**Chapter 2**

**Ultraviolet Disinfection**

According to Childress J. (2021), the 254-nm UV light and 222-nm UV are germicidal light wavelengths that inactivate bacteria and viruses. Like standard 254-nm UVC, 222-nm UV light breaks the DNA bonds inside a microbe’s nucleus, which can prevent microbes from replicating. Furthermore, 222-nm UV is highly absorbed by protein bonds in the membrane shells of microbes and human cells. This protein interaction makes 222-nm light effective at defeating microbes and much safer than 254-nm UV for human exposure. The data indicates that 222-nm light is much safer for humans than 254-nm light. This can allow 222-nm UV to be safely used when humans are present.

According to Childress J. (2021), Not all UV light is the same. Some UV wavelengths are better than others at disinfection, and some are safer for humans. Invisible to the human eye, UV is light at wavelengths shorter than 400 nm and greater than 100 nm. The UV spectrum is broken into sub-bands of UVA, UVB, and UVC. The UVA waveband is nearly visible and commonly called black light. UVB, a slightly shorter wavelength, is a major factor in getting sunburned and can cause skin cancer. Both UVA and UVB easily enter the earth’s atmosphere and are present in sunlight. On the other hand, the UVC wavelengths, which are shorter than UVB, are blocked by the ozone in the earth’s upper atmosphere and not typically present in sunlight at the earth’s surface. This is important for germicidal effectiveness because it means microbes have fewer defenses against the shorter UVC wavelengths. Even within this UVC band, not all light is the same. According to studies at Columbia, UV light at the 222-nm wavelength has similar germicidal capabilities of the more widely used 254-nm UV light to kill or inactivate microbes (bacteria and viruses), but it does not produce the same damaging effects on skin or eyes as 254-nm light. This improved safety is because the shorter 222-nm UV wavelength has reduced penetration depth in human tissue. While the negative effects on humans are reduced, 222-nm light has increased performance for killing some bacteria and viruses.

According to Childress J. (2021), the output intensity of the 222 nm lamp can be varied by changing the input power, allowing the lamp to be instantly brightened or dimmed as required. Depending on design, excimer lamps can be run at power levels from as low as a few watts to kilowatts. To improve human safety even further, an optical filter can be added to remove small amounts of harmful wavelengths that might also have been generated above 230 nm.

Light from UVC systems is absorbed by DNA. The absorption of UVC by the DNA of a virus or bacteria damages its DNA, preventing the microbe from replicating. A microbe that cannot make copies of itself cannot cause harm. The 254-nm UV is highly absorbed by DNA but not easily absorbed by protein. This means that 254-nm light penetrates deeper into layers of protein-rich skin cells. While 254-nm UV damages microbe DNA, it can also penetrate deeper into human skin and damage the DNA of actively dividing skin cells. Damaged DNA in actively dividing human cells can lead to cancer (Childress J., 2021).

Furthermore, the 222-nm UV, on the other hand, is highly absorbed by both proteins and DNA. The outer membrane shell of all bacteria and viruses contains protein. Thus, 222-nm UV interacts not only with the DNA of the microbe but also the outer membrane shell of the microbes. Compared to 254-nm UVC, this dual mechanism of both DNA damage and protein shell interaction can increase the effectiveness of 222-nm UV against some microbes. It also makes it safer for humans.

All cells are rich in protein. Since 222-nm light is highly absorbed by protein, it cannot penetrate very far into thick layers of cells. The 222-nm light will fully penetrate viruses and bacteria but cannot penetrate the thick protein-rich outer layer of the skin, which is composed of dead skin cells. The outer layer of dead skin cells contains no active cells and much thicker than the largest bacteria or virus. This layer acts as an armor against 222-nm light. A similar outer protection layer of cells, the tear layer, protects the eyes. This makes 222-nm UV much safer for humans because the 222-nm light never reaches the DNA of active cells dividing inside the body. Since the 222-nm light does not reach actively dividing cells, it cannot cause cancer.

According to Geiger, the Duke Health researchers are using a portable machine called “Tru-D SmartUVC” to disinfect rooms of the patients. They have observed that there are bacteria that remained inside the patient rooms because of the patient that carried the organism inside the room. These bacteria are harmful because it can also affect the next patients that will occupy the same room. They have proven the effectivity of the usage of UVC lights using their portable machine as it not only disinfects patient rooms from viruses, they can also eradicate superbugs such as MRSA or Methicillin-resistant Staphylococcus aureus.

