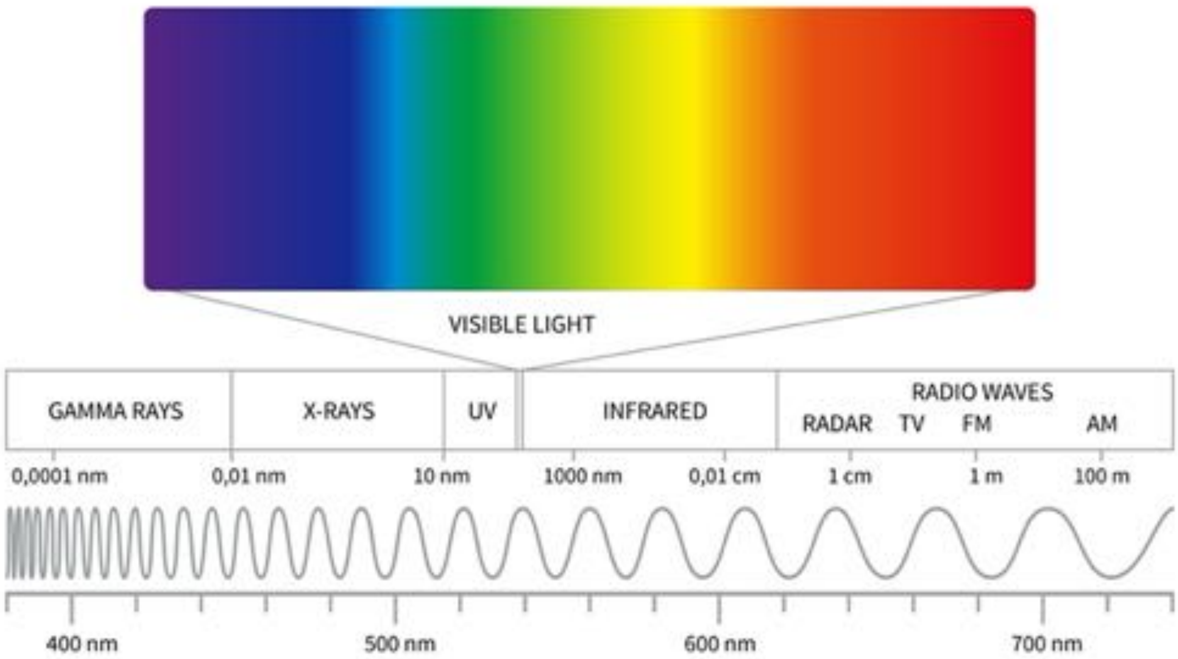
UVC LIGHT: DEFINING THE FACTS, DEBUNKING THE MYTHS

DEFINITIONS ∴ USAGE ∴ EFFICACY ∴ SAFETY ∴ MATERIALS

Published by Cleanbox Technology, Inc., August 2020

The electromagnetic spectrum



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References:
International UV Association; other experts and publications as indexed

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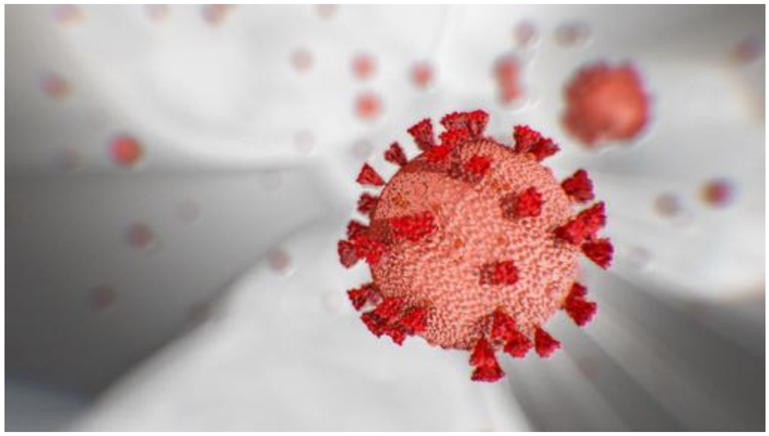


Introduction

“The problem of microbial contamination is not new to the field of medicine, it is just now that the rest of society is aware of these risks. As industries from airlines to retail turn towards physicians for solutions, we must provide them based upon our cumulative experience. UVC light has repeatedly been proven to effectively kill all known pathogenic bacteria, fungi and viruses including the Covid19 virus, SARS-Cov2. This has been demonstrated in both solid and porous surfaces and is non-destructive and non-toxic.” ***Dr. Robert Louis, FAANS, Head of Neurological Surgery at Hoag Memorial Hospital, Empower 360 Endowed Chair for Skull Base and Minimally Invasive Neurosurgery at Pickup Family Neurosciences Institute***

Premise: UVC as a surface disinfectant

UVC is a wavelength of light that doesn’t exist naturally in the earth’s atmosphere. Because UVC can’t be “found on earth,” common pathogens that prove dangerous or deadly to humans have no natural immunity to it. Since UVC can be artificially created in a bulb—and more recently in an LED substrate—UVC has been used as a very effective disinfectant against viruses, bacteria and fungi for decades.

It is important to understand that UVC’s effectiveness at eradicating a contagion on surfaces without damaging materials or humans is dependent on: 1. The form factor in which UVC is generated; 2. Nanometer wavelength; 3. Intensity; 4. Distance from surface; 5. Radius of coverage; 6. Length of exposure; and 7. Substance being decontaminated (air, water, surface).

This publication explains the basic concepts and science behind UVC surface decontamination, how it works, when it works and best practices. This document does not address UVC water or air decontamination.

Understanding the disinfection problem

Current solutions have serious limitations when it comes to disinfecting surfaces and ensuring cleanliness, especially with the impact COVID has had on our present environment. This section will address the following areas of concern: 1) inadequacies of current cleaning processes; 2) residue from most cleaning products is harmful and causes additional waste in PPE; 3) the introduction of COVID has brought a renewed focus on infection prevention and caused severe reductions in business productivity.

