Demystifying Ultraviolet Germicidal Irradiation – How UV-C Disinfection Technology Inactivates Airborne Microorganisms

Executive Summary

It is well known that some diseases can be transmitted from airborne particles, also called aerosols, generated by an infected person. Common countermeasures include hand washing, covering the face when sneezing, and disinfecting surfaces such as door handles. However, the magnitude of the 2020 COVID-19 pandemic has shown that these countermeasures are not sufficient, and further preventative measures must be taken. Many businesses have implemented face coverings and social distancing; however, these measures are inconsistent and can be challenging to enforce. At best, these measures enable reduced services with partial risk reduction.

An additional measure to consider is Ultraviolet Germicidal Irradiation (UVGI). If appropriately used, UVGI can be safe and highly effective in disinfecting the air, thereby significantly reducing the transmission of various airborne infections.[1]

What is Ultraviolet-C (UV-C) Radiation?

Ultraviolet light (UV) is a form of electromagnetic radiation with wavelengths that are shorter than visible light radiation. As shown in Figure 1, UV radiation is classified into several types across wavelength ranges. Most people associate UV radiation with UV-A and UV-B, which come from sunlight and transfer through the atmosphere. UV energy (regardless of type) is absorbed by human skin, and the skin's natural defense (a pigment called melanin) attempts to convert the UV energy to heat. If there is too much UV energy, melanin cannot keep up, and the skin cell DNA is damaged, leading to sunburn or melanoma.

Short-Wave UV (also called UV-C) has the same potential to damage humans; however, it is absorbed by the atmosphere and ozone layer. UV-C has a more

[1] N. G. Reed, ""The History of Ultraviolet Germicidal Irradiation for Air Disinfection,"" *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2789813/,* 2010.

substantial effect on microorganisms, and for over 100 years, has been used as a method to kill or inactivate microorganisms such as viruses and bacteria.

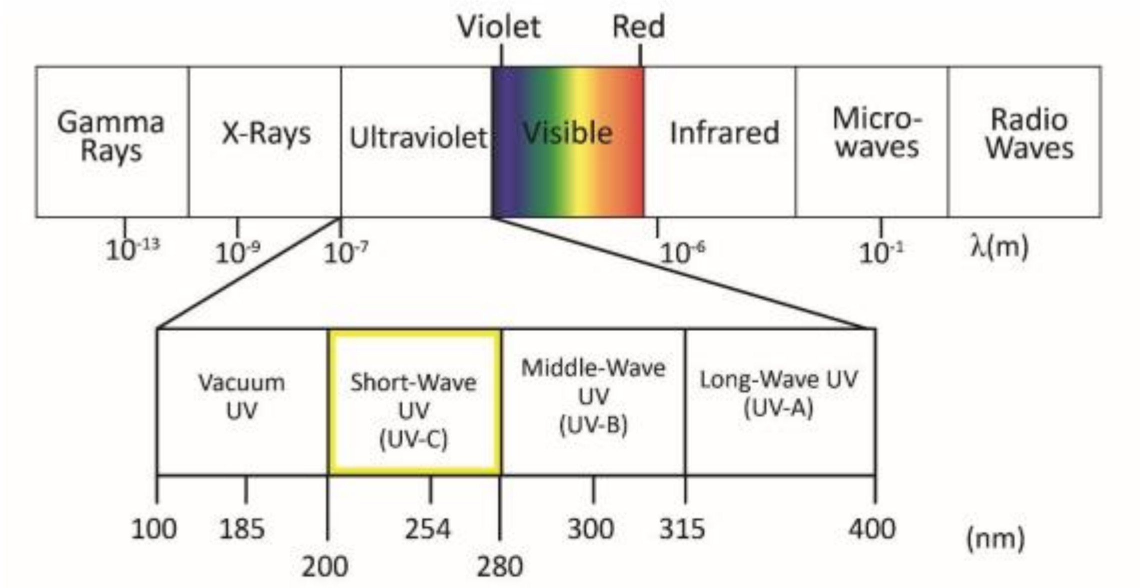

Figure 1: Electromagnetic Spectrum highlighting the ultraviolet portion[2] [2].

How Does UV-C Damage Microorganisms?

