, restaurants, public buildings, mass transit areas and more. Mercury-free excimer lamps with quartz glass are the artificial light source of choice when implementing far-UV disinfection on surfaces.

Both far-UV 222 nm and conventional 254 nm have similar germicidal capabilities, but their properties and behavior under varying conditions differ slightly. Notably, far-UV bands are not readily absorbed by water vapor. UV 254 nm does not possess these qualities; however, artificial light sources that emit 254 nm typically decline in effectiveness when exposed to temperatures above 40°C for extended periods of time. Far-UV 222 nm artificial light sources are compact, energy efficient and mercury-free.

As both UV bands utilize the same mechanism when deactivating bacteria and viruses, other factors must be considered when choosing between far-UV 222 nm and conventional 254 nm lamps. Such factors include the area of deployment (occupied or empty), distance of target surface or area, access to UV lamp technology (to date, 222 nm excimer lamps are not readily available in mainstream markets) and preferred method of disposal (traditional, mercury-based 254 nm UV lights are toxic and require sustainable disposal at the end of their lifecycle).

3.0 UV Light Sanitation

UV light contains special properties that deactivate the RNA and DNA of harmful microbes. The UV-C range of 200 nm to 280 nm is responsible for this germicidal mechanism. Both far-UV 222 nm and traditional 254 nm bands are included in this germicidal range.

3.1 How Does UV-C Light Disinfection Work?

UV light consists of three primary wavelength ranges: long-wave UV-A (315nm to 400nm), medium-wave UV-B (280nm to 315nm) and short-wave UV-C (200nm to 100nm), as defined in ISO-21348 Standard[4]. In outdoor environments, UV-C is completely absorbed by the ozone layer of the Earth's atmosphere. This UV range is known as the germicidal range due to its ability to deactivate viruses and bacteria (UV-A and UV-B do not have the capabilities – because of this, the focus of the paper is the UV-C range). UV-C light can be generated by artificial light sources, such as excimer, mercury vapor and fluorescent lamps. This technological advancement ushered the widespread application of UV disinfection, allowing UV-C light to be used in buildings.

During sanitation, UV-C light in large, concentrated doses causes RNA and DNA mutations in microbes during absorption. The ideal wavelength for peak absorptivity occurs at wavelengths of 254nm to 262nm (for traditional UV sanitation) and 222 nm. According to a 2012 study published in US National Library of Medicine National Institutes of Health, UV-C treatment has the following devastating effects on microbes:

"The light-induced damage to the DNA and RNA of a microorganism often results from the dimerization of pyrimidine molecules. In particular, thymine (which is only found only in DNA) produces cyclobutane dimers. When thymine molecules are dimerized, it becomes very difficult for the nucleic acids to replicate and if replication does occur it often produces a defect that prevents the microorganism from being viable."

It should be emphasized that when enough thymine dimers are made in the cell, DNA replicated in cell mitosis ceases. This deactivation mechanism is also applicable to viruses that only have RNA, i.e. "photochemical dimerization reaction takes place between two uracil bases". UV sanitation of an area is considered successful when the virus or bacteria is deactivated and reproductive capabilities are significantly reduced or stopped. Such objectives prevent the microbe from spreading and decreases the rate of infection (for harmful viruses or bacteria). Higher UV doses must be applied to bacteria that is capable of actively repairing thymine dimers.

Far-UV 222 nm and conventional 254 nm UV light utilizes the same mechanism (as described above) to eliminate microorganisms on surfaces and in the air. Both types of UV bands are capable of achieving above 99 percent inactivation rates. Choosing between the two artificial light sources depend on other factors, such as cost, area of deployment, etc.

4.0 Far UV-C 222 nm

Far-UV 222 nm bands have intense germicidal properties with decreased risks of photo-reactivation, which are considered to be eye and skin safe for humans. Excimer lamps that offer 222 nm are energy efficient, non-toxic and easily disposable at the end of their expected lifecycle.

4.1 UV 222 nm Wavelength Properties

Far-UV 222 nm light is at the low range of the UV-C spectrum. Leveraging its germicidal abilities, this UV band is capable of inactivating harmful microbes. The 222 nm wavelength is particularly effective in disrupting chemical bonds in dangerous or toxic gases and bio-toxins, according to Edward Neister in US Patent US59362605P[5]. In the 2006 patent, Neister also highlighted that UV absorption by cells to the DNA increases as the UV band decreases. Applying this observation in comparing the properties of 222 nm and 254 nm, the far-UV band could achieve higher UV absorption than conventional 254 nm. The possibility of photo-reactivation is also decreased due to the high energy of 222 nm.

Spectral-selective excimer lamps are the artificial light source of choice when generating far-UV 222 nm light for sanitation. The term “excimer” is short for excited dimer, which refers to the presence of dimeric molecules with nanosecond-lifespans in an excited state. The specific working excimer molecule is closely associated with the UV wavelength that the lamp emits, as well as the light’s use and application. In the case of 222 nm excimer lights, the working exciplex molecule is KrCl. The compound consists of one atom of krypton (Kr) and one atom of chlorine (Cl). This granular approach to leveraging a single UV wavelength, e.g. 222 nm, 172 nm, 308, nm, etc., suggests that excimer lamps release (and can be classified as) quasi-monochromatic light. A bandpass filter can be applied to remove lower, higher and stray UV bands to ensure safe and effective sanitation.

Excimer germicidal lamps typically take the form of conventional, compact linear lights. These lights are non-toxic, mercury free and do not contain fluid. Excimer lights feature instant on and off capabilities, reaching 100 percent output in less than a second. This artificial light source can be toggled and deployed in locations within a temperature range of 0°C to 100°C. Compared to conventional UV 254 nm light sources, excimer lamps offer high power density. Reflectors around the lamp can be added to improve light beam distribution and intensity. With a compact footprint, smaller disinfection lights can be used to eliminate microbes. The units require support from a driver that protects the device from abnormal power conditions and ensures power stability. Unlike traditional 254 nm UV sanitation lights, excimer lights do not require extensive safety gear during use. Furthermore, the lamps can be secured close to the target surface without generating intense heat in the surrounding area.

4.2 Safety Considerations

Far-UV 222 nm light contains effective germicidal properties that are significantly safer to humans, compared to other penetrative UV wavelengths, as the bands are not cytotoxic or mutagenic to mammalian cells. A 2017 study[6] highlights the level of safety 222 nm light imposes on mammalian skin, which directly resembles human skin, during exposure. Authors of the study cited that far-UV light cannot penetrate the stratum corneum of the skin, thus protecting foundational basal cells from damage. By comparison, UV rays in the 254 nm spectrum can penetrate the stratum corneum of the skin, capable of reaching as far as the stratum spinosum, and damage basal cells. Far-UV 222 nm is considered to be safe on human eyes, as suggested by the researchers of the study. This specific UV band cannot penetrate the thick barrier protecting the cornea.

Researchers in the 2017 study tested the safe characteristics of far-UV 222 nm by exposing skin samples to 222 nm UV rays. In the tests, a 222 nm UV-C excimer light was positioned at a distance of 9 cm with a power density of 0.036 mJ/cm^2. Researchers also tested chronic exposure of far-UV 222 nm light by administering a far-UV dose of 157 mJ/cm^2 in a 7-hour period to mice. In both tests (skin samples and chronic exposure), traditional UV sanitation lights in the 254 nm range were tested using the same types of samples for comparison.