According to a study by Nozomi et al. (2020), 222-nm UVC lamps can be safely used for sterilizing human skin as far as the perspective of skin cancer development. Germicidal lamps that emit primarily 254 nm ultraviolet radiation (UV) are routinely utilized for surface sterilization but cannot be used for human skin because they cause genotoxicity. As an alternative, 222-nm UVC has been reported to exert sterilizing ability comparable to that of 254-nm UVC without producing cyclobutane pyrimidine dimers (CPDs), the major DNA lesions caused by UV. However, there has been no clear evidence for safety in chronic exposure to skin, particularly with respect to carcinogenesis. Nozomi et al investigated the long-term effects of 222-nm UVC on skin using highly photocarcinogenic phenotype mice that lack xeroderma pigmentosum complementation group A (Xpa-) gene, which is involved in repairing of CPDs. CPDs formation was recognized only uppermost layer of epidermis even with high dose of 222-nm UVC exposure. No tumors were observed in Xpa-knockout mice and wild-type mice by repetitive irradiation with 222-nm UVC, using a protocol which had shown to produce tumor in Xpa-knockout mice irradiated with broad-band UVB. Furthermore, erythema and ear swelling were not observed in both genotype mice following 222-nm UVC exposure.

According to Buonanno et al. (2020), a direct approach to limit airborne viral transmissions is to inactivate them within a short time of their production. Germicidal ultraviolet light, typically at 254 nm, is effective in this context but, used directly, can be a health hazard to skin and eyes. By contrast, far-UVC light (207–222 nm) efficiently kills pathogens potentially without harm to exposed human tissues. to Buonanno et al. (2020) demonstrated that 222-nm far-UVC light efficiently kills airborne influenza virus and we extend those studies to explore far-UVC efficacy against airborne human coronaviruses alpha HCoV-229E and beta HCoV-OC43. Low doses of 1.7 and 1.2 mJ/cm2 inactivated 99.9% of aerosolized coronavirus 229E and OC43, respectively. As all human coronaviruses have similar genomic sizes, far-UVC light would be expected to show similar inactivation efficiency against other human coronaviruses including SARS-CoV-2. Based on the beta-HCoV-OC43 results, continuous far-UVC exposure in occupied public locations at the current regulatory exposure limit (~3 mJ/cm2/hour) would result in ~90% viral inactivation in ~8 minutes, 95% in ~11 minutes, 99% in ~16 minutes and 99.9% inactivation in ~25 minutes. Thus, while staying within current regulatory dose limits, low-dose-rate far-UVC exposure can potentially safely provide a major reduction in the ambient level of airborne coronaviruses in occupied public locations.

According Kitagawa et al. (2020), the effectiveness of 222-nm UVC irradiation on viable SARS-CoV-2 suggest that this technology could be used for infection prevention and control against COVID-19, not only in unoccupied spaces but also occupied spaces.

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes coronavirus disease 2019 (COVID-19), has emerged as a serious threat to human health worldwide. Efficient disinfection of surfaces contaminated with SARS-CoV-2 may help prevent its spread. Kitagawa et al. (2020) aimed to investigate the in vitro efficacy of 222-nm far-ultraviolet light (UVC) on the disinfection of SARS-CoV-2 surface contamination.

Kitagawa et al. (2020) investigated the titer of SARS-CoV-2 after UV irradiation (0.1 mW/cm2) at 222 nm for 10-300 seconds using the 50% tissue culture infectious dose (TCID50). In addition, they used quantitative reverse transcription polymerase chain reaction to quantify SARS-CoV-2 RNA under the same conditions.

One and 3 mJ/cm2 of 222-nm UVC irradiation (0.1 mW/cm2 for 10 and 30 seconds) resulted in 88.5 and 99.7% reduction of viable SARS-CoV-2 based on the TCID50 assay, respectively. In contrast, the copy number of SARS-CoV-2 RNA did not change after UVC irradiation even after a 5-minute irradiation.