The current cleaning processes for most commercial and consumer facing products is liquid based. This means that surfaces need to be either sprayed or wiped down with a disinfectant product, then allowed to dry naturally. The process of alcohol or other liquid surface decontamination may be adequate for a smooth, flat surface but the introduction of any edges or pockets or change in surface texture as with soft or mixed materials creates an opportunity for missing an area where contaminants exist. In hospital settings, the number of electronic devices such as mobile phones, keyboards, etc., have enough hard-to-reach surface space that traditional liquid disinfectants either cannot fully reach all areas, or if they can, may potentially harm the device. This is a problem for many portable electronic and other devices that can go from room to room and potentially transmit disease.

Traditionally, a hospital requires a much higher level of these chemical disinfectants to treat a wide range of bacterial, viral and fungal agents than a consumer product, but with the introduction of COVID-19, there is a growing demand for medical-grade disinfectant materials in multiple business and consumer settings. While supplies chains are now able to provide these higher grades, the potential impact on consumers is troubling. Given the intense levels of disinfectant, the risk of chemical exposure in both adults and children is rising and will likely result in unintended health issues.

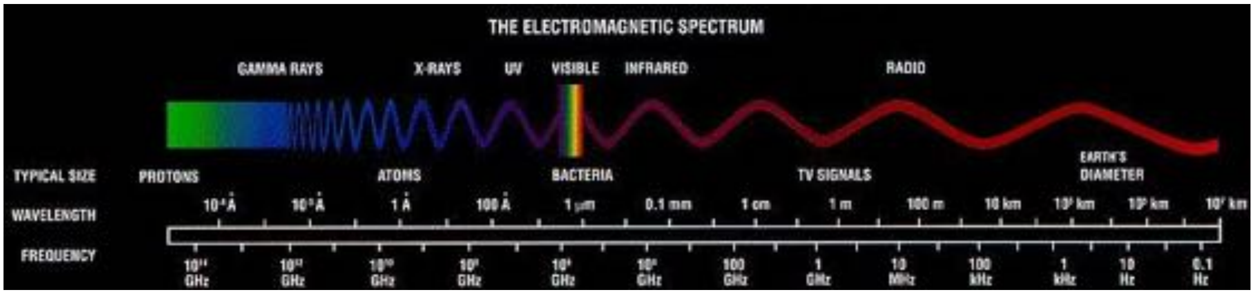
From a commercial standpoint, the impact of COVID-19 on policy and procedures has been damaging. With an increased focus from both regulatory and consumer audiences, the visibility of appropriate hygiene is at the forefront. Because there is so much scrutiny around cleaning protocols, companies must now visually disinfect with traditional cleaning products, often requiring an extended amount of time for the liquid product to dry naturally to complete the cleaning process. This extra time has dramatically reduced productivity and with traditional cleaning methods, only so much time can be recaptured. (14)

COVID-19

Ultraviolet rays, specifically the C wavelength of ultraviolet light (UVC), sanitize and clean more thoroughly and more quickly than other cleaning methods. (14)

With the advent of the COVID-19 pandemic, robust disinfectant protocols have become more relevant than ever before. While traditional, liquid-based cleaning methods may be adequate for limited applications, ultraviolet ray cleaning devices may provide an improved method for cleaning; creating hygienically safe environments and reducing the amount of time needed to sterilize. Both commercial organizations and consumers who want to improve the cleanliness of their environments should utilize properly applied Ultraviolet C rays. Ultraviolet C rays should be utilized by both commercial organizations and consumers that want to improve the sanitation of their environments.

Radiation energy and light: What is UV Light?



UV LIGHT	Wavelength Nanometer Range
UVA	315 - 400
UVB	280 -315
UVC	200-280 (disinfection range)
Vacuum UV	100-200

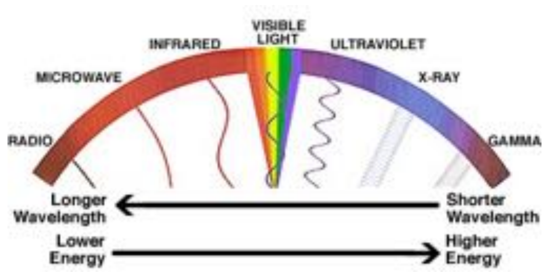
Ozone producing UV	160-240 nm
Far UVC	222 nm
UVC bulbs & tubes	Average 254 nm
UVC LEDs	Average 265 nm

UVA, UVB and UVC

When measuring energy, radiation energy includes gamma rays, X-Rays, ultraviolet waves, visible light, infrared, microwaves and radio waves. UV light is a measurement on the energy spectrum, and one that has a broad range of impact on human life.

Ultraviolet light (UV light) is a form of electromagnetic radiation ranging in wavelengths from 100-400 nanometers and is invisible to the human eye. On the spectrum of radiation energy, ultraviolet wavelengths lie beyond the purple edge of the spectrum, past visible light.

UV wavelengths are divided into three categories: UVA, UVB and UVC.



UVC is naturally absorbed by the earth's atmosphere and does not reach the earth. Thus, it does not exist naturally in earth's atmosphere, but it can be generated from artificial sources including mercury, pulsed xenon lamps and more recently, LEDs.

Because of its absence in earth's atmosphere, contagions found on earth have no resistance to UVC and are not immune to the effect of UVC on their DNA or RNA. Thus, UVC has been used as a decontamination method by exposing the DNA and RNA strands of contagions to the UVC wavelength of light, resulting in DNA or RNA molecule disruption. (12)

Tanning, burning and decontamination—which does what?

The UVA range of UV light causes sun tanning and burning of the human skin. The UVB range causes sun burning. The UVC range is most effective in inactivating bacteria and viruses because it disrupts the DNA and RNA strands of the exposed contagions. The deconstruction of nucleic acid through the induction of thymine dimers results in the inactivation of these microorganisms—disabling their ability to replicate and thus rendering them a non-replicable, non-contagion. (12)

Is Germicidal UVC different than far-UVC?

