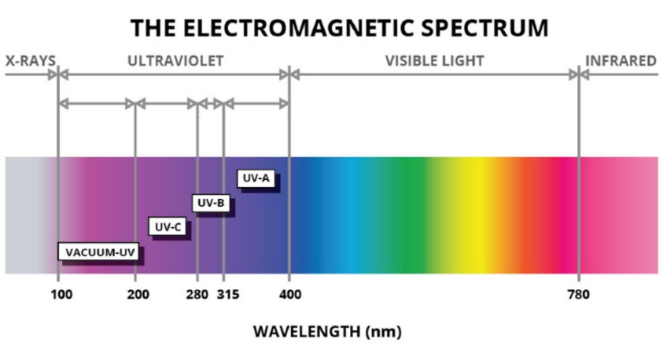
Introduction

The goal of this white paper is to examine the benefits and risks of using Germicidal Ultra Violet (GUV) light systems in fighting the transmission of infectious diseases. These systems have been used for over a century in water treatment, air systems, and for disinfecting surfaces. GUV has been most commonly used in hospitals, pharmaceutical, manufacturing and clean room applications. It is a proven technology for disinfection and killing of viruses, bacteria and fungal organisms. GUV is becoming increasingly well known to the general public due to the COVID-19 outbreak.

UV Spectrum

Ultra Violet (UV) Light is the region of the electromagnetic spectrum between 100 nm[1] and 400 nm in wavelength, just below the visible light spectrum. It can be separated into four regions:



The Electromagnetic Spectrum

Vacuum-Wave UV, VUV (100 nm - 200 nm) – This wavelength region is extremely harmful to humans if there is any direct exposure. However this UV spectrum is strongly absorbed by air, causing ionization of the oxygen molecules, and therefore does not present a significant exposure risk to humans, except under laboratory conditions. This wavelength region is called "vacuum-wave" UV due to its inability to propagate in atmospheres containing oxygen. It was initially thought to propagate only under vacuum conditions, but was later observed to propagate in nitrogen also.

Short-Wave UV, UV-C (200 nm - 280 nm) – This wavelength region is the most damaging to humans. UV-C contains the highest energy level capable of propagating through air. This UV spectrum has powerfully destructive effects on the DNA of living organisms and is therefore used as a disinfectant for air, water, food and contaminated surfaces, but only when protected from human exposure.

Middle-Wave UV, UV-B (280 nm - 315 nm) – This UV spectrum can cause sunburn with prolonged exposure, thereby increasing the risk of skin cancer in humans. It does not have significant sterilization potential, due to the lower energy of the photons.

Long-Wave UV, UV-A (315 nm - 400 nm) – This wavelength is more commonly called 'black light'. Many birds and insects can visibly perceive these wavelengths, however it is generally not visible to the human eye and has minimal impact on human tissues and microorganisms.

Germicidal UV Lamps

GUV (UV-C) lamps typically generate 254 nm light, which is very effective at breaking the molecular bonds of viral, bacterial and fungal DNA upon exposure to light of sufficient intensity. After this occurs, thymine dimers[2] are produced in the microorganisms' DNA, which prohibit growth and reproduction, thereby killing the viral, bacterial and fungal microorganism. Similar DNA damage occurs when human skin or eyes are exposed to GUV lamps of sufficient intensity or over a relatively short duration.

UV-C Exposure Standards

Human exposure to UV-C light can cause severe skin burns, skin cancer, and eye damage, however the FDA has currently approved the use of some UV-C light systems for public use under an emergency action for COVID-19. This has raised concerns about the safety of the GUV devices being sold to the public.

[1] nm – "nanometer is a unit of length in the metric system, equal to one billionth of a meter. One nanometer can be expressed in scientific notation as 1×10^{-9} m, in engineering notation as 1 E−9 m, and as simply meters." (Wikipedia)

[2] Ultra-violet radiation causes thymine (a compound which is one of the four constituent bases of nucleic acids) dimers (a molecule or molecular complex consisting of two identical molecules linked together). These are a pair of abnormally bonded adjacent thymine bases found in DNA.