It has been well established that UV-C radiation (primarily at 254 nm) will inactivate microorganisms by damaging their DNA rendering the affected virus or bacteria unable to replicate[3]. The amount of UV-C energy needed, also called the **kill dose**, is well established for many different microorganisms. The dose is expressed as the amount of radiation intensity for one second per square meter to kill or inactivate some amount of the microorganism. Typically, a kill dose refers to the radiation needed to kill or inactivate 90% of the microorganism.

While studies have yet to confirm if UVC light can kill SARS-CoV-2, the virus that causes COVID-19, multiple studies have shown that it can kill similar viruses, including influenza and other seasonal coronaviruses. Top experts believe UV-C disinfection technologies will be effective against COVID-19.[4]

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[2] "IES Photobiology Committee - Germicidal Ultraviolet (GUV) – Frequently Asked Questions," 2020.
[3] N. G. Reed, "The History of Ultraviolet Germicidal Irradiation for Air Disinfection, " *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2789813/,* 2010.
[4] D. Coffey, "Does UV light kill the new coronavirus?" - https://www.livescience.com/uv-light-kill-coronavirus.html, 2020.

Table 1 shows a sample of such microorganisms and susceptibility to UV-C energy.[5]

Type	Name	Dose (J/m^2)*
Virus	Hepatitis A	73
Virus	Polio virus	58
Virus	Rotavirus	81
Bacteria	Salmonella enteritidis	40
Bacteria	Legionella pneumophila	9
Bacteria	Tuberculosis	60

* Units J/m2 stands for Joule per meter squared. One Joule is equal to 1 Watt of energy for 1 second.

Effective UVGI Implementation and Safety

Natural UV-C energy comes from the sun and is absorbed by the atmosphere and ozone layer, UV-C is commonly generated by energizing a mixture of argon and mercury in a vacuum bulb. This results in UV-C energy generated at 253.7nm.[6] These bulbs are commercially available in a wide variety of sizes and power. However, implementing UVGI is not as simple as placing a UV-C lamp in the center of a patient exam room or a classroom and walking away.

Exposure to UV-C energy is dangerous to human skin and especially to the eyes. Ultraviolet Keratitis (also known as welder's eye) is an eye condition described as sunburn of the cornea. This usually manifests itself as a feeling of pain or burning in the eyes. Welding torches also generate UV-C, and welding without proper eye protection leads to this condition. Any solution that uses UV-C energy must be implemented in a way to avoid human exposure.

A common UV-C treatment method, known as Upper Room UVGI, has to contend with this challenge. Upper Room UVGI involves placing UV-C lamps at high positions in the room, with baffling or other barriers preventing the UV-C radiation from going below a certain height. This barrier itself presents a challenge, and air circulation must be present to continuously move air up into the higher space to be treated. Upper Room UVGI can be effective but is error-prone and costly due to the large number of UV-C bulbs and fixtures needed. Spaces with ceilings lower than 8 feet are usually not conducive to this solution.

Some solutions exist that rely on spaces being empty while they are being treated. Such solutions are UV-C bulbs on pedestals or robots carrying UV-C lamps that move down hallways. These solutions address some of the disadvantages of Upper Room UVGI but must rely on human controls to ensure the space is empty while it is being treated.

[5] Philips, "Ultraviolet Purification Application Information," (https://www.assets.signify.com/is/content/PhilipsLighting/Assets/philips-lighting/global/20200504-philips-uv-purification-application-information.pdf)
[6] "http://www.uvresources.com/resources/faqs," International Ultraviolet Association (UVR Resources).

This presents a much greater safety risk in addition to preventing space from being used while being treated. In these solutions, the UV-C must go to the infected air and will likely miss air that is outside line of sight, such as behind equipment or below a chair. It is generally more effective to bring the air to the UV-C device, versus take the UV-C to the air.

UV-C Works Best at Close Range

In an Upper Room UVGI implementation, even if the air circulates to the upper part of a room, microorganisms must be close to the light source to be deactivated quickly. If a particle moves twice as far away, it only gets a quarter of the energy. This property, called the inverse square law, works against solutions attempting to treat large spaces. As shown in Figure 2, the further away microorganisms are from UV-C energy, the less radiation they receive. As a result, more time will be required to achieve the kill dose.