Germicidal ultraviolet light is typically at the 254-280 nm range. By contrast, far UVC light is in the 207-222 nm range. There are several factors to keep in mind with far-UVC. The 222nm wavelength is a more intense, but shorter wavelength. That means that it is even easier to stop than UVC at 265nm reach. Practically speaking, this means materials including glass, acrylic and plastics barrier the UVC ray at 265, and an even more fragile barrier is effective at 222nm. Because of these properties, UVC can in theory be used more safely around skin and eyes. UVC at the 222nm range has caused excitement in the scientific community for its potential application in decontaminating airborne particles. However, it falls into the ozone emitting range of UV light which presents a more toxic byproduct than non-ozone emitting light. Studies around far-UVC on air cleaning are still in early stages at the time of this publication. (11)

History of UVC for decontamination: Air, water, surfaces

In 1800 Sir Frederik William Herschel's experiments with temperature and visible light indicated that infrared light existed past the visible light spectrum. Ultraviolet radiation was identified in 1801 when Johann Ritter investigated the existence of energy beyond the violet end of the visible spectrum by using photographic paper to create visible results. Ritter continued his studies using silver chloride, a substance susceptible to light, to determine which colors of light could break it down. (6)

As studies continued on the effect of light on substances, it was known as early as 1845 that microorganisms responded to light. In 1877 Arthur Downes and Thomas Blunt observed that sunlight could prevent growth of microorganisms and continued to demonstrate the differing effects of various wavelengths, intensity, and duration of exposure on neutralizing bacteria. (5)

Protecting people with proven technology is vital. When used properly, UVC for disinfection is safe and highly effective and has been used for decontamination of air, water and surfaces. Note that level of efficacy on the element (air, water or surfaces) being disinfected will be impacted by several key factors including dosage required and dissemination of UVC protocol. (12)

When, where and how UVC disinfects

Nanometer range

UVC radiation in the range of 250nm - 280nm renders harmful microorganisms such as bacteria and viruses inactive by destroying the genetic information in their DNA. The DNA chain is disrupted so that when the cell undergoes mitosis or cell division, DNA replication is prevented. Thus, microorganisms lose their reproductive capability and are destroyed. (3)

Intensity and distance

Intensity of light can range significantly depending on the form factor. A UVC bulb on average emits 254nm while a UVC LED may emit between 260-280nm. The level of intensity is important when measuring the range of distance from the surface to reach the level of decontamination desired. (12)

Watts and Joules

When determining the math behind effective use of UVC, you will encounter the terms "watts" and "joules" both of which are measurements of energy. The International Ultraviolet Association (1) provides the following simple explanations:

> *A Watt is a measure of the rate of energy delivery (analogous to gallons-per-minute flow rate for water delivery).*
>
> *A Joule is a cumulative measure of the total amount of energy delivered (analogous to total gallons of water delivered).*

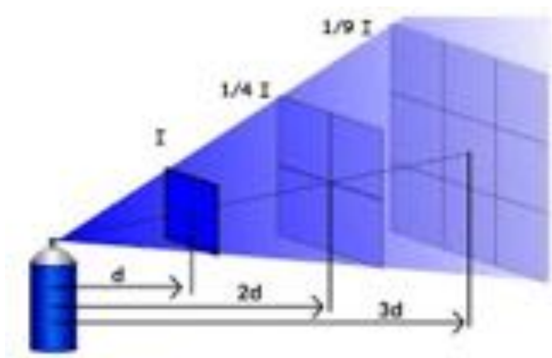
It usually is associated with how much time was needed to deliver the energy.

The way the units work is 1 Joule (J) of energy delivered = delivering 1 Watt (W) of energy for 1 second. In the UV world, we usually measure things in small increments, i.e., thousandths of a Joule or Watt. These are shown as 'milli-Joules' (i.e., 'mJ' or 1/1,000 of a Joule), and milli-Watts (i.e., 'mW' or 1/1,000 of a Watt).

Example: 40mJ (cumulative energy) = 10mW delivered for 4 seconds (1)

Inverse-square law

All light including UVC light, obeys the inverse-square law. The inverse square law dictates that a physical quantity is inversely proportional to the square of the distance from its source. This means that the further the light travels, the less intense that light becomes, and because of the inverse-squared relationship, that intensity drops quickly the further the distance from surface to light source. For example, if light is of intensity "X" at a distance of 2", then it is 1/4X at 4" and 1/16X at 8". Importantly, even short distance variation can have a huge effect on how well that UVC light is doing its job. (11)



Form Factor: lamps, bulbs and LEDs

UVC light can be created and emitted through different form factors including mercury lamps (or bulbs) or light emitting diodes (LEDs). Historically, mercury lamps have been used in healthcare settings. The superiority of the LED substrate and its increasing availability has caused its use in hospital settings to expand rapidly in the past few years.

Mercury lamps require warm-up time in order to reach full output power. However, LEDs can be turned on instantly to achieve full output. Unlike traditional UVC sources, UVC LEDs can be produced at specific deep UV wavelengths which align with the peak absorption capabilities of targeted microbes. Finally, the compact size of LEDs can make it easier to integrate this disinfection technology into applications where space may be limited. (3)

Mercury bulbs resonate at 254nm and are limited to that range. UVC LEDs typically resonate at 265-280m because LED substrates can be built to resonate at specific and varied frequencies. Studies have shown that these slightly higher wavelengths are more effective against a wider array of pathogens than those of a mercury bulb, and that the 265-270nm range is ideal for disinfection. Mercury bulbs and UVC LEDs are often used for surface material and water disinfection. Mercury vapor lamps emit more than 90 percent of their radiation at 253.7 nm. (7)

How to use UVC effectively—Factors impacting efficacy

- Line of sight
- Shadowing
- Surface
- Distance
- Duration
- Intensity
- Reflectivity

Line of sight

UVC is line-of-sight only. If the light can't shine directly on a pathogen, then it can't break it down and that pathogen is still able to replicate. UVC is also a very short wavelength that can be blocked by most materials including glass and acrylic and—as mentioned above in UVC and the human body—UVC is also blocked by layers of dead skin cells. However, there are some materials that allow UVC pass through.