After exposure to 222 nm light, the skin samples in the first test did not produce lesions or display signs of irritation, as well as did not generate damaging levels of cyclobutane pyrimidine dimers (CPD) and pyrimidine-pyrimidone 6-4 photoproducts (6-4PP). In the second set of tests involving mice, researchers analyzed the effects of the UV-C lights on the epidermis (skin). Observations were taken 48 hours after exposure. The results showed that the skin of mice exposed to far-UV 222 nm lights did not significantly increase in epidermal thickness at 20.1 um. While mice exposed to traditional 254 nm UV-C lamps displayed 60.9um or a 3-fold increase in epidermal thickness. This reaction is closely associated with severe tissue hyperplasia, i.e. an increase in cellular proliferation that can lead to (but not always) tumors and cancer. Based on the results from the tests, the researchers concluded that far-UV 222 nm light can be recommended as an effective sanitation method. According to the researchers, this form of UV germicidal treatment can be administered safely without extensive protective clothing and imposing significant risks related to skin cancer.

In a 2019 study[7], scientists compared the effects of far-UV 222 nm and 254 nm light on the cornea. The cornea is the outer layer of the eye that acts as a protective barrier against irritants, such as debris and bacteria, and plays a primary role in light absorption. Damage to the cornea often results in vision impairment or loss. During the study, researchers exposed rats to 222 nm and 254 nm lights at 30, 150, and 600 mJ/cm^2 intensities. The animals exposed to far-UV 222 nm did not display corneal damage. Moreover, cyclobutane pyrimidine dimer-positive cells were not present in the samples exposed to 222 nm, which reduces cellular proliferation risks responsible for cancer. By comparison, UV 254 nm imposed a wide range of damage at various UV intensities on the samples. At 600 mJ/cm^2, corneal erosion was evident. Superficial punctate keratis (eye disorder from cellular death on the cornea) was observed on samples exposed to UV 254 nm at doses higher than 150 mJ/cm^2.

4.3 Germicidal Effectiveness

In the 2017 study from section 4.2, scientists tested the effectiveness of 222 nm on MRSA (USA300, multilocus sequence type 8, clonal complex 8, staphylococcal cassette chromosome mec type IV). The samples were separated and exposed to 222 nm excimer lamps (filtered) and 254 nm lights for comparison. The results of the tests showed 222 nm bands to be “almost as efficient” in eliminating MRSA as conventional 254 nm.

At 222 nm, UV light is capable of inactivating airborne aerosolized viruses at low doses. A 2018 study[8] presents the effectiveness of this type of artificial light source in eradicating aerosolized H1N1 influenza virus. In the study, researchers used excimer lamps as a primary disinfection device. A far-UV dose of 2 mJ/cm^2 was administered on the sample. The lights were positioned 11 cm from a UV transparent plastic film, with a 65 percent transmission rate. A certified class II type A2 biosafety cabinet housed the chamber with the samples. The results showed that the 222 nm light eliminated more than 95 percent of the aerosolized H1N1 influenza virus.

A 2020 study (pre-print; under review)[9] aimed to determine the effectiveness of far-UV 222 nm light on human coronaviruses from subgroups alpha (HCoV-229E) and beta (HCoV-OC43). During the tests, researchers applied a far-UV dose of 1.2 and 1.7 mJ/cm^2 to aerosolized alpha coronavirus 229E and beta coronavirus OC43 samples. The 222 nm UV light source inactivated 99.9% of both viruses. Researchers concluded that based on the results of the tests, adhering to the far-UV exposure limit of 3 mJ/cm^2/hour would inactivate 99.9% of coronaviruses in public locations within 25 minutes. Increasing the intensity of the light, e.g. by a factor of 2, would reduce the required exposure time without exceeding exposure limits. It is important to highlight that although the tests were not conducted specifically on SARS-CoV-2 strain, the scientists issued recommendations on using far-UV 222 nm light to eliminate the latest SARS-CoV-2 coronavirus because all human coronaviruses share similar genome sizes. The genome size of viruses is an essential determinant of UV radiation sensitivity.

Far-UV 222 nm light has the potential to revolutionize food processing and sanitation standards. A 2020 study[10] showed that far-UV 222 nm lamps can inactivate *Alicyclobacillus acidoterrestris* spores, which are known to have high thermal resistance. In food processing facilities handling juices, the microorganisms also thrive in extreme conditions and can germinate at low pH levels. Scientists were able to achieve complete inactivation by 5 logs at a concentrated dose of 2,011 mJ/cm^2. Compared to mercury-based UV 254 nm lights, non-toxic 222 nm excimer lamps come with lower contamination risks when used in large-scale food processing.

5.0 UV-C 254 nm

Conventional UV 254 nm contains powerful disinfection properties and is rapidly absorbed by microorganisms. When using UV 254 nm lights, typically in the form of UV-C fluorescent lamps, operators must wear protective gear to prevent skin burns and corneal damage.

5.1 UV 254 nm Wavelength Properties

UV 254 nm is within the germicidal range of the UV-C spectrum. Compared to UV-B and UV-A, this range has up to 2 times more electron volt energy (eV). UV-C 254 nm light is absorbed rapidly by microbes, contributing to its ability to destroy bacteria and viruses. This UV band is powerful and can force doubly-bonded molecules to rearrange their structures. Damage imposed on microorganisms are typically long term or fatal.

Fluorescent fixtures, medium-pressure mercury discharge lights and induction lamps are the most common types of UV 254 nm artificial light sources used for sanitation. In order to generate the UV 254 nm band, phosphor is removed from the tube. Furthermore, the tube is manufactured using doped fused quartz (can produce 185 nm ozone) or soda-lime glass (cannot produce 185 nm ozone) so that UV 254 nm bands from the mercury arc can pass through the material. Quartz-based UV-C lights increase electrical efficiency and require a short warm-up time of 30 seconds to reach full output. This type of 254 nm fluorescent light source typically overheats in environments above 40°C. At this temperature, UV-C output decreases. T5 or T6 high-output quartz UV lamps can be used for areas requiring intense disinfection. This alternative provides up to 2 times more output compared to legacy quartz UV-C lights. UV fluorescent units rely on mercury to produce illumination, via two electrodes. Induction lights that offer UV 254 nm do not contain electrodes, resulting in a longer lifespan and increased reliability. The units are well sealed and energy efficient.

5.2 Safety Considerations

UV-C 254 nm light is a powerful solution against disease-causing microorganisms. For humans, exposure to this range of UV light is harmful. Direct exposure can lead to skin burns and damage the cornea. Human cells attempt to repair DNA damage when exposed to UV-C 254 nm. Failure to repair the damage can result in tumor growth. Unlike standard (non-UV) illumination, looking at UV lamps does not cause a natural squinting reaction. In some cases, the negative effects of UV exposure are delayed by more than six hours. As a safety precaution when sanitizing rooms, humans should not be present in the area during the process. Operators may setup temporary signs around the space to ensure people are aware of ongoing sanitation and avoid exposure. Exposure to chemicals, such as mercury, xenon and argon, is a possibility should the lamp or bulb shatter during use. Moreover, due to the presence of toxic chemicals, the lamp must be properly disposed at the end of its lifecycle.