The study shows the efficacy of 222-nm UVC irradiation against SARS-CoV-2 contamination in an in vitro McLeod (2020)

According to Buonnano et al., the exposure of 222nm can efficiently and safely inactivate the coronaviruses that will then become harmless for human interaction. It is said in their study that 254 nm is used more often in disinfecting coronavirus but can be harmful for humans due to its radiation. They demonstrated that 222 nm of UVC light can also efficiently inactivate the virus but is less harmful to humans unlike 254 nm. 1.7 and 1.2 mJ/c^2 doses of the 222 nm inactivated 99.9% of the aerosol coronaviruses and other human coronaviruses like SARS-CoV 2.

According to Garcia et al., UV-C (Ultraviolet C) lights are proven to sanitize different surfaces reached by the said lighting and can also eradicate different viruses and bacteria such as escherichia coli. With only 10 minutes of exposure to the said light with the intensity of 0.15 - 0.4 W/m^2, it is proven to remove harmful bacteria such as e-coli. UV-C is capable of inactivating the bacteria within the 167cm distance from the UV-C lamp. Though UV-C was proven and tested to sanitize surfaces from dangerous bacteria, the researchers said that the application of manual sanitation will make the UV-C lights most effective.

Based on the “Guidelines on UV Disinfection” by the Philippine Dermatology Society, the usage of UVGI (Ultraviolet Germicidal Irradiation) has captured the interests of different groups in efforts of reducing the spread of infection that transfers itself to another host by the means of touching or getting exposed to an infected item wherein a person uses or interacts a device or item that a Covid-19 infected person has previously used. UVGI is currently being used to disinfect the air and surfaces in the attempt of providing extra precaution to people given that PPEs (Personal Protective Equipment) are not enough for the people working in the medical fields. Although UV exposure being dangerous to a person is a fact, with proper dilution of the radiation, it can be used to eradicate viruses at a microscopic level. With a dosage of 0.5 - 1.8 J/cm^2, viruses such as influenza (H1N1, H5N1, H7N9), MERS-CoV, and SARS-CoV are proven and tested to be disinfected and has little to no effect to other people. Though such viruses can be disinfected with only 0.5 J/cm^2, other authors urged the need to use at least 1 J/cm^2 on all surfaces to ensure the safety of the medical workers and prevent any exposure to lingering viruses attached to a surface.

According to Ramos et al. (2020), Because of its efficiency as a germicidal agent, UV-C has been proven to be a useful addition to terminal manual cleaning. More research is needed to establish a safe exposure dose standard, particularly for 222 nm germicidal lamps. Any targeted deployment of UV-C during the Coronavirus Disease 2019 (COVID-19) epidemic requires direct evidence.

According to Miranda et al. (2020) there has been research on the effectiveness of land mobile devices using UV technology in removing and deactivating pathogenic germs from contaminated surfaces in public areas by 60%. Only 40% of the studies included in this review found insufficient scientific evidence to establish the impact of UV technology on disease control in affected areas. This leads to the conclusion that there is enough research on the positive usage of this sort of technology in the control of contaminated area disinfection.

According to Eubania et al. (2021) Various UV-C lamps and Pulsed Xenon UVC (PX-UV) lamps were utilized in twelve research, including one cluster RCT, seven quasi-experimental studies, and four uncontrolled before and after studies. Because of research design flaws, imprecision, and a significant likelihood of bias, the overall certainty of evidence from these 12 studies was rated low. Only one study found a 44% decrease in viral infections among pediatric patients at that clinic. In ten of the 12 studies, UV-C was found to be an effective supplement to existing cleaning techniques, with the latter proving to be significantly more effective at eradicating bacteria.

Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA) are the genetic materials that make up all living organisms. These are responsible for controlling the growth, development, functioning, and the reproduction of these organisms. These acids that make up all living organisms can be damaged by UV radiation. UV or Ultraviolet radiation produces electromagnetic energy that can disrupt an organism’s ability to reproduce and when prolonged exposure occurs, it can lead to permanent inactivation and can lead to either mutation or cell death (VioletDefense.com).

According to Ploydaeng et al., since mid-18th century, there have been studies relating to UV-C lights and their capacity to prevent microbial growth. UV-C lights are mostly absorbed by DNA and RNA of an organism which can make them unable to produce and will eventually lead to mutation and/or cell death. The radiation frequently causes thymine and cytosine, two pyrimidine nucleoside bases, to cross-link and become non-pairing bases in the same DNA strand. Cyclobutyl pyrimidine dimers are the most prevalent photoproducts in DNA (CPD). By interfering with DNA replication, transcription, and translation, this product impairs cellular activity, which in turn causes bacterial cell death and viral inactivation.

MDR or Multidrug-Resistant Pathogens are one of the reasons why there are certain increases in mortality rates. The number of these pathogens is significant to the increase of deaths because these make it harder for professionals to cure their patients when they are inflicted with these pathogens that are resistant to drugs such as antibiotics. Researchers Yang et al. conducted research regarding these pathogens and their reaction towards UV-C lights especially to those MDR pathogens that are common in hospital areas. They exposed MDR-Pseudomonas aeruginosa, MDR- Acinetobacter baumannii, methicillin-resistant Staphylococcus aureus (MRSA), vancomycin-resistant Enterococcus faecium (VRE), Mycobacterium abscessus and Aspergillus fumigatus to UV-C lights and observed if there will be an effect to these pathogens. The research concluded that UV-C light can deactivate and kill these MDR pathogens after the 15-minute-long exposure to UV-C light.

According to Kodoth et. Al. (2020), “Ultraviolet (UV) radiation is known to inhibit cell growth and induce gene damage. For these reasons, UV radiation is used as a method to sterilize surgical instruments because it kills the bacteria present and disrupts bacterial reproduction. Infections acquired from hospitals, particularly post-surgical infections, have become increasingly common, and require the use of UV disinfection systems”. The study investigated the effect of UV light on Escherichia coli (E. coli). Specifically, the study explored the effects of the small UV lights currently used in school laboratories, in an attempt to extend UV radiation methods to common households. Kodoth et. Al. (2020) used the number of colony-forming units (CFUs) to determine whether or not the UV light increases or decreases cell growth. E. coli were exposed to UV light with a wavelength of 254 nm. The number of CFUs under control and UV-exposed conditions were measured after 24 and 48 hours. It is observed that UV light exposure at 254 nm from a small school laboratory light inhibits bacterial growth.

Pullerits et. Al. (2020) investigated that water in a full-scale drinking water treatment plant and irradiated with ultraviolet (UV) doses of 250, 400, and 600 J/m2, and the effect on bacterial communities investigated using 16s rRNA gene amplicon sequencing, heterotrophic plate counts (HPCs), coliform, and Escherichia coli counts. The bacteria in the irradiated water were also analyzed following storage for 6 days at 7 °C, to approximate the conditions in the distribution system. The log10 reduction of HPCs at 400 J/m2 was 0.43 ± 0.12. Phylogenetic examination, including DESeq2 analysis, showed that Actinobacteria was more resistant to UV irradiation, whereas Bacteroidetes was sensitive to UV. Phylum Proteobacteria contained monophyletic groups that were either sensitive or resistant to UV exposure. The amplicon sequence variants (ASVs) resistant to UV irradiation had a greater average GC content than the ASVs sensitive to UV, at 55% ± 1.7 (n = 19) and 49% ± 2.5 (n = 16), respectively. Families Chitinophagaceae, Pelagibacteraceae, Holophagaceae, Methylophilaceae, and Cytophagaceae decreased linearly in relative abundance, with increasing UV dose (P < 0.05, Pearson’s correlation). When irradiated water was stored, Chitinophagaceae, Comamonadaceae, and Flavobacteriaceae families decreased in relative abundance, whereas ACK-M1, Mycobacteriaceae, and Nitrosomonadaceae were increasing in relative abundance. This suggests that the impact of UV irradiation cannot only be considered directly after application but that this treatment step likely continues to influence microbial dynamics throughout the distribution system.

The number of multidrug resistant pathogens is significantly proportional to the mortality rate is as stated by Yang J. et al. (2019). The transmission of these pathogens can be reduced dramatically through environmental cleaning. Hospitals encouraged the enhancement of the effectiveness of disinfection and conducted an experiment wherein different MDR pathogens were exposed to a disinfection robot which uses UV C light. The results showed that there has been a significant reduction in the number of colonies of the exposed MDR pathogens.

Dr. Anthony Griffiths, an associate professor from Boston University school of Medicine, and his team conducted research to find out the Ultraviolet C dosage needed to inactivate different bacteria and viruses. The dosage is proportional to the time the UV C is used to expose a surface. The experiment included Coronavirus. The results showed that all bacteria and viruses can be inactivated by UV C exposure and only differ on the time exposure to inactivate them. The coronavirus needed 3 J/m^2 to be inactivated which is a humble amount of dosage compared to other bacteria and viruses listed along with it.

Ultraviolet (UV) light is a type of radiation from the sun that has less energy than X-rays and gamma rays. The sun produces three spectrums of light namely, UVA, UVB, and UVC. A person can only absorb UVA and UVB lights from the sun because UVC is absorbed by the ozone layer. UV C lights are germicidal lights that are manmade and can kill bacteria and viruses and that includes SARS (severe acute respiratory syndrome) COV(Coronavirus)2 which is a beta coronavirus that is from the family of MERS (Middle East Respiratory Syndrome) and SARS (severe acute respiratory syndrome). As stated in light-sources.com (2021), UV C light can kill viruses in surfaces, air, and in water.

According to Helingloh, high vulnerability to UV light was shown for SARS-CoV-2. SARS-CoV-2 was completely inactivated at a dose of 5 106 TCID50/mL after 9 minutes of combined UVA and UVC irradiation. According to nonlinear regression calculations, 50% of the virus may become inactive after 1.4 minutes of UV exposure. Viral inactivation was less successful when only exposed to UVA. 1 log reduction in the viral load was seen after 9 minutes of radiation at a dosage of 292 mJ/cm2. On the other hand, full viral inactivation was attained after 9 minutes of UVC exposure and a 1048 mJ/cm2 UVC dose. These results emphasize UVC irradiation as a successful approach for the inactivation of SARS-CoV-2 and support earlier findings that UVC is more effective in inactivating viruses.

**Time to Inactivate Microorganisms**

According to the Americanultraviolet (2022), the effectiveness of UVC light is based on the variables of time or the length of exposure, intensity of the source, and the distance or how far the source is from the target. Different microorganisms require various levels of UVC for inactivation and it rest on how the bacterial cell is built.

**UVC Direct Exposure**

According to the U.S Food & Drug Administration (2022), there are also limitations to how effective UVC radiation can be at inactivating viruses, generally. UVC radiation can only inactivate a virus if the virus is directly exposed to the radiation. Therefore, the inactivation of viruses on surfaces may not be effective due to blocking of the UV radiation by soil, such as dust, or other contaminants such as bodily fluids. Many of the UVC lamps sold for home use are of low dose, so it may take longer exposure to a given surface area to potentially provide effective inactivation of a bacteria or virus.

UVC radiation is commonly used inside air ducts to disinfect the air. This is the safest way to employ UVC radiation because direct UVC exposure to human skin or eyes may cause injuries, and installation of UVC within an air duct is less likely to cause exposure to skin and eyes. There have been reports of skin and eye burns resulting from improper installation of UVC lamps in rooms that humans can occupy.

**UV-C Penetrable Plastic & Materials**

According to Kosta G. (2020), short wave UV (UVC) cannot pass through most plastics or ordinary glass. Most acrylic plastics do not allow UV-C wavelengths (100-280 nm) to penetrate. Also, very thin acrylic sheets of below 5 millimeters do not let UVC light penetrate.

In addition, suitable transparent media do not exist anymore, limiting the choices to reflective optics such as Highly purified calcium fluoride(CaF2), Magnesium Fluoride (MgF2), Lithium Fluoride (LiF). UV-grade fused silica, Artificial diamond and Borate crystals. Two microbial culture technique has been utilized in the experiment.

**UVC Exposure Risks**

According to the FDA (2022), UVC radiation can cause severe burns of the skin and eye injuries (photokeratitis). Skin burns and eye injuries from UVC exposure usually resolve within a week with no known long-term damage. Since the penetration depth of UVC radiation is very low, the risk of skin cancer, cataracts or permanent vision loss is also thought to be very low. The type of eye injury associated with exposure to UVC causes severe pain and a feeling of having sand in the eyes. Sometimes people are unable to use their eyes for one to two days. It can occur after a very short exposure (seconds to minutes) to UVC radiation.

According to the FDA (2022), some UVC lamps emit small amounts of UVB radiation. Therefore, exposure to a high dose or prolonged low dose of radiation from some UVC lamps can potentially contribute to effects like cataracts or skin cancer that are caused by cumulative exposure to UVB radiation.

Additionally, some UVC lamps generate ozone which could cause irritation to breathing passages (that is nose, throat, and lungs), particularly for those who have respiratory sensitivity such as asthma or allergies. Exposure to high levels of ozone gas may also worsen chronic respiratory diseases, such as asthma, or increase vulnerability to respiratory infection.

According to the FDA (2020), UVA and UVB rays can cause damage to the skin. Sunburn is a sign of short-term overexposure, while premature aging and skin cancer are side effects of prolonged UV exposure.

There is no considerable natural irradiation of humans on Earth because UVC is strongly reduced by air gases. It is likely that more human exposures will occur with increased germicidal applications of man-made UVC radiation, perhaps especially in hospital settings where there is a strong concern about the spread of harmful bacteria, and future studies may show some links with disease that we have not yet identified. Since UVC radiation can harm the eye's superficial tissues, it is important to take precautions to limit eye exposure to UVC radiation. According to Chabot G., though extreme discomfort will be brought to the eye when exposed, the symptoms usually subside in a short time and no persisting malignant effects have been ever noted yet.

Of the three types of UV, UVC has the shortest wavelength. UV radiation is more damaging the shorter the wavelength. Fortunately for humans, UVC cannot enter the atmosphere of the earth. As a result, even though UVC has the shortest wavelength and is therefore the most damaging, it poses little risk to the average person because UVC rays from the sun don't penetrate skin. Keep in mind that they don't even normally enter the atmosphere of the earth. The ozone layer entirely absorbs UVC. According to stouchlighting.com, although UVC is more dangerous than UVA and UVB because of its shorter wavelengths, the ozone layer usually absorbs most of the UVC but certain precautions should be taken when recreating UVC lights with manmade devices.

As stated by fda.gov, UVC rays can result in severe skin burns and eye damage (photokeratitis). Never stare directly at a UVC light source, not even momentarily. Avoid direct skin exposure to UVC radiation. UVC exposure commonly results in skin burns and eye problems, but there is no known long-term harm. The danger of developing skin cancer, cataracts, or irreversible eyesight loss is also believed to be very minimal due to the limited penetration depth of UVC radiation. The form of eye injury linked to UVC exposure results in excruciating pain and the sensation that sand is in the eyes. Sometimes people lose the ability to see for a day or two. It can happen after a brief (seconds to minutes) exposure to UVC rays.

According to Cesarini et al, human protection from transmission of airborne diseases including tuberculosis germs, influenza viruses, and other aerosolized agents is being provided by UV-C (100 nm - 280 nm) mediated air disinfection, which primarily utilises 254 nm radiant radiation from low-pressure mercury lamps. For some UV-C applications, room air must be directly exposed in a horizontal plane right above occupants' heads. There is a chance that reflected or dispersed UV-C radiation from these environments could expose people to it. Overexposure to UV-C radiation has been linked to temporary skin irritation (erythema) and corneal and conjunctival irritation (photokeratoconjunctivitis), which go away in 24 to 48 hours and are not yet known to cause long-term biological harm. The right installation of well-engineered UV-C systems satisfies the 6 mJcm-2 (60 Jm-2) threshold limit for 8 hours of continuous exposure to UV-C radiation at 254 nm. Poor installations have occasionally caused unintentional UV-C overexposures. Open air UV-C systems have come under fire for their safety due to generalizations that claim all UVR is carcinogenic. Although UV-C radiation is carcinogenic according to fundamental biophysical principles for the same reason that it is a powerful germicide, attenuation provided by the stratum corneum and epithelial tissues of the skin significantly lowers the risk compared to UV-B radiation. With minimal chance of long-term delayed consequences such skin cancer, UV germicidal irradiation can be utilized to safely and effectively disinfect upper air.

**Ultraviolet Disinfection Machines**

Paras E. (2020), created a device called Parazap, a portable Ultraviolet room disinfection unit that is electrically operated. The device is designed to disinfect PPEs, specifically N95 masks, killing almost 99% of microorganisms by means of exposure to ultraviolet (UV) radiation. It consists of two sets of UV-C germicidal lamps having 15 and 18-wattage and can accommodate up to10 N95 masks in one cycle. The UV-C chamber can also be adjusted according to duration of exposure – from 60seconds to 60 minutes depending on the prescribed length of exposure to kill a certain type of microorganism. All of the materials in making the equipment were locally available.

Zakaria F. (2016), studied Ultraviolet germicidal (short wavelength UV-C) light as surface disinfectant in an Emergency Sanitation Operation System® smart toilet to aid to the work of manual cleaning. The UV-C light was installed and regulated as a self-cleaning feature of the toilet, which automatically irradiate after each toilet use. Two experimental phases were conducted i.e., preparatory phase consists of tests under laboratory conditions and field-testing phase. The laboratory UV test indicated that irradiation for 10 min with medium–low intensity of 0.15–0.4 W/m2 could achieve 6.5 log removal of Escherichia coli. Field testing of the toilet under real usage found that UV-C irradiation was capable to inactivate total coliform at toilet surfaces within 167-cm distance from the UV-C lamp (UV-C dose between 1.88 and 2.74 mW). UV-C irradiation is most effective with the support of effective manual cleaning. Application of UV-C for surface disinfection in emergency toilets could potentially reduce public health risks.

Alba et. Al. (2021) examined the microbicidal activity of ultraviolet (UV)-C185–256-nm irradiance (robot 1) and ozone generated at UV-C 185-nm by low-pressure mercury vapor lamps (robot 2) adapted to mobile robotic devices for surface decontamination, which was achieved in less than 1 h. Depending on their wall structure and outer envelopes, many microorganisms display different levels of resistance to decontaminating agents. Thus, the need for novel disinfection approaches is further exacerbated by the increased prevalence of multidrug-resistant bacteria, as well as the potential of novel microorganisms, with the ability to cause disease outbreaks. To set up a rapid and effective approach for microorganism’s propagation prevention, Alba et. Al. (2021) focused on the effects of UV-C and ozone on a distinct microorganism survival ratio. A set of microorganisms, including Escherichia coli, Micrococcus luteus, Saccharomyces cerevisiae, Trichoderma harzianum, and Bacillus subtilis, were used to evaluate the disinfection power of UV-C and UV-C plus ozone generating robots. UV-C disinfection can be suited to ad hoc tasks, is easy to operate, requires low maintenance, does not have the need for the storage of dangerous chemicals, and does not produce by-products that may affect human health and the environment. The robotic cumulative irradiation technology developed (fluence accumulated values of 2.28 and 3.62 mJ cm−2, for robot 1 and 2, respectively), together with the production of ozone (with a maximum peak of 0.43 ppm) capable of reaching UV-C shaded surfaces, and analyzed in the study, despite being designed for the need to reduce the risk of epidemic outbreaks in real-life scenarios, represents a versatile tool that could be employed for air and surface disinfection within many circumstances that are faced daily.

Ewan Eadie and his team conducted research named “Far-UVC (222 nm) efficiently inactivates an airborne pathogen in a room-sized chamber” which utilizes 5 Krypton Chloride excimer lamps which is known as Far-UVC which is proven to efficiently inactivate pathogens such as coronavirus and influenza in the air. These lamps can filter the intensity of the radiation and prevent lights that exceed 230 nm. According to Wells et al, pathogens travel on a downward slope. This was utilized in the chamber created by the research team and tested the air located at the lower section of the chamber. The results showed that the percentage of pathogens in the chamber drastically decreased at the 10-minute mark of exposure from the Far-UVC lamps.

It has been demonstrated that implementing environmental cleaning and disinfection reduces the prevalence of infections connected with healthcare. Following an evaluation of the current standard operating procedure (SOP), the effectiveness of an improved terminal room disinfection strategy using pulsed xenon-based ultraviolet light no-touch disinfection systems (PX-UVC) was determined. Five high-touch surfaces in various important sections of a teaching hospital were evaluated for their efficiency in lowering the total bacterial count (TBC) and removing high-concern microorganisms before and after cleaning and disinfection processes (345 sampling sites). Compared to 63 percent (72/115) following SOP, PX-UVC showed just 18 percent (15/85) of positive samples after treatment. The efficiency of PX-UVC was also seen when a chemical disinfectant was used in place of manual cleaning. According to the Italian Workers Compensation Authority's suggested hygienic criteria, 9 of 80 (11%) operating room surfaces exhibited TBC 15 CFU/24 cm2 following the SOP, while all samples were in compliance when the SOP was combined with PX-UVC disinfection. Only after the SOP were Klebsiella pneumoniae (KPC) and Clostridium difficile (CD) spores identified. With the PX-UVC treatment integrated, the usual cleaning and disinfection method yielded good results in reducing hygiene failures and controlling the environmental contamination by high-concern bacteria as stated by Casini B. (2019, October).

**Streak Plate Method**

According to Dahal (2022), the streak plate method is a microbiological culture technique where a sample is spread in a petri dish in the form of a long, thin line over the surface of solid media. The objectives of the streak plate method is to obtain a pure culture of bacteria from a mixed culture, obtain well-isolated colonies and propagate bacteria.

The streak plate method relies on dilution to produce well-isolated colonies of the sample at the terminal streaks during the mechanical spreading of inoculum over the surface of solidified culture media.

Sample can be either colony on solid media or suspension in broth. The most common tool used to collect the sample is a sterile inoculating loop or swab. A smear is created by placing the sample over a sterile solid media surface at the petri dish's edge. The smear is successively streaked over the agar media using the instrument in various patterns. The inoculum is gradually diluted as the streaking process goes on, resulting in the separation of bacterial cells as individual cells or as colony-forming units (CFU) at a spacing of a few millimeters. These inoculation plates will produce a well-isolated colony when they are incubated with the isolated bacterium or CFU. This will enable us to obtain a pure culture and define the organism's colony form.

**Spread Plated Method**

According to Dahal (2022), “The spread plate method is a microbiological laboratory technique for isolating and counting the viable microorganisms present in a liquid sample by spreading a certain volume of the sample over an appropriate solidified culture media”.

In a successful spread plate, distinct colonies will emerge after incubation in an even distribution throughout the surface of the culture media.This method is used to isolate and count all colony-forming units per milliliter (CFU/mL) of viable bacteria present in the sample. It also serves as a means of mass producing the outdated culture. It works with every culturable fungus and bacterium.

The objectives of spread plate method is to isolate the microorganisms from the liquid specimen (or suspension), calculate viable microbial load by counting colony formation unit (CFU) per mL, isolate the pure culture of microorganisms from a mixed population, isolate microorganisms in discrete colonies in order to study their colony characters and obtain sufficient growth for conducting antimicrobial sensitivity testing and biochemical studies (Dahal, 2022).

**Kirby Bauer Disc Diffusion Method for Antibiotic Susceptibility Testing**

According to Sharma (2022), “Kirby Bauer tests also known as the Disc diffusion test is used for antibiotic susceptibility testing”. The test is performed to determine the sensitivity or resistivity of aerobes or facultatively anaerobes against different classes of antibiotics. The aim of the method is to aid physicians to assist in selecting treatment options and to determine the ability of antibiotics to inhibit the organisms.

**Synthesis of the Reviewed Literature and Studies**

Since 222-nm light is both deadly to microbes and safer for humans, it has the potential to be used in applications where humans are present during UV disinfection while still remaining within government UV exposure guidelines. The 222-nm lights can be installed in ceilings or walls and turned on when needed for disinfection. The UV lamp installation can be as large as a fluorescent light or as small as a smoke detector, depending on the desired speed of disinfection. The applications are limitless. A few examples include health facilities, visitor areas, office areas, food service areas, lavatories, and transport vehicles of all types (Figure 5). Almost any communal space can benefit from safe and effective disinfection that is automatic and uses no chemicals. Indicating the potential of 222-nm UV disinfection.

Source:

Cesarini, J.-P. (2019). UV-C photocarcinogenesis risks from germicidal lamps. CIE. Retrieved July 25, 2022, from <https://cie.co.at/publications/uv-c-photocarcinogenesis-risks