Shadowing

Again, anything blocking light limits the effects of UVC decontamination. Thus, avoiding shadows is a must in any device that uses UVC light for disinfection.

The most common shadow-creating component seen in many UVC devices is a wire rack. An object to disinfect is laid on a rack and the lights are turned on. This means that every place where the rack blocks the light, there is the potential for pathogens to be completely untouched by UVC light, and contaminants are not eradicated.

Frequently there will need to be a touch point on the device being cleaned to hold it in place. For appropriate decontamination, the touch point(s) should be few and should be in a location that is the least likely to be a contagion point. Again, there are some materials that allow UVC pass through, but aluminum and metals are not such materials.

Properly engineered lighting must be utilized to address this critical issue.

Surface

It is easier to eradicate contagions on a flat non-porous surface than on porous, mixed material or uneven surfaces. The more nuanced a surface, the more opportunity for shadows or spaces in which contagions can hide and grow. Hard and flat surfaces create a different environment for contagions than do soft, porous, textile or other inconsistent surface schematics. Surfaces must be taken into account because they directly impact the level of efficacy that can be achieved using UVC light. For example, a hard, flat surface leave less room for contagions to gather, versus surfaces with height or depth differences. (12)

Again, properly engineered lighting—taking surface schematics and shadowing into account—is a vital consideration for UVC light to disinfect optimally.

Distance

Because of the inverse square law of light, it is important to understand and measure the amount and intensity of UVC light that is reaching the intended surface. Several factors will impact distance and efficacy, including intensity and duration of UVC exposure. These observations indicate that proximity to the item being contaminated has a significant impact in cycle time required for targeted levels of decontamination.

Duration of Exposure

Low-intensity lights can be safer for use and reduce the possibility of causing damage to the materials being disinfected. However, with lower intensity, longer exposure is required to ensure the same rate of pathogen reduction. This exposure may lead to the degradation of material and/or yellowing of clear materials over time. The higher intensity, the shorter the decontamination cycle time can be. There is definitely a sweet spot in the middle where intensity is high enough to get the job done in the least amount of time, and low enough that it would take years of exposure before materials would be damaged. **NOTE**: A big box with intense lights on the edges is problematic. Objects close to the lights receive greater and potentially damaging, levels of exposure to UVC than objects in the center. See more on UVC and materials below to understand how to use UVC without risk of damage to sensitive materials including plastics. (11)

Intensity

Because distance is a critical component of light intensity, it is important that any materials you wish to disinfect are positioned at an optimal distance from the lights, and that materials placed within the disinfecting device receive consistent intensities on all surfaces being treated. Failure to factor this may result in intensities that are too high (which can cause material breakdown and damage) or intensities that are too low (preventing effective disinfection). (11)

Reflectivity

Many UVC boxes purporting to provide hygienic solutions are "big box with lights on the edges and reflective surfaces inside". As mentioned previously, reflectivity can be a useful tool when distances are relatively short. In large boxes, reflectivity effectiveness drops off dramatically with each reflective bounce. Each bounce back of the light means the light has traveled a longer distance. UVC light intensity, and therefore decontamination effectiveness, plummets sharply with each bounce. The intensity of reflected light becomes low so quickly that those reflections have little impact, and do not compensate for shadows in a meaningful way.

There are a large variety of reflective surfaces, which vary in effectiveness. Mirrors are one of the least effective reflective surfaces because they reflect the light too precisely. Other materials (like aluminum) bounce light in a more distributed pattern, which makes them more likely to fill an area with light, making them more useful. The trade-off is often evaluating how much light the reflective surface actually absorbs and finding a material that reflects all or most of the light while dispersing it outward in all directions. These reflective materials do exist, but because of their cost, most UVC devices currently on the market do not utilize them.

Non-precise application of reflectivity for UVC decontamination applications is generally ineffective. However, reflectivity can be used to great purpose with: a) short distances, and; b) the correct reflective materials. (11)

How to use UVC safely

Form factor components

Not all UVC is equal. Mercury bulbs are more readily available than LEDs but emit heat and operate at 254 nm. LEDs can operate at higher nm ranges such as 265-280, without heat or mercury, but are more expensive. Far UVC is promising for efficacy but operates at a nanometer range that emits ozone.

Consider the sensitivity of the product you are decontaminating. Determine if heat, ozone, mercury or other toxins are acceptable for your environment. Finally, consider how simple you need the operation of your decontamination device to be. User-friendly hygienic solutions are important. Ease of use and quick, effective results are key components to consider.

Ozone

Ozone is emitted at lower wavelengths of UV light. UV wavelengths between 160nm – 240nm will emit ozone. The nanometer range for UVC decontamination is 200-280, so whether or not your UVC emits ozone will depend on the type and form factor of UVC light you are using.

Ozone is a produced when oxygen interacts with UV, resulting in photolysis of the oxygen molecule. Although ozone is a disinfectant, it is a chemical with corrosive properties. While ozone dissipates over time, its use is regulated by NIOSH and has specific handling requirements. (12)

UVC and the human body

According to George Chabot, PHD, of Health Physics Society “The UVC radiation is sufficiently energetic that individual photons may produce chemical bond breakage and ionization of some atoms and molecules. The preferential absorption of particular energy photons by materials, both organic and inorganic, is evident throughout the electromagnetic spectrum from microwaves through infrared and visible light, ultraviolet, x rays, and gamma rays. The absorption at particular wavelengths may be associated with resonance-type effects in which the gaps between certain energy states in an atom or molecule are nearly matched by the energies of the incoming photons. Atomic or molecular excitation may occur as a result of the absorption, or an electron may be ejected from an atom when the incoming photon energy exceeds the binding energy of the electron in the atom. It is common that photon absorption by particular atoms or molecules may be small at a given energy, increase with increasing energy, and then decrease again at yet higher energies, so it is not surprising that some higher-energy UV radiation may be more strongly absorbed than lower-energy UV." (8)