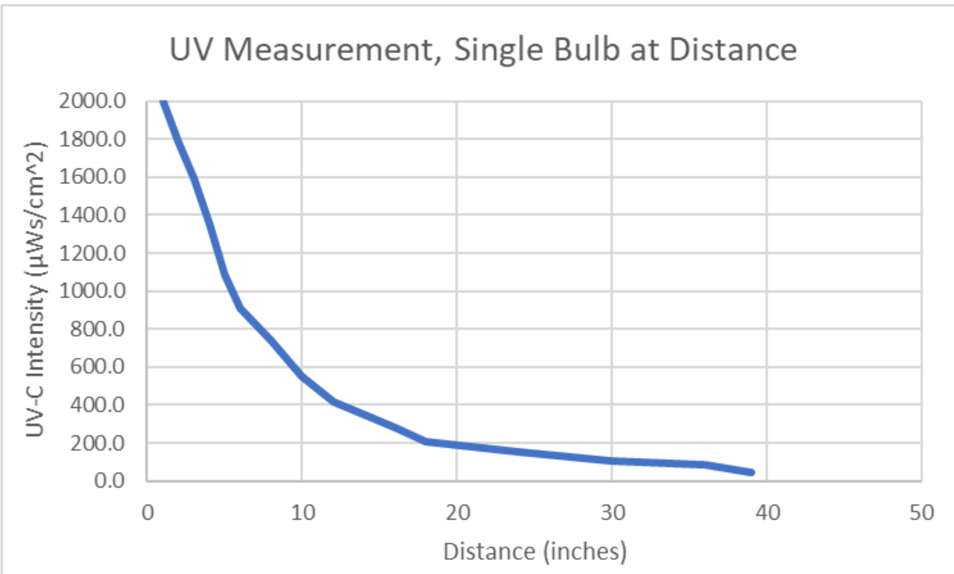

Figure 2 Reduction in UV radiation as the microorganism moves further away from the UV-C source. Bulb Type: Philips TUV TL Mini (16W 4P-SE).

Achieving Close Contact

An effective way to achieve closer contact with microorganisms in the air is to use powerful air circulation, which pulls the contaminated air into a self-contained chamber containing the UV-C bulbs. A stand-alone air purification unit can be placed in a room, and a powerful motor inside the unit will pull in the air that travels through the UV-C chamber, returning sanitized air into the room.

With this approach, the UV-C chamber itself can be quite compact, and air flows through it rapidly. Microorganisms travel so close to the UV-C lamps that the kill dose is achieved. This is a direct result of the inverse square law previously mentioned.

With this solution, the UV-C energy stays contained inside the chamber, ensuring no exposure to people in an occupied space without concerns.

The COVID-19 Kill Dose

The question that's top of mind today is obvious: Can UV-C inactivate SARS-CoV-19, and if so, what is the kill dose? With a century of UV-C treatments across many pathogens, including some similar to SARS-CoV-19, all signals indicate that it can. Many researchers are working to prove this hypothesis and determine the kill dose needed. A recent study conducted at The National Emerging Infectious Diseases Laboratories (NEIDL) at Boston University School of Medicine published that a UV-C dose of 50 J/m^2 was required to achieve a 99% reduction of SARS-CoV-19 (six-second dose).[7]

Armed with this knowledge, Omni CleanAir has developed a solution that provides non-stop high-speed air ventilation through a safe and contained chamber. With each air change, the UV-C chamber inactivates pathogens continuously. Using a combination of empirical measurements and a mathematical model of both virus and UVC properties, Omni CleanAir's team of experts have determined that the OCA500 Air Purifier delivers a kill dose of 5.91 J/m^2 over a single pass of exposure to a given particle. For all particles to be treated with the dosage determined by NEIDL, the OCA must circulate the entirety of the room’s air 1.41 times. For example, in a room 1,500 ft^3 feet in volume, the OCA500 will completely recirculate the air every five minutes and thus provide a kill dose equivalent to the NEIDL study in approximately 7 minutes. The OCA500 delivers a continuous and safe deployment of UVGI.

[7] E. R. B. III, "SARS-CoV-2 UV Dose-Response Behavior," 2020.