The Illuminating Engineering Society (IES – est. 1906, www.ies.org) and the International Ultraviolet Association (IUVA – est. 1999, www.iuva.org) are partnering to establish the American National Standards for the use of GUV in connection with human exposure. These standards will be created by a team of experts in the field of measurement and characterization of UV-C performance. The standards will provide guidance for the accurate measurement and comparison of different GUV product types.

The new partnership between the IES and IUVA aims to promote and improve the usage of the UV-C lighting spectrum for sterilization, while establishing and maintaining safety standards to protect against potentially harmful human exposure. The new America National Standard will include standardized measurement protocols for different products including UV lamps, luminaires, and lighting systems, establishing much needed regulatory control of these systems. These organizations are planning to publish two standards by the end of 2020 – Approved Method for Electrical and Ultraviolet Measurement of Solid-State Sources and Approved Method for Electrical and Ultraviolet Measurement of Discharge Sources.

Another standards organization, The International Organization for Standardization (ISO – est.1947 www.iso.org) has published *ISO 15858:2016 UV-C Devices - Safety information - Permissible Human Exposure*. This standard adopts the REL maximum[3] permissible UV-C exposure values, reprinted in the table below. These exposure levels do not exceed the American Conference of Governmental Industrial Hygienists (ACGIH – est. 1938, www.acgih.org) Threshold Limit Values (TLV) and the National Institute for Occupational Safety and Health (NIOSH – est. 1970, www.niosh.org) REL of 6.0 $\mathrm{mJ/cm^2}$[5] for an 8-hour day, 40-hour week with UV-C radiation at 254 nm.

Until recently, nearly all human exposure to UV-C occurred in workplace environments, due to the fact that most UV-C generation occurs from artificial sources used in manufacturing and sterilization processes. (The earth's atmosphere is 100% effective at filtering UV-C exposure from the Sun.) UV-C exposure in the workplace can occur from arc welding, integrated circuit manufacturing and sterilization processes, among others. The REL recommendations are intended to protect workers from the harmful effects of UV-C exposure.

Maximum Permissible UV-C Exposure for Radiation at 254 nm	
Permissible Exposure Time	Effective Irradiance μW/cm^2 [4]
24 h	0.07
18 h	0.09
12h	0.14
10 h	0.17
8 h	0.2
4 h	0.4
2 h	0.8
1 h	1.7
30 min	3.3
15 min	6.7
10 min	10
5 min	20
1 min	100
30 sec	200
15 sec	400
5 sec	1200
1 sec	6000
NOTE: This table is based on NIOSH/ACGIH maximum UV exposure times. Chart from ISO – 15858 2016	

Exposure times exceeding the recommended levels above require that personal protection equipment (PPE) is utilized at all times. The PPE for UV-C protection that is required by these standards when the maximum exposure levels are exceeded is as follows:

- Protective eyewear or face shields. The most suitable eye protectors need to comply with BS EN 170:2002 and BS EN 166:2001.[5]
- Non-transparent clothing preventing UV-C radiation penetration covering all exposed skin.

[3] REL maximum is a relative maximum point where the function changes direction from increasing to decreasing (making that point a "peak" in the graph). Similarly, a relative minimum point is a point where the function changes direction from decreasing to increasing (making that point a "bottom" in the graph). www.khanacademy.org

[4] microWatts/Square Meter. (μW/m2)

[5] The European Standards covering Eye & Face Protection are some of the most comprehensive of all dealing with any item of PPE. EN 170 covers the requirements for UV filter and transmittance.

UV-C Anti-Viral Efficacy

The ability of UV-C lighting to kill all known forms of microbes, including some of the most deadly forms like SARS, MERS and MRSA is undisputed in scientific research. Most GUV systems utilize the wavelength of 254 nm, as the most effective germ and virus killing wavelength. Provided sufficient light intensity and exposure time, conventional UV-C lighting (254nm) is considered 100% effective.