What does this mean? It means that the degree to which UV radiation is absorbed is dependent on the intensity of the UV and the overall exposure of the light to the object being considered: in this case, the human body. (12)

Dr. Chabot continues his explanation: "Because UVC is strongly attenuated by atmospheric gases, no significant irradiation of human beings on earth results from natural sources. … As has been recognized for some time, UVC radiation can damage the superficial tissues of the eye, and care must be taken to avoid excessive exposures of the eye. We should note, though, that while eye exposures to UVC may cause extreme discomfort, the symptoms usually subside within a rather short time, and no evidence of any malignant effects has ever been noted." (8)

Simply put, UVC will never reach humans by means of the atmosphere. Overall, UVC is an extremely safe and manageable method of decontamination. (12)

Why is UVC safe to humans? First, because its wavelengths are entirely absorbed by our atmosphere and so it only exists on earth through artificial mechanisms. Second, while those mechanisms may have some level of hazard—for example, the risk of a crushed mercury bulb—the mechanisms themselves can be managed. Because UVC is a short wavelength of light, the further away from the light, the exposure rate falls off exponentially. Thus, any exposure that could cause discomfort to humans would need to be extensive and intentional. (12)

As described by Dr. Kevin Kahn, "The intensity from point sources like UVC LEDs falls off as 1 over distanced squared. Once past the scattering length, intensity falls off exponentially. This means that: 1) the further away the UVC source from a human, the lesser dose he [or she] is exposed to; 2) the absorption length of UVC radiation in human skin is extremely short so that almost no UVC radiation can reach the living cells in the skin; all the absorption occurs in the dead cell layers." (9)

Does UVC cause skin cancer?

UVA and UVB are the primary sources of UV radiation that causes skin cancer. UVC is a shorter, higher energy wavelength of UV that reacts with ozone in the upper atmosphere, resulting in it being filtered out from entering the earth's atmosphere.

As described in this National Center for Biotechnology Information publication, "The UVC spectrum is highly mutagenic but does not reach the earth's surface because it is absorbed by the stratospheric ozone layer. Although it is generated by artificial light sources such as arc welding lamps, germicidal lamps or lasers causing irritation and damage to skin and eyes, little is known about UVC-induced damage in humans since exposure of people to this range of UV radiation is limited. Only a small group of people are exposed to this UV spectrum range. Furthermore, UVC penetration of deeper layers of the skin is limited. On the other hand, UVA and UVB wavelengths represent 95% and 5% of the UV spectrum reaching the earth's surface, respectively, with UVA penetrating the atmospheric and stratospheric ozone, while UVB radiation is predominantly absorbed by these layers." (10)

Testing contagion eradication using UVC

How is UVC efficacy evaluated when testing against a virus?

For a virus to be tested against UVC as a disinfectant, an assay or analysis is done to determine the presence and amount of a substance. The virus is inoculated onto a coupon, such as stainless steel, glass, Formica, or fabric swatch. The inoculum will generally include an organic soil, such as artificial mucin or serum. These inoculated coupons are then exposed to UVC light. Following exposure, viable virus is recovered and enumerated following dilution plating on host cells (in the case of influenza or coronavirus testing, the host cells are mammalian in origin). The level of viral inactivation is then determined by TCID50, plaque forming assay, or focus forming assay. (4)

- **TCID50** – this assay measures the 50% Tissue Culture Infective Dose for a specific virus/host cell combination. The TCID50 identifies the amount of virus required to kill 50% of the host cells. It is performed by dilution plating viable virus onto a host cell monolayer. TCID50 assays are often performed when viruses do not form plaques well and may also be used with the formation of cytopathic effects (CPE, see below).

- **CPE** – this assay counts the percentage of cells in a monolayer that exhibit cytopathic effects (CPE) following incubation of cells with viable virus. Results may be reported as percentage of cells exhibiting CPE.

- **Plaque Forming Assay** – this assay counts the number of plaques, gaps in a cellular monolayer where cell death has occurred, that develop on a monolayer of appropriate mammalian cells. Plaques are visualized after fixing and staining the monolayer. Results may be reported as Plaque Forming Units (PFU)/ml of inoculum.

- **Focus Forming Assay** – this assay counts the number of foci, spots of viral propagation in cells, that develop on a monolayer of appropriate mammalian cells. Foci are visualized after fixing cells and incubating with virus-specific antibodies. After a secondary antibody reaction, foci will appear as dark spots on the monolayer. Results may be reported as Focus Forming Units (FFU)/ml of inoculum. (4)

How is UVC efficacy evaluated when testing against bacteria?

Measuring the effect of UVC on bacteria follows the same protocol as with a virus, with the following exceptions:

Following exposure, viable bacteria are recovered and enumerated by dilution plating directly on the appropriate agar medium. The results may be reported as Colony Forming Units (CFUs)/ml of inoculum. (4)

What is a UV-resistant contagion and in what environments is such a contagion generally found?

Some microorganisms are UV resistant, meaning it takes additional UVC exposure, intensity or other application than with most microorganisms, before seeing breakdown of that microorganism. A UV-resistant microorganism may be bacteria, fungi, or viruses with the ability to withstand greater than normal levels of UVC. Typically, such UV resistance is found in extreme environments and can be referred to as extremophiles. However, there are UV-resistant contagions found in everyday environments. *Clostridiodes difficile* is extremely UV resistant when in its spore form. To a lesser extent, *Pseudomonas aeruginosa* and *Candida auris* are also UV resistant. (4)

How does UVC decontamination compare in efficacy to other methods of decontamination including heat, chemicals (such as peroxide or ozone)?