5.3 Germicidal Effectiveness

A 2020 study[11] provides a comprehensive overview of the germicidal effectiveness of 254 nm UV light. The researchers from the study applied a mercury vapor lamp with a UV 254 nm band to the following types of microbes (on nitrocellulose filter papers):

- Escherichia coli ATCC25922 (*E. coli)*
- Extended Spectrum Beta-Lactamase-producing *E. coli* (ESBL)
- MRSA
- *Mycobacterium tuberculosis* (MTB)
- Influenza A Viruses H1N1 and H3N2

The results showed successful elimination at a rate of 3-$\log_{10}$ inactivation for bacteria, 4-$\log_{10}$ inactivation for viruses and 5-$\log_{10}$ inactivation for MTB. It took between 10 to 30 minutes of exposure to achieve such levels of inactivation during the tests.

In another 2020 study[12], recommendations to use germicidal UV light to prevent "viral replication" of SARS-COV-2 and improve lung capabilities for patients were issued. Researchers from the study concluded that such devices, which include systems used to administer UV-C light or radiation, can improve survival rate of individuals. At the front lines, UV-C light is proven to be effective in sanitizing N95 filtering facepiece respirators (N95 FFRs). Medical staff must deal with the shortage in N95 respirators and other protective devices by disinfecting the equipment and reusing them. This practice was tested by researchers from the University of Nebraska Medical Center, through administering a 300 mJ/cm^2 dose of UV germicidal irradiation on N95 FFRs. The scientists highlighted that single-stranded RNA SARS-COV-2 can be inactivated with UVGI exposure of 2-5 mJ/cm^2, which was exceeded by the researchers in the study.

UV 254 nm light is capable of eradicating common dust mites (*Dermatophagoides pteronyssinus [D. pteronyssinus]* and *Dermatophagoides farinae [D. farinae]*). A 2012 study[13] demonstrated such capabilities through direct UV exposure. Researchers tested exposure times ranging between 5-60 minutes and distances between 10-55 cm. An immediate mortality success rate of 100 percent was achieved when the UV lamp was positioned at 10 cm distance for 60 minutes. Egg-hatching capabilities were reduced by a whopping 50 percent for both types of mites. Increasing the duration of exposure also increased the mortality rate of UV treatment, while increasing the distance between the UV lamp and the samples decreased such rates. Interestingly, UV treatment had a more devastating effect on the eggs compared to the adult mites. Based on the results of the study, the scientists cited UV 254 nm light to be effective in disrupting the lifecycle of mites at the embryonic stage to reduce the proliferation of allergens.

6.0 Conclusion

Both far-UV 222 nm and conventional 254 nm wavelengths are effective in eliminating viruses, bacteria, spores and other disease-causing microbes. As these bands fall within the UV-C germicidal range of 200 nm to 280 nm, the UV rays utilize the same mechanism to disrupt and inactivate microorganisms. A closer look at the properties of 222 nm UV bands suggests that it is not easily absorbed by water vapor. Therefore, for long irradiation distances in the air, the far-UV band could be less effective (but still capable of inactivating viruses and bacteria and achieving above 99% inactivation success rates) in environments saturated with water vapor. The safety benefits of 222 nm UV light dictate its applications in buildings and busy locations. The wavelength is considered to be eye and skin safe for humans, as it does not cause the formation of potentially cancerous CPDs. Additionally, 222 nm excimer lamps are mercury-free, energy efficient and environmentally friendly. The units can be deployed in occupied areas, public locations and busy facilities without imposing devastating health risks.

Traditional 254 nm UV light is a very powerful sanitation solution that leverages fluorescent or induction units. From a health perspective, the UV band can cause skin burns and corneal damage. This type of artificial light source is most effective when deployed in empty rooms, cabinets, UV boxes or ovens and via handheld devices. UV 254 nm lamps should not be administered in occupied or busy areas without protective equipment. Safety gear in the form of bio-hazard suits, coats, safety glasses, visors, gloves, barriers and curtains must be used at all times when using traditional 254 nm lamps to prevent exposure.

7.0 References

[1] Fact Sheet on UV Disinfection for COVID-19; International Ultraviolet Light Association- http://www.iuva.org/COVID-19
[2] Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae; 2006- https://www.iuvanews.com/stories/pdf/archives/180301_UVSensitivityReview_full.pdf
[3] Chronic irradiation with 222-nm UVC light induces neither DNA damage nor epidermal lesions in mouse skin, even at high doses; 2018- https://www.ncbi.nlm.nih.gov/pubmed/30044862
[4] ISO 21348 Definitions of Solar Irradiance Spectral Categories; International Organization for Standardization, published by Space Environment Technologies- https://www.spacewx.com/pdf/SET_21348_2004.pdf
[5] USUS8753575B2- Method and apparatus for sterilizing and disinfecting air and surfaces and protecting a zone from external microbial contamination; 2006- https://patents.google.com/patent/US8753575
[6] Germicidal Efficacy and Mammalian Skin Safety of 222-nm UV Light; 2017- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5552051/
[7] Evaluation of Acute Corneal Damage Induced by 222-nm and 254-nm Ultraviolet Light in Sprague-Dawley Rats; 2019- https://pubmed.ncbi.nlm.nih.gov/30947566/
[8] Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases; 2018- https://www.nature.com/articles/s41598-018-21058-w
[9] Far-UVC light efficiently and safely inactivates airborne human coronaviruses; 2020- https://www.researchsquare.com/article/rs-25728/v1
[10] Application of a Krypton-Chlorine Excilamp To Control Alicyclobacillus acidoterrestris Spores in Apple Juice and Identification of Its Sporicidal Mechanism; 2020- https://aem.asm.org/content/86/11/e00159-20
[11] The efficacy of vacuum-ultraviolet light disinfection of some common environmental pathogens; 2020- https://bmcinfectdis.biomedcentral.com/articles/10.1186/s12879-020-4847-9
[12] N95 Filtering Facepiece Respirator Ultraviolet Germicidal Irradiation (UVGI) Process for Decontamination and Reuse; 2020- https://www.nebraskamed.com/sites/default/files/documents/covid-19/n-95-decon-process.pdf
[13] Effect of germicidal UV-C light(254 nm) on eggs and adult of house dustmites, Dermatophagoides pteronyssinus and Dermatophagoides farinae (Astigmata: Pyroglyhidae); 2012- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3609379/

TEST REPORT
IEC 62471
Photobiological safety of lamps and lamp systems

Report Reference No.....................:	SHES210400791171
Date of issue.................................:	2021-05-13
Total number of pages ....:	18
Name of Testing Laboratory preparing the Report...............................:	SGS-CSTC Standards Technical Services (Shanghai) Co., Ltd.
Applicant's name...........................:	Larson Electronics LLC.
Address ....:	9419 E US HWY 175, Kemp, TX 75143, USA
Test specification:	
Standard ....:	IEC 62471:2006
Test procedure ....:	SGS-CSTC
Non-standard test method…………..:	N/A
Test Report Form No.....................:	IEC62471B
TRF Originator..............................:	VDE Testing and Certification Institute
Master TRF ....:	Dated 2018-08-16

This report is not valid as a CB Test Report unless signed by an approved CB Testing Laboratory and appended to a CB Test Certificate issued by an NCB in accordance with IECEE 02.

