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.
- **NEVER LOOK DIRECTLY AT THE BULB OR DISINFECTING TARGET ZONE**

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

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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.

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