Vapors such as hydrogen peroxide or ozone are largely considered the most lethal to microorganisms. The biggest drawback to these vapors is the extreme lethality to humans and the need for containment. Heat, given enough time, is also extremely effective at killing microorganisms. However, heat is not compatible with many materials. UVC is also very effective at killing microorganisms. (4)

Understanding log kill and efficacy measurement standards

Standard Terms of Measurement

Log reduction is a mathematical term used to describe the relative number of living microbes eliminated by disinfection. The determined log reduction (for example log 4 or log 5) is found by measuring the result of the difference between colony forming units (CFUs) in the control and the test product and expressing them as a measure of reduction. As described by Crystal IS "A 1 log reduction corresponds to inactivating 90% of a target microbe with the microbe count being reduced by a factor of 10. Thus, a 2 log reduction will see a 99% reduction, or microbe reduction by a factor of 100, and so on." (3)

Log Reduction	Reduction Factor	Percent Reduced
1	10	90%
2	100	99%
3	1,000	99.9%
4	10,000	99.99%
5	100,000	99.999%
6	1,000,000	99.9999%

What is an "acceptable" log kill for an average consumer product

There is currently no consumer product standard when it comes to acceptable log kill. Most healthcare scenarios require a log kill of 5-6 or better. Most readily available consumer disinfection products state claims of log 3-4.

If you need to qualify as sterile, then your product will require a 12 log kill. For most healthcare scenarios, a log 5-6 kill is acceptable.

UV light on plastics: UVA, UVB and UVC and their effects on materials

What causes damage to plastics, polymers, glass or lenses?

The effects of UVA and UVB on plastics are widely known. Both wavelengths of light can cause brittleness and discoloration of plastics over time based on level and duration of exposure. What is less widely known is the impact of UVC on these materials.

When determining at what point visual impact or physical change might be detected, a number of factors must be considered. These primary factors include the material's thickness and color, the intensity of the UVC, distance from surface to UVC source, and duration of continual (non-interrupted) exposure. For example, shorter durations of exposure of polymers to UVC light at a distance that is adequate for surface decontamination—multiplied by the intensity and nanometer range of that light—will impact whether or not material changes can be detected over time. Note that most continual use cases referenced in this paper are based on a simulated one year of consistent exposure, measured by cumulative light/distance/intensity. (12)

Polymers can absorb UVC light and activate the active ingredient in the material. The process of absorbing the light on the top surfaces only may lead to further reaction in the material causing color change over extended time, but again any color change or physical impact will vary based on type of materials, thickness and color, and exposure intensity. The measure of absorption is dependent on the intensity, distance and duration of exposure.

Typically, UVC delivery form factor will not matter in terms of physical impact to the plastic, unless heat is a consideration. The biggest factor impacting color change and other degradation is based on the light intensity or dosage. (3)

(See appendices for wet lab testing protocol and results of short and long-term exposure of UVC LEDs on polymers, glass and lenses)

What happens after long term (one year+) UVC exposure

Plastic material may go through various changes depending on intensity and exposure time. Other things impacted by exposure could include color of plastic material and, to a lesser extent, the thickness of material. As mentioned before, plastic materials tend to show changes in color before the actual degradation of the material will occur. Color change visibility is more likely for clear or white material, followed by grey, and least visible in black or dark material. Such degradation is not rapid and takes a long period of concentrated exposure to occur. (3)

What is Important in a UVC Device?

There are several factors that are critical to consider in any UVC decontamination device.

Efficacy

Are you using the appropriate light wavelength to accomplish your purpose? For disinfecting material surfaces, UVC LEDs are the better choice because the light and wavelength (260-275nm) can be precisely measured and targeted.

For optimal coverage, your UVC device should have multiple overlapping light sources ensuring that every surface is covered from varying angles. This greatly diminishes the possibility of shadows.

> **Side note (Reflective surfaces):** Reflective surfaces can be helpful to avoid shadowing, but because of the inverse-squared law, light traveling to a reflective surface and then back again has traveled a much longer distance and becomes less additive to any material disinfection. The bigger the chamber, the less useful reflection is to the intensity. But reflectivity can be quite effective when used with smaller chambers and appropriate and effective reflective material.

Heat and Toxicity

UVC has historically been used in mercury bulbs or tubes, and most UVC devices still utilize this delivery form. However, the fragility of the glass tubes along with the toxicity of mercury must be considered when creating operational, handling and disposal protocol. Bulbs also generate significant heat which can impact sensitive electronics or product materials.

Exposure for decontamination

Because distance is a critical component of light intensity, it is important that any materials you wish to disinfect are positioned at an optimal distance from the lights. Materials placed within the disinfecting device must receive consistent light intensities on all surfaces being treated. Failure to do this may result in intensities that are too high (causing material breakdown and damage) or intensities that are too low (causing ineffective disinfection).

Summary

The basics:

- Not all UVC is "created equal"
- UVC won't hurt you or cause cancer
- UVC is invisible, but that doesn't mean it isn't working
- You can use UVC safely and effectively if you follow the general rules
- You have to use it correctly for it to work correctly
- UVC for disinfection won't harm plastics and glass. See above.

When determining the best use of UVC decontamination of surfaces, use the following protocol:

- Ensure that light intensity is even across all surfaces and that multiple light sources are covering all surfaces. Consistent, even coverage results in predictable outcomes. A design with uneven coverage will not provide you with the pathogen reduction you need.
- Ensure shadowing is reduced to the absolute minimum, especially on surfaces the user touches frequently.
- Remove the potential for human error as completely as possible. A device requiring only: "Insert object. Push button." is best.
- Limited, inexpensive reflectivity or generic lab results that say "UVC is a proven disinfectant" is not sufficient to protect the health and safety of consumers. Hygienic solutions should be both qualitative and quantitative.
- Rule of thumb: You get what you pay for. Quality UVC lights and the designs to apply them correctly are not cheap, but they are very cost effective. Properly engineered products that meet specific requirements to ensure predictable decontamination outcomes require the proper application of math, science and quality control.

Conclusion

In a world that has been brought to a standstill in an unprecedented way, it is not only important to understand the basics of how viruses and other contagions impact people and societies, it's equally important to understand how to fight back and protect people and businesses with proven technology and science.

Application of mathematics and scientifically measurable standards remains the best approach to effective, quantifiable results when addressing decontamination standards.