General disclaimer:

The test results presented in this report relate only to the object tested.
This report shall not be reproduced, except in full, without the written approval of the Issuing CB Testing Laboratory. The authenticity of this Test Report and its contents can be verified by contacting the NCB, responsible for this Test Report.

Test item description ....:	UV Tube
Trade Mark.......................................:	-
Manufacturer ....:	Yuyao Lighting Technology Co., Ltd. Wuxing Village, Yuyao City, Zhejiang
Model/Type reference......................:	FRL-48-1X-T8HO-120W-UV-C, FRL-48-1X-T8-40W-UV-C, FRL-24-1X-T8HO-60W-UV-C, FRL-24-1X-T8-20W-UV-C
Ratings ....:	FRL-48-1X-T8HO-120W-UV-C: 150 V; 800 mA; 120 W FRL-48-1X-T8-40W-UV-C: 160 V; 220 mA; 40 W FRL-24-1X-T8HO-60W-UV-C: 50 V; 800 mA; 60 W FRL-24-1X-T8-20W-UV-C: 80 V; 260 mA; 20 W

Responsible Testing Laboratory (as applicable), testing procedure and testing location(s):		
☒ **Testing Laboratory:**	SGS-CSTC Standards Technical Services (Shanghai) Co., Ltd.	
Testing location/ address ....:	588 West Jindu Road, Xinqiao, Songjiang, 201612 Shanghai, China.	
Tested by (name, function, signature) ....:	Lisa Li	Lisa Li
Approved by (name, function, signature) ..:	Abby Yang	Abby Yang
☐ **Testing procedure: CTF Stage 1:**		
Testing location/ address ....:		
Tested by (name, function, signature) ....:		
Approved by (name, function, signature) ..:		
☐ **Testing procedure: CTF Stage 2:**		
Testing location/ address ....:		
Tested by (name + signature)....................:		
Witnessed by (name, function, signature). :		
Approved by (name, function, signature) ..:		
☐ **Testing procedure: CTF Stage 3:**		
☐ **Testing procedure: CTF Stage 4:**		
Testing location/ address ....:		
Tested by (name, function, signature) ....:		
Witnessed by (name, function, signature). :		
Approved by (name, function, signature) ..:		
Supervised by (name, function, signature) :		

List of Attachments (including a total number of pages in each attachment): Attachment A: Photo documentation (2 pages in total)	
Summary of testing:	
Tests performed (name of test and test clause): UV tests	**Testing location:** SGS-CSTC Standards Technical Services (Shanghai) Co., Ltd. 588 West Jindu Road, Xinqiao, Songjiang, 201612 Shanghai, China.
Summary of compliance with National Differences (List of countries addressed): **List of countries addressed:** N/A	
Copy of marking plate: **The artwork below may be only a draft. The use of certification marks on a product must be authorized by the respective National Certification Body that own these marks.** **N/A**	

Test item particulars ....:	
Tested lamp ....:	☒ continuous wave lamps ☐ pulsed lamps
Tested lamp system ....:	☐ continuous wave lamps ☐ pulsed lamps
Lamp classification group ....:	☐ exempt ☐ risk 1 ☐ risk 2 ☒ risk 3
Lamp cap ....:	N/A
Bulb..:	UV lamp
Rated of the lamp..:	N/A
Furthermore marking on the lamp ....:	N/A
Seasoning of lamps according IEC standard ....:	N/A
Used measurement instrument................................:	Spectroradiometer
Temperature by measurement.................................:	25 °C
Information for safety use ....:	N/A
Possible test case verdicts:	
– **test case does not apply to the test object...... :**	N/A
– **test object does meet the requirement .... :**	P (Pass)
– **test object does not meet the requirement...... :**	F (Fail)
Testing:	
Date of receipt of test item.................................. :	2021-04-29
Date (s) of performance of tests .... :	2021-04-29 to 2021-05-06

General remarks:

"(See Enclosure #)" refers to additional information appended to the report.
"(See appended table)" refers to a table appended to the report.

Throughout this report a ☒ comma / ☐ point is used as the decimal separator.

This document is issued by the Company subject to its General Conditions of Service printed overleaf, available on request or accessible at http://www.sgs.com/en/Terms-and-Conditions.aspx and, for electronic format documents, subject to Terms and Conditions for Electronic Documents at http://www.sgs.com/en/Terms-and-Conditions/Terms-e-Document.aspx. Attention is drawn to the limitation of liability, indemnification and jurisdiction issues defined therein.

Any holder of this document is advised that information contained hereon reflects the Company's findings at the time of its intervention only and within the limits of Client's instructions, if any. The Company's sole responsibility is to its Client and this document does not exonerate parties to a transaction from exercising all their rights and obligations under the transaction documents. This document cannot be reproduced except in full, without prior written approval of the Company. Any unauthorized alteration, forgery or falsification of the content or appearance of this document is unlawful and offenders may be prosecuted to the fullest extent of the law.

Unless otherwise stated the results shown in this test report refer only to the sample(s) tested and such sample(s) are retained for 30 days only.

Manufacturer's Declaration per sub-clause 4.2.5 of IECEE 02:

The application for obtaining a CB Test Certificate includes more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided ....:	☐ **Yes** ☒ **Not applicable**

When differences exist; they shall be identified in the General product information section.

Name and address of factory (ies)........................ :	Same as manufacturer
General product information and other remarks: To consider the worst case, the product was tested at 200mm. UV tests according to IEC62471: 2006. The appliances are classified as **Risk Group 3.**	

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

4	**EXPOSURE LIMITS**		**P**
4.1	General		P
	The exposure limits in this standard is not less than 0,01 ms and not more than any 8-hour period and should be used as guides in the control of exposure		P
	Detailed spectral data of a light source are generally required only if the luminance of the source exceeds 10^4 cd·m^{-2}	see clause 4.3	P
4.3	Hazard exposure limits		P
4.3.1	Actinic UV hazard exposure limit for the skin and eye		P
	The exposure limit for effective radiant exposure is 30 J·m^{-2} within any 8-hour period		P
	To protect against injury of the eye or skin from ultraviolet radiation exposure produced by a broadband source, the effective integrated spectral irradiance , E_S, of the light source shall not exceed the levels defined by:		P
	$E_s \cdot t = \sum_{200}^{400} \sum_{t} E_\lambda(\lambda,t) \cdot S_{UV}(\lambda) \cdot \Delta t \cdot \Delta\lambda \le 30$ J·m^{-2}		P
	The permissible time for exposure to ultraviolet radiation incident upon the unprotected eye or skin shall be computed by:		P
	$t_{max} = \frac{30}{E_s}$ s		P
4.3.2	Near-UV hazard exposure limit for eye		P
	For the spectral region 315 nm to 400 nm (UV-A) the total radiant exposure to the eye shall not exceed 10000 J·m^{-2} for exposure times less than 1000 s. For exposure times greater than 1000 s (approximately 16 minutes) the UV-A irradiance for the unprotected eye, E_{UVA}, shall not exceed 10 W·m^{-2}.		P
	The permissible time for exposure to ultraviolet radiation incident upon the unprotected eye for time less than 1000 s, shall be computed by:		P
	$t_{max} \le \frac{10\,000}{E_{UVA}}$ s		P
4.3.3	Retinal blue light hazard exposure limit		N/A
	To protect against retinal photochemical injury from chronic blue-light exposure, the integrated spectral radiance of the light source weighted against the blue-light hazard function, B(λ), i.e., the blue-light weighted radiance, L_B, shall not exceed the levels defined by:		N/A
	$L_B \cdot t = \sum_{300}^{700} \sum_{t} L_\lambda(\lambda,t) \cdot B(\lambda) \cdot \Delta t \cdot \Delta\lambda \le 10^6$ J · m^{-2} · sr^{-1}	for t ≤ 10^4 s $t_{max} = \frac{10^6}{L_B}$	N/A

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict
	$L_B = \sum_{300}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \le 100$ $\quad W \cdot m^{-2} \cdot sr^{-1}$	for t > 10^4 s	N/A
4.3.4	Retinal blue light hazard exposure limit - small source		N/A
	Thus the spectral irradiance at the eye E_λ, weighted against the blue-light hazard function B(λ) shall not exceed the levels defined by:	see table 4.2	N/A
	$E_B \cdot t = \sum_{300}^{700} \sum_{t} E_\lambda(\lambda,t) \cdot B(\lambda) \cdot \Delta t \cdot \Delta\lambda \le 100$ $\quad J \cdot m^{-2}$	for t ≤ 100 s	N/A
	$E_B = \sum_{300}^{700} E_\lambda \cdot B(\lambda) \cdot \Delta\lambda \le 1$ $\quad W \cdot m^{-2}$	for t > 100 s	N/A
4.3.5	Retinal thermal hazard exposure limit		N/A
	To protect against retinal thermal injury, the integrated spectral radiance of the light source, L_λ, weighted by the burn hazard weighting function R(λ) (from Figure 4.2 and Table 4.2), i.e., the burn hazard weighted radiance, shall not exceed the levels defined by:		N/A
	$L_R = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \le \frac{50\,000}{\alpha \cdot t^{0,25}}$ $\quad W \cdot m^{-2} \cdot sr^{-1}$	(10 µs ≤ t ≤ 10 s)	N/A
4.3.6	Retinal thermal hazard exposure limit – weak visual stimulus		N/A
	For an infrared heat lamp or any near-infrared source where a weak visual stimulus is inadequate to activate the aversion response, the near infrared (780 nm to 1400 nm) radiance, L_{IR}, as viewed by the eye for exposure times greater than 10 s shall be limited to:		N/A
	$L_{IR} = \sum_{780}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \le \frac{6\,000}{\alpha}$ $\quad W \cdot m^{-2} \cdot sr^{-1}$	t > 10 s	N/A
4.3.7	Infrared radiation hazard exposure limits for the eye		N/A
	The avoid thermal injury of the cornea and possible delayed effects upon the lens of the eye (cataractogenesis), ocular exposure to infrared radiation, E_{IR}, over the wavelength range 780 nm to 3000 nm, for times less than 1000 s, shall not exceed:		N/A
	$E_{IR} = \sum_{780}^{3\,000} E_\lambda \cdot \Delta\lambda \le 18\,000 \cdot t^{-0,75}$ $\quad W \cdot m^{-2}$	t ≤ 1000 s	N/A
	For times greater than 1000 s the limit becomes:		N/A
	$E_{IR} = \sum_{780}^{3\,000} E_\lambda \cdot \Delta\lambda \le 100$ $\quad W \cdot m^{-2}$	t > 1000 s	N/A
4.3.8	Thermal hazard exposure limit for the skin		N/A
	Visible and infrared radiant exposure (380 nm to 3000 nm) of the skin shall be limited to:		N/A

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

	$E_H \cdot t = \sum_{380}^{3000} \sum_{t} E_\lambda(\lambda,t) \cdot \Delta t \cdot \Delta\lambda \le 20\,000 \cdot t^{0,25} \quad J \cdot m^{-2}$		N/A
5	**MEASUREMENT OF LAMPS AND LAMP SYSTEMS**		**P**
5.1	Measurement conditions		P
	Measurement conditions shall be reported as part of the evaluation against the exposure limits and the assignment of risk classification.		P
5.1.1	Lamp ageing (seasoning)		N/A
	Seasoning of lamps shall be done as stated in the appropriate IEC lamp standard.		N/A
5.1.2	Test environment		P
	For specific test conditions, see the appropriate IEC lamp standard or in absence of such standards, the appropriate national standards or manufacturer's recommendations.		P
5.1.3	Extraneous radiation		P
	Careful checks should be made to ensure that extraneous sources of radiation and reflections do not add significantly to the measurement results.		P
5.1.4	Lamp operation		P
	Operation of the test lamp shall be provided in accordance with:		P
	– the appropriate IEC lamp standard, or		N/A
	– the manufacturer' s recommendation		P
5.1.5	Lamp system operation		N/A
	The power source for operation of the test lamp shall be provided in accordance with:		N/A
	– the appropriate IEC standard, or		N/A
	– the manufacturer' s recommendation		N/A
5.2	Measurement procedure		P
5.2.1	Irradiance measurements		P
	Minimum aperture diameter 7mm.		P
	Maximum aperture diameter 50 mm.		P
	The measurement shall be made in that position of the beam giving the maximum reading.		P
	The measurement instrument is adequate calibrated.		P
5.2.2	Radiance measurements		P
5.2.2.1	Standard method		P
	The measurements made with an optical system.		P
	The instrument shall be calibrated to read in absolute radiant power per unit receiving area and per unit solid angle to acceptance averaged over the field of view of the instrument.		P

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict
5.2.2.2	Alternative method		N/A
	Alternatively to an imaging radiance set-up, an irradiance measurement set-up with a circular field stop placed at the source can be used to perform radiance measurements.		N/A
5.2.3	Measurement of source size		P
	The determination of α, the angle subtended by a source, requires the determination of the 50% emission points of the source.		P
5.2.4	Pulse width measurement for pulsed sources		N/A
	The determination of Δt, the nominal pulse duration of a source, requires the determination of the time during which the emission is > 50% of its peak value.		N/A
5.3	Analysis methods		P
5.3.1	Weighting curve interpolations		P
	To standardize interpolated values, use linear interpolation on the log of given values to obtain intermediate points at the wavelength intervals desired.	see table 4.1	P
5.3.2	Calculations		P
	The calculation of source hazard values shall be performed by weighting the spectral scan by the appropriate function and calculating the total weighted energy.		P
5.3.3	Measurement uncertainty		P
	The quality of all measurement results must be quantified by an analysis of the uncertainty.	see Annex C in the norm	P
6	**LAMP CLASSIFICATION**		**P**
	For the purposes of this standard it was decided that the values shall be reported as follows:	see table 6.1	P
	– for lamps intended for general lighting service, the hazard values shall be reported as either irradiance or radiance values at a distance which produces an illuminance of 500 lux, but not at a distance less than 200 mm		N/A
	– for all other light sources, including pulsed lamp sources, the hazard values shall be reported at a distance of 200 mm		P
6.1	Continuous wave lamps		P
6.1.1	Except Group		N/A
	In the except group are lamps, which does not pose any photobiological hazard. The requirement is met by any lamp that does not pose:		N/A
	– an actinic ultraviolet hazard (E_S) within 8-hours exposure (30000 s), nor		N/A
	– a near-UV hazard (E_{UVA}) within 1000 s, (about 16 min), nor		N/A

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict
	– a retinal blue-light hazard (L_B) within 10000 s (about 2,8 h), nor		N/A
	– a retinal thermal hazard (L_R) within 10 s, nor		N/A
	– an infrared radiation hazard for the eye (E_{IR}) within 1000 s		N/A
6.1.2	Risk Group 1 (Low-Risk)		N/A
	In this group are lamps, which exceeds the limits for the except group but that does not pose:		N/A
	– an actinic ultraviolet hazard (E_S) within 10000 s, nor		N/A
	– a near ultraviolet hazard (E_{UVA}) within 300 s, nor		N/A
	– a retinal blue-light hazard (L_B) within 100 s, nor		N/A
	– a retinal thermal hazard (L_R) within 10 s, nor		N/A
	– an infrared radiation hazard for the eye (E_{IR}) within 100 s		N/A
	Lamps that emit infrared radiation without a strong visual stimulus and do not pose a near-infrared retinal hazard (L_{IR}), within 100 s are in Risk Group 1.		N/A
6.1.3	Risk Group 2 (Moderate-Risk)		N/A
	This requirement is met by any lamp that exceeds the limits for Risk Group 1, but that does not pose:		N/A
	– an actinic ultraviolet hazard (E_S) within 1000 s exposure, nor		N/A
	– a near ultraviolet hazard (E_{UVA}) within 100 s, nor		N/A
	– a retinal blue-light hazard (L_B) within 0,25 s (aversion response), nor		N/A
	– a retinal thermal hazard (L_R) within 0,25 s (aversion response), nor		N/A
	– an infrared radiation hazard for the eye (E_{IR}) within 10 s		N/A
	Lamps that emit infrared radiation without a strong visual stimulus and do not pose a near-infrared retinal hazard (L_{IR}), within 10 s are in Risk Group 2.		N/A
6.1.4	Risk Group 3 (High-Risk)		P
	Lamps which exceed the limits for Risk Group 2 are in Group 3.		P
6.2	Pulsed lamps		N/A
	Pulse lamp criteria shall apply to a single pulse and to any group of pulses within 0,25 s.		N/A
	A pulsed lamp shall be evaluated at the highest nominal energy loading as specified by the manufacturer.		N/A
	The risk group determination of the lamp being tested shall be made as follows:		N/A

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict
	– a lamp that exceeds the exposure limit shall be classified as belonging to Risk Group 3 (High-Risk)		N/A
	– for single pulsed lamps, a lamp whose weighted radiant exposure or weighted radiance does is below the EL shall be classified as belonging to the Exempt Group		N/A
	– for repetitively pulsed lamps, a lamp whose weighted radiant exposure or weighted radiance dose is below the EL, shall be evaluated using the continuous wave risk criteria discussed in clause 6.1, using time averaged values of the pulsed emission		N/A

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

Table 4.1	Spectral weighting function for assessing ultraviolet hazards for skin and eye		
Wavelength[1] λ, nm	**UV hazard function $S_{UV}(\lambda)$**	**Wavelength λ, nm**	**UV hazard function $S_{UV}(\lambda)$**
200	0,030	313*	0,006
205	0,051	315	0,003
210	0,075	316	0,0024
215	0,095	317	0,0020
220	0,120	318	0,0016
225	0,150	319	0,0012
230	0,190	320	0,0010
235	0,240	322	0,00067
240	0,300	323	0,00054
245	0,360	325	0,00050
250	0,430	328	0,00044
254*	0,500	330	0,00041
255	0,520	333*	0,00037
260	0,650	335	0,00034
265	0,810	340	0,00028
270	1,000	345	0,00024
275	0,960	350	0,00020
280*	0,880	355	0,00016
285	0,770	360	0,00013
290	0,640	365*	0,00011
295	0,540	370	0,000093
297*	0,460	375	0,000077
300	0,300	380	0,000064
303*	0,120	385	0,000053
305	0,060	390	0,000044
308	0,026	395	0,000036
310	0,015	400	0,000030

[1] Wavelengths chosen are representative: other values should be obtained by logarithmic interpolation at intermediate wavelengths.
* Emission lines of a mercury discharge spectrum.

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

Table 4.2	Spectral weighting functions for assessing retinal hazards from broadband optical sources	
Wavelength nm	**Blue-light hazard function B (λ)**	**Burn hazard function R (λ)**
300	0,01	
305	0,01	
310	0,01	
315	0,01	
320	0,01	
325	0,01	
330	0,01	
335	0,01	
340	0,01	
345	0,01	
350	0,01	
355	0,01	
360	0,01	
365	0,01	
370	0,01	
375	0,01	
380	0,01	0,1
385	0,013	0,13
390	0,025	0,25
395	0,05	0,5
400	0,10	1,0
405	0,20	2,0
410	0,40	4,0
415	0,80	8,0
420	0,90	9,0
425	0,95	9,5
430	0,98	9,8
435	1,00	10,0
440	1,00	10,0
445	0,97	9,7
450	0,94	9,4
455	0,90	9,0
460	0,80	8,0
465	0,70	7,0
470	0,62	6,2
475	0,55	5,5
480	0,45	4,5
485	0,40	4,0
490	0,22	2,2
495	0,16	1,6
500-600	$10^{[(450-\lambda)/50]}$	1,0
600-700	0,001	1,0
700-1050		$10^{[(700-\lambda)/500]}$
1050-1150		0,2
1150-1200		$0{,}2 \cdot 10^{0{,}02(1150-\lambda)}$
1200-1400		0,02

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

Table 5.4 Summary of the ELs for the surface of the skin or cornea (irradiance based values)

Hazard Name	Relevant equation	Wavelength range nm	Exposure duration sec	Limiting aperture rad (deg)	EL in terms of constant irradiance $W \cdot m^{-2}$
Actinic UV skin & eye	$E_S = \sum E_\lambda \cdot S(\lambda) \cdot \Delta\lambda$	200 – 400	< 30000	1,4 (80)	30/t
Eye UV-A	$E_{UVA} = \sum E_\lambda \cdot \Delta\lambda$	315 – 400	≤1000 >1000	1,4 (80)	10000/t 10
Blue-light small source	$E_B = \sum E_\lambda \cdot B(\lambda) \cdot \Delta\lambda$	300 – 700	≤100 >100	< 0,011	100/t 1,0
Eye IR	$E_{IR} = \sum E_\lambda \cdot \Delta\lambda$	780 –3000	≤1000 >1000	1,4 (80)	$18000/t^{0,75}$ 100
Skin thermal	$E_H = \sum E_\lambda \cdot \Delta\lambda$	380 – 3000	< 10	2π sr	$20000/t^{0,75}$

Table 5.5 Summary of the ELs for the retina (radiance based values)

Hazard Name	Relevant equation	Wavelength range nm	Exposure duration sec	Field of view radians	EL in terms of constant radiance $W \cdot m^{-2} \cdot sr^{-1}$)
Blue light	$L_B = \sum L_\lambda \cdot B(\lambda) \cdot \Delta\lambda$	300 – 700	0,25 – 10 10-100 100-10000 ≥ 10000	$0,011 \cdot \sqrt{(t/10)}$ 0,011 $0,0011 \cdot \sqrt{t}$ 0,1	$10^6/t$ $10^6/t$ $10^6/t$ 100
Retinal thermal	$L_R = \sum L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	380 – 1400	< 0,25 0,25 – 10	0,0017 $0,011 \cdot \sqrt{(t/10)}$	$50000/(\alpha \cdot t^{0,25})$ $50000/(\alpha \cdot t^{0,25})$
Retinal thermal (weak visual stimulus)	$L_{IR} = \sum L_\lambda \cdot R(\lambda) \cdot \Delta\lambda$	780 – 1400	> 10	0,011	6000/α

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

Table 6.1	Emission limits for risk groups of continuous wave lamps									P
Risk	Action spectrum	Symbol	Units	Emission Measurement (α=0,1000 rad, 120W)						
				Exempt		Low risk		Mod risk		
				Limit	Result	Limit	Result	Limit	Result	
Actinic UV	$S_{UV}(\lambda)$	E_S	$W\cdot m^{-2}$	0,001	5,159	0,003	5,159	0,03	5,159	
Near UV		E_{UVA}	$W\cdot m^{-2}$	10	$9,326 *10^{-1}$	33	--	100	--	
Blue light	$B(\lambda)$	L_B	$W\cdot m^{-2}\cdot sr^{-1}$	100	--	10000	--	4000000	--	
Blue light, small source	$B(\lambda)$	E_B	$W\cdot m^{-2}$	1,0*****	--	1,0	--	400	--	
Retinal thermal	$R(\lambda)$	L_R	$W\cdot m^{-2}\cdot sr^{-1}$	28000/α	--	28000/α	--	71000/α	--	
Retinal thermal, weak visual stimulus**	$R(\lambda)$	L_{IR}	$W\cdot m^{-2}\cdot sr^{-1}$	6000/α	--	6000/α	--	6000/α	--	
IR radiation, eye		E_{IR}	$W\cdot m^{-2}$	100	--	570	--	3200	--	

* Small source defined as one with α < 0,011 radian. Averaging field of view at 10000 s is 0,1 radian.
** Involves evaluation of non-GLS source

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

Table 6.1	Emission limits for risk groups of continuous wave lamps								P
Risk	Action spectrum	Symbol	Units	Emission Measurement (α=0,1000 rad, 60W)					
				Exempt		Low risk		Mod risk	
				Limit	Result	Limit	Result	Limit	Result
Actinic UV	$S_{UV}(\lambda)$	E_s	$W\cdot m^{-2}$	0,001	3,620	0,003	3.620	0,03	3.620
Near UV		E_{UVA}	$W\cdot m^{-2}$	10	5,982 $*10^{-1}$	33	--	100	--
Blue light	B(λ)	L_B	$W\cdot m^{-2}\cdot sr^{-1}$	100	--	10000	--	4000000	--
Blue light, small source	B(λ)	E_B	$W\cdot m^{-2}$	1,0*****	--	1,0	--	400	--
Retinal thermal	R(λ)	L_R	$W\cdot m^{-2}\cdot sr^{-1}$	28000/α	--	28000/α	--	71000/α	--
Retinal thermal, weak visual stimulus**	R(λ)	L_{IR}	$W\cdot m^{-2}\cdot sr^{-1}$	6000/α	--	6000/α	--	6000/α	--
IR radiation, eye		E_{IR}	$W\cdot m^{-2}$	100	--	570	--	3200	--

* Small source defined as one with α < 0,011 radian. Averaging field of view at 10000 s is 0,1 radian.
** Involves evaluation of non-GLS source

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

Table 6.1	Emission limits for risk groups of continuous wave lamps									P
Risk	Action spectrum	Symbol	Units	Emission Measurement (α=0,1000 rad, 40W)						
				Exempt		Low risk		Mod risk		
				Limit	Result	Limit	Result	Limit	Result	
Actinic UV	$S_{UV}(\lambda)$	E_s	W•m^{-2}	0,001	2,504	0,003	2,504	0,03	2,504	
Near UV		E_{UVA}	W•m^{-2}	10	3,287 *10^{-1}	33	--	100	--	
Blue light	B(λ)	L_B	W•m^{-2}•sr^{-1}	100	--	10000	--	4000000	--	
Blue light, small source	B(λ)	E_B	W•m^{-2}	1,0*****	--	1,0	--	400	--	
Retinal thermal	R(λ)	L_R	W•m^{-2}•sr^{-1}	28000/α	--	28000/α	--	71000/α	--	
Retinal thermal, weak visual stimulus**	R(λ)	L_{IR}	W•m^{-2}•sr^{-1}	6000/α	--	6000/α	--	6000/α	--	
IR radiation, eye		E_{IR}	W•m^{-2}	100	--	570	--	3200	--	

* Small source defined as one with α < 0,011 radian. Averaging field of view at 10000 s is 0,1 radian.
** Involves evaluation of non-GLS source

IEC 62471			
Clause	Requirement + Test	Result – Remark	Verdict

Table 6.1	Emission limits for risk groups of continuous wave lamps								P
Risk	Action spectrum	Symbol	Units	Emission Measurement (α=0,1000 rad, 20W)					
				Exempt		Low risk		Mod risk	
				Limit	Result	Limit	Result	Limit	Result
Actinic UV	$S_{UV}(\lambda)$	E_s	$W\bullet m^{-2}$	0,001	2,096	0,003	2,096	0,03	2,096
Near UV		E_{UVA}	$W\bullet m^{-2}$	10	$3.041 * 10^{-1}$	33	--	100	--
Blue light	$B(\lambda)$	L_B	$W\bullet m^{-2}\bullet sr^{-1}$	100	--	10000	--	4000000	--
Blue light, small source	$B(\lambda)$	E_B	$W\bullet m^{-2}$	1,0*****	--	1,0	--	400	--
Retinal thermal	$R(\lambda)$	L_R	$W\bullet m^{-2}\bullet sr^{-1}$	28000/α	--	28000/α	--	71000/α	--
Retinal thermal, weak visual stimulus**	$R(\lambda)$	L_{IR}	$W\bullet m^{-2}\bullet sr^{-1}$	6000/α	--	6000/α	--	6000/α	--
IR radiation, eye		E_{IR}	$W\bullet m^{-2}$	100	--	570	--	3200	--
* Small source defined as one with α < 0,011 radian. Averaging field of view at 10000 s is 0,1 radian. ** Involves evaluation of non-GLS source									

— End of Test Report —

Attachment A

Photo documentation

Type of equipment, model: See main report

Details of: Overview: FRL-48-1X-T8HO-120W-UV-C

View:

[x] general

[ ] front

[ ] rear

[ ] right

[ ] left

[ ] top

[ ] bottom

Details of: Overview: FRL-48-1X-T8-40W-UV-C

View:

[x] general

[ ] front

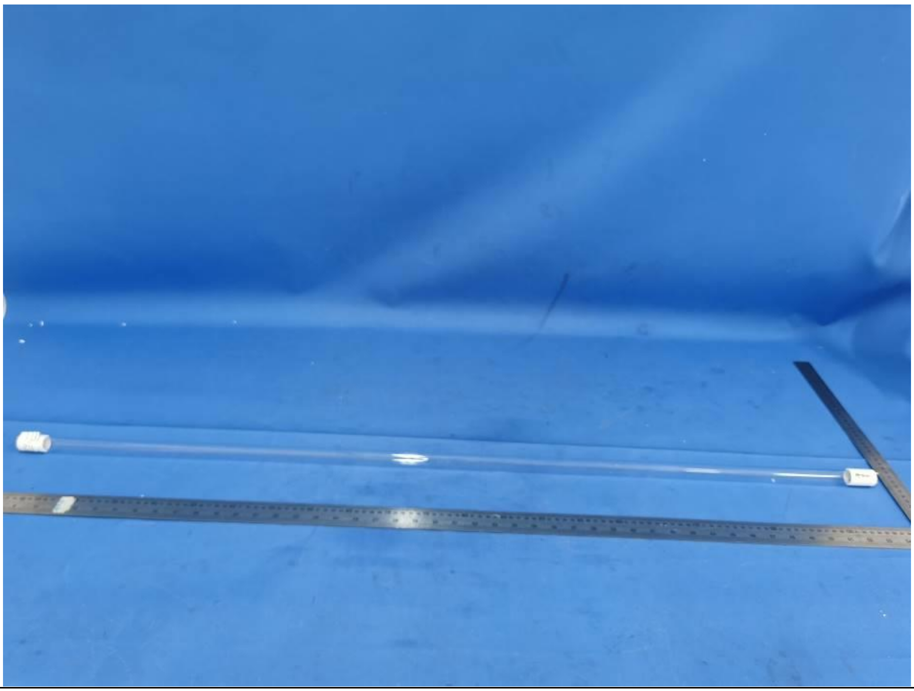
[ ] rear

[ ] right

[ ] left

[ ] top

[ ] bottom



Attachment A

Details of: Overview: FRL-24-1X-T8HO-60W-UV-C

View:

[x] general

[ ] front

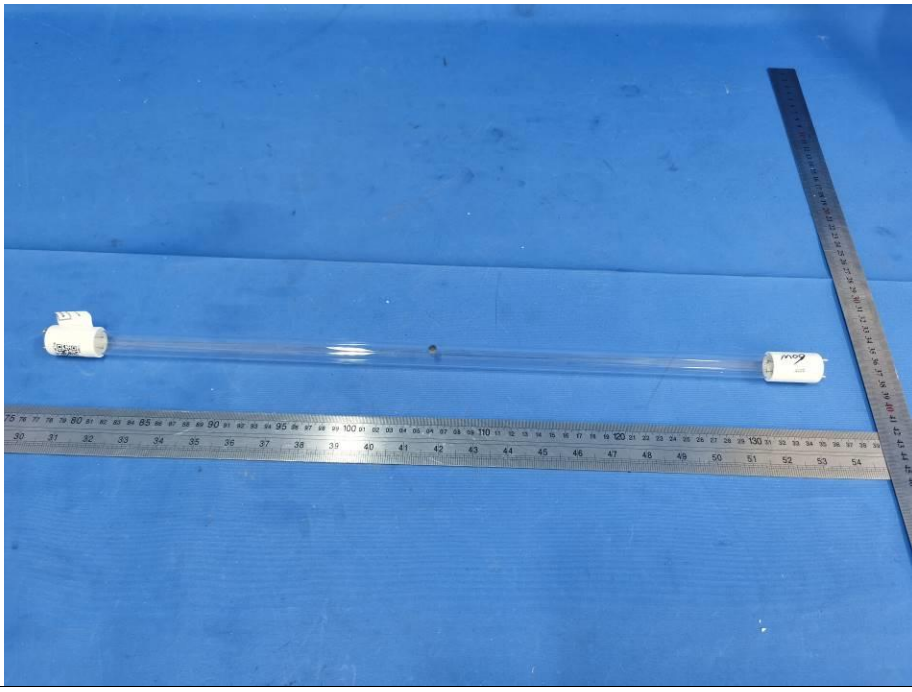
[ ] rear

[ ] right

[ ] left

[ ] top

[ ] bottom



Details of: Overview: FRL-24-1X-T8-20W-UV-C

View:

[x] general

[ ] front

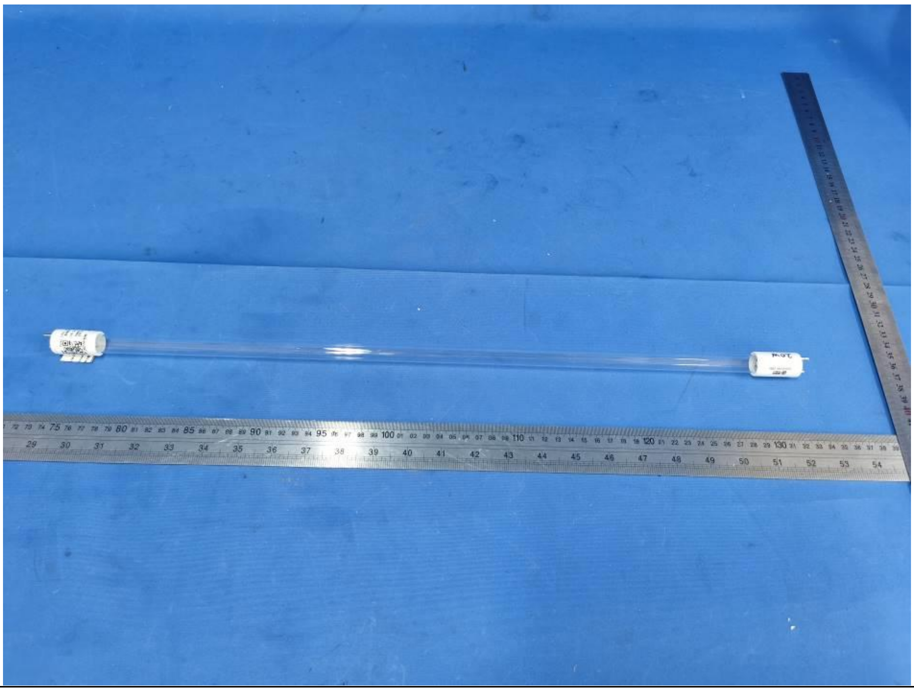
[ ] rear

[ ] right

[ ] left

[ ] top

[ ] bottom



— End of Attachment A —