Recent studies have reported that a new "far-UV-C" artificial light, operating at a 222 nm wavelength, may be nearly as effective at neutralizing airborne viruses as conventional 254 nm UV-C light, without the associated risks to human cells and DNA. According to a study published in June 2020 by researchers at Columbia University's Irving Medical Center[6], "*There is a regulatory limit as to the amount of 222 nm light to which the public can be exposed, which is 23 mJ/cm² per 8-hour exposure. Based on our results here for the beta HCoV-OC43 coronavirus, continuous far-UVC exposure at this regulatory limit would result in 90% viral inactivation in approximately 8 minutes, 95% viral inactivation in approximately 11 minutes, 99% inactivation in approximately 16 minutes and 99.9% inactivation in approximately 25 minutes. Thus continuous airborne disinfection with far-UVC light at the currently regulatory limit would provide a major reduction in the ambient level of airborne virus in occupied indoor environments.*

"In conclusion, we have shown that very low doses of far-UV-C light efficiently kill airborne human corona-viruses carried by aerosols. A dose as low as 1.2 to 1.7 mJ/cm2 of 222-nm light inactivates 99.9% of the airborne human coronavirus tested from both genera beta and alpha, respectively. As all human coronaviruses have similar genomic size, a key determinant of radiation sensitivity, it is likely that far-UVC light will show comparable inactivation efficiency against other human coronaviruses, including SARS-CoV-2."

The human exposure safety claim is based on research by some of the same research team that indicates the 222 nm far-UVC light will not penetrate the dead skin layer or the tear layer on the human eye, but will penetrate very small airborne virus aerosol particles, disrupting their DNA after a sufficient exposure time.[7]

The average particle size distribution in this study was 83% between 0.3 µm and 0.5 µm, 12% between 0.5 µm and 0.7 µm, and 5% >0.7 µm. The effectiveness of far-UVC light on the larger size (>1µm) droplet particles that accompany respiration, sneezing, coughing and speaking, was not studied. Droplet particles larger than 1.0µm typically drop out of the air quickly and fall to the floor or onto adjacent surfaces to become fomites – objects or materials which are likely to carry infection, such as clothes, utensils, and furniture.

Far-UVC (222nm) Implementation

Magnolia Bakery in NYC's upper West Side has been installing far-UVC lighting based "cleanse portals" to help mitigate the spread of COVID-19. As customers walk through the entrance of the bakery, they are exposed to far-UVC lighting for a requested time period of 20 seconds, reportedly killing any viruses, bacteria or fungal organisms that are exposed to the light during this brief encounter. In addition, the overhead lighting inside the bakery is being replaced with bulbs which generate far-UVC light, bathing employees and customers in the light for the duration of their shift or visit.

The bakery is still requiring clients to wear masks and comply with social distancing recommendations. Employees will wear gloves, which will be changed frequently.

This type of system raises concerns and questions regarding customer and employee safety of far-UVC exposure and its efficacy in killing viruses and other microbes. The minimal exposure time of 20 seconds is not consistent with the scientific research even at

[6] Manuela Buonanno, David Welch, Igor Shuryak & David J. Brenner, "Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses." Scientific Reports, (2020) 10:10285. David Brenner is the Higgins Professor of Radiation Biophysics at Columbia University, Vagelos College of Physicians and Surgeons and Director of the Center for Radiological Research at Columbia University Irving Medical Center.

[7] Manuela Buonanno, Brian Ponnaiya, David Welch, Milda Stanislauskas, Gerhard Randers-Pehrson, Lubomir Smilenov, Franklin D. Lowy, David M. Owens, David J. Brenner "Germicidal Efficacy and Mammalian Skin Safety of 222-nm UV Light," Radiation Research, 187(4), 493-501, (22 February 2017)

a 23mJ/cm^2 light intensity level (the actual light intensity in the bakery is not known). Also, since the virus is typically spread through aerosol or droplet particles emitted during normal respiration, talking, sneezing and/or coughing in close proximity to others, the overall human irradiation systems, such as the ones proposed at Magnolia Bakery, will not provide much protection once the customer is in the store with other customers. Viruses and bacteria are not killed by any UV-C lighting system unless they are *directly* exposed to the light for a sufficient period of time at a sufficient lighting intensity.

With the prolonged outbreak of the virus, many public health experts fear that this type of technology may be installed in other restaurants and public spaces before its true efficacy and safety risks can be thoroughly assessed. This emphasizes the need for strict exposure standards for all UV-C spectrums to ensure that in the quest to eradicate the virus, other potentially more serious health concerns are not created.