Appendix A: A Study of UVC LEDs on plastics done by Cleanbox Technology

Prepared by David Georgeson, CTO, Cleanbox Technology, Inc.

Objective

Materials Testing Report – [redacted] (Commonly used VR headset)

This document provides the results of "normal use" testing of Cleanbox Technology, Inc. engineering of UVC LEDs for surface disinfection, equal to **three years of regular** use on the [redacted] headset to determine degradation risks on plastics, polymers, glass and lenses.

Summary and Parameters

The Cleanbox CX1 was modified to ignore the logic board and be able to use direct current to power the UVC LEDs and Vent Fan. In this way, we were able to run the unit continuously, 24/7, for a period of time that equates to three years of normal use in only 5.5 days.

Cleanbox Testing Parameters

There are two sets of testing parameters we use here at Cleanbox. For this test, we used the "Normal Use" parameters.

Normal Use

Many training facilities, museums, retail kiosks, etc. don't utilize their visors constantly through the day and some seemingly "heavy-use" scenarios (like tradeshows) have high bursts of usage, but long periods of inactivity between shows. So the "Normal Use" case was developed to more closely model their behaviors.

Normal usage assumes a cleaning cycle is run 10 times daily, 5 days a week and 52 weeks per year. We normally test three years of usage on any given material at this rate, so that's 7800 minutes or 130 hours of cumulative exposure.

We can simulate that in a shorter period of time by running the lights continuously, 24 hours a day, 7 days a week for 5.5 days (7920 minutes).

Heavy Use

Venues like VR arcades, theme parks, etc., are all about turnaround and moving customers through their experience as quickly as possible. They run cleaning cycles much more often. It should be noted that this type of customer is truly an exception to how most people use the CX1, but this is included for completeness.

We model heavy use as follows: one cleaning cycle every five minutes (twelve times an hour), eight hours a day, six days a week, 52 weeks per year and for a period of three years. That equates to 89,856 minutes or just shy of 1500 hours. By running a 24/7 model of testing, that period of exposure can be accomplished by running the lights for 62.4 days (a bit over two months). Obviously, this is a much longer test, but still reasonably easy to accomplish if this seems necessary.

This test can be completed, if necessary, but it has been done on many materials previously and has never revealed any additional discoloration or physical degradation of materials.

The Test

Before the test began, pictures were taken of all angles on the headset to show the state of the materials and lenses. NOTE: There were some specks of dust and detritus on the headset, but those proved quite difficult to remove, so they were left as they have no bearing on the outcome of the test. (Images from before the test are included at the end of this document.)

The CX1 was turned on briefly and a photometer was used to verify that the light intensity on the surfaces of the headset was in the desired range of 0.5 – 0.6 mW/cm2. The unit was then powered off and the [redacted] (commonly used VR headset) was placed into the CX1 and positioned correctly on the visor hanger so that it was centered both vertically and horizontally to get the greatest saturation of light coverage possible.

The unit was then activated on Tuesday May 26th, 2020 at 3pm Pacific, and the test began. One week later, on Tuesday, June 2nd 2020 at 3pm Pacific, the CX1's power was turned off and the test was concluded.

The [redacted] (commonly used VR headset) was removed from the CX1 and visually inspected for discolorations and material degradation. There was none. Pictures were taken of the headset at that time and those images are included at the end of this document.

Observation and Conclusion

The test ran for seven complete days, or 168 hours instead of the original target of 132 hours. Thus, after a total of 192hrs of exposure under an intensity of 0.5 – 0.6 mW/cm2, a cumulative dosage of 302,400 mJ/cm2 was applied to the headset's various materials. The testing which was carried out was an aggressive form of testing as the material will not be exposed to such continuous UVC light for such an extended period of time and exposure time was well beyond the requested 132 hours of constant exposure.

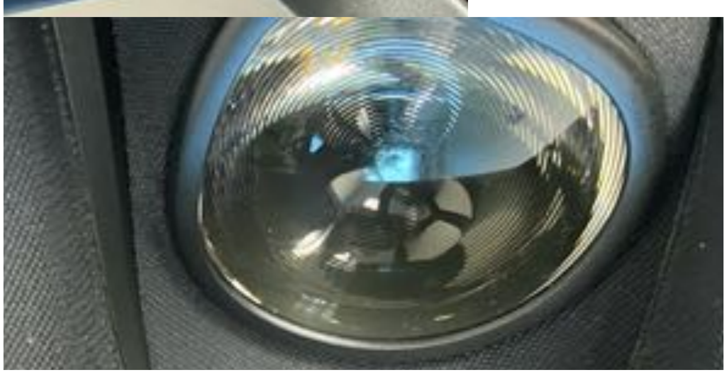
Despite the extended test period, there was no discoloration or material degradation visible by either visual inspection or touch. We recommend this test be done again with microscopic assessment both before and after, but no additional degradation is expected to be found.

Appendix A: Pre-test Images






Appendix A: Post-test Images

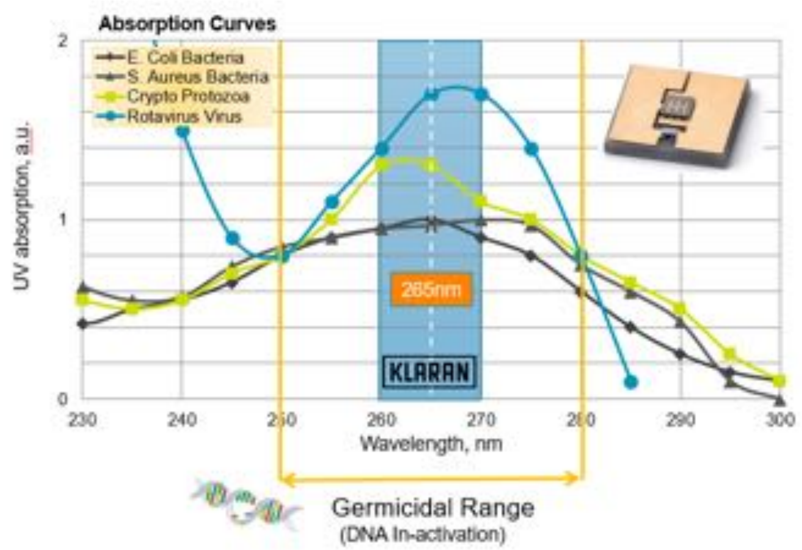


Appendix B: A Study of UVC LEDs on plastics done by Crystal IS

Prepared by Dr. Rajul Randive, Application Director, Crystal IS

This document provides an initial technical feasibility on the effects of long term UVC exposure on "normal use" testing of Cleanbox Technology, Inc. engineering of UVC LEDs for surface disinfection, equal to three years of regular use on the [redacted] (commonly used AR headset) to determine degradation risks on plastics, polymers, glass and lenses.

Light at 265nm provides the most efficient disinfection performance. This represents an important margin of safety when designing for a specific disinfection performance target that relies on referenced dosage values (typically at 254nm).



- ➢ UVC LEDs at 265nm reduce the uncertainty from production tolerances and ensure consistent germicidal performance.

Overall Summary

Two different materials were obtained from Cleanbox Technology for the exposure study with three samples of each material. Once the exposure was started, Crystal IS staff visually monitored the material and kept photo records of the material to evaluate any impact on the material (typically a color change) or any obvious material degradation.

Test Parameters

UVC irradiance (power intensity) range at part surface: 0.5-0.6 mW/cm2
Exposure time: (1 minute per each sanitization session) x (10 sessions daily) x (5 work days per week) x (52 weeks per year) x (3 years) = 7800 minutes or 130 hours

We took the images of the material before the testing started as shown below in figure 1.

Figure 1: Day 1 before exposing the materials to UV light

We placed the material in a UV box and adjusted the height to get to the intensity level of 0.5 to 0.6mW/cm2. The measurement of the intensity was done by using Gigahertz Optiks X1-1 irradiance meter which is calibrated for 265nm LEDs. The LEDs that were used for the testing were “U” bin Klaran UVC LEDs manufactured by Crystal IS which are the same power and strength of the LEDs that are currently used in any of the Cleanbox disinfecting units.

After operating the LEDs for 4 days of continuous operation (~96hrs), the UV light was turned off and the visual observation was made to see if there is any indicator on the color change. We did not observe any color change and we also took the following images on day 4 as shown in Figure 2

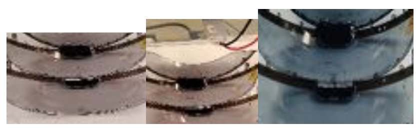


Figure 2: Images of plastic material after exposure for 4 days with 0.5 – 0.6 mW/cm2 of UV light

After the measurements were completed the material was put back under UV light for further exposure and was exposed for additional 4 days. (~96 hrs). After the exposure of additional 96 hrs the images were taken as shown in figure 3 and then they were packed and shipped back to Cleanbox.

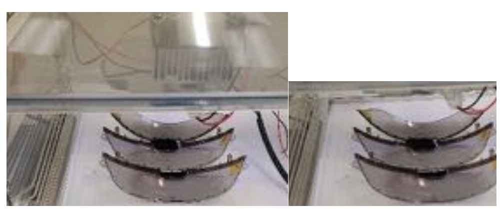


Figure 3: Another 96hrs of exposure

Observation and Conclusion

Thus, after a total of 192hrs of exposure under an intensity of 0.5 – 0.6 mW/cm2, a cumulative dosage of 345600 mJ/cm2 was applied to the plastic material. We did not see any sign in wear and tear on the material with that dosage in that duration. The testing which was carried out was an aggressive form of testing as the material will not be exposed to such continuous UVC light for such an extended period of time and exposure time was well beyond the requested 130 hours of constant exposure.

The material that was exposed should be observed under microscope to see if there was any material degradation but none was obvious to the human eye.

***Note from Cleanbox Technology, Inc.: Tested materials were returned to Provider for microscopic evaluation and confirmed by Provider to be of acceptable market quality post-testing. UVC impact was evaluated to be non-detrimental to the product and materials.**

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Definitions

Assay: An analysis done to determine the presence and amount of a substance

Extremophile: A microorganism, especially an archaean, that lives in conditions of extreme temperature, acidity, alkalinity, or chemical concentration. Extremophiles have been found depths of 6.7 km inside the Earth's crust, more than 10 km deep inside the ocean—at pressures of up to 110 MPa; from extreme acid (pH 0) to extreme basic conditions (pH 12.8); and from hydrothermal vents at 122 °C to frozen sea water, at −20 °C.

Inoculum: A substance used for inoculation

Inverse square law: The inverse square law dictates that a physical quantity is inversely proportional to the square of the distance from its source.

Joules: A Joule is a cumulative measure of the total amount of energy delivered (analogous to total gallons of water delivered)

LED: A light-emitting diode (a semiconductor diode which glows when a voltage is applied)

Mercury Bulb: A mercury-vapor lamp (bulb) is a gas-discharge lamp that uses an electric arc through vaporized mercury to produce light

Nanometer: A nanometer is a unit of length in the metric system equal to one billionth of a meter

Ozone: A highly reactive gas found in the earth's upper and lower atmosphere. When UVC reaches the earth's stratosphere and is absorbed by oxygen, the UVC splits oxygen molecules into oxygen atoms which react with other oxygen molecules to produce ozone.

Photon: A particle representing a quantum of light or other electromagnetic radiation. A photon carries energy proportional to the radiation frequency but has zero rest mass.

TCID50 assay: Median Tissue Culture Infectious Dose, a method used to verify viral titer, signifying the concentration at which 50% of cells are infected when a when a well plate upon which cells have been cultured is inoculated with a diluted solution of viral fluid.

UV Spectrum: Ultraviolet light (UV light) refers to the region of the electromagnetic spectrum between visible light and X-rays.

Watt: A Watt is a measure of the rate of energy delivery (analogous to gallons-per-minute flow rate for water delivery).