UV-C (254nm) Implementation

According to The New York Daily News, the Metropolitan Transit Authority (MTA), will begin using powerful full-spectrum UV lighting to kill viral, bacterial and fungal microorganisms on trains and buses. This program will be a partnership with Columbia University to study the effects of UV lighting on microorganisms. This will be accomplished by placing dual headed lamps on stands placed on subway cars and buses at two rail yards and bus depots. These lamps will emit standard UV-C to kill microorganisms, along with UV-A and UV-B spectrum light. These sterilization procedures will occur only when the subway cars are completely evacuated of all people, eliminating any risk of human exposure to UV-C light.

NYC MTA Subway UV Sterilization Program

According to a news article from NBC on July 30, 2020, Jet Blue airlines has also started a similar pilot program. They are utilizing a robotic system which has UV-C lamping. The robotic system is about the size of a beverage cart that rolls down the aisle. It has two arms with UV-C lights attached, which are located at the top of the robotic system. The arms extend over the tops of the seats and blanket the cabin with UV-C light to kill microorganisms. This system can disinfect one aircraft in less than 10 minutes. So far this program is set to begin at John F. Kennedy International Airport in NYC and Fort Lauderdale-Hollywood International Airport in Florida. This will be a 90 day pilot program. If successful, the program will be implemented at other airports. Like the MTA project, this program also ensures that there is no human exposure to the UV-C light by using robotic technology on vacant aircraft.

Additional Safety Related Information Regarding UV Light

UV-C damages the DNA of microorganisms, therefore it can also be damaging to humans. It can cause skin irritation, damage to the cornea and cell mutation leading to cancer. Even short exposures can cause chronic damage to the human body and must be avoided.

UV-C radiation from the sun is completely absorbed by the ozone layer in the earth's atmosphere, along with 90% of the sun's UV-B radiation. No UV-C radiation from the sun reaches the surface of the earth, therefore all UV-C sources are man-made and must be carefully controlled to avoid damaging levels of human exposure.

UV-A radiation from the sun is less affected by the atmosphere and reaches the surface of the earth along with a small component of the UV-B spectrum. UV-A radiation is very close to visible light and is not as damaging to human tissues and microbes. Areas on the earth that have experienced a significant depletion of the ozone layer are at greater risk of hazardous exposure levels for humans, particularly in the UV-B spectrum, since the reduction in the thickness, or "holes" in the ozone layer will allow a larger portion of the UV-B spectrum to reach the surface.

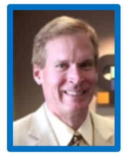
About Light Plan Design

Light Plan Design is an architectural lighting design consultancy group based out of New York City. Light Plan Design was born out of a need for creative lighting design with the ease of coordination, convenience and practicality that clients have come to expect from our firm. Light Plan Design offers interior, exterior and landscape lighting applications design for commercial, institutional and residential projects.

About Bonny:

Bonny Whitehouse, Director of Lighting Design, is dedicated to developing creative, state- of-the-art, energy efficient lighting solutions, in keeping with the rapidly evolving lighting and control technologies and budgetary constraints of our clients. She stresses the importance of the innovative application of creativity while recognizing technical standards and the needs of end users. She is sensitive to the needs and requirements of the built environment, and works closely with other trades to deliver an integrated design to our clients. Bonny received a Bachelor of Science in theatrical design. While attending NYU for her Masters of Fine Arts, she worked on various Off- Off Broadway and Off Broadway shows.

About Greg:



Gregory Schnackel, P.E., LEED AP has been involved in the design of mechanical, electrical, lighting, plumbing, fire protection and information technology systems for malls, mixed-use developments, corporate offices, national retail roll-outs, schools, hospitals, medical facilities, commercial and institutional buildings for over 40 years with Schnackel Engineers.

Schnackel Engineers, Inc. has recently published a series of white papers on Enhanced HVAC Infection Control, including one specifically focused on the use of UV-C air sterilization in a building's heating, ventilating and air conditioning systems, as well as Upper Room GUV applications. Please click here to learn more about how UV-C can help in the fight against the spread of infectious particles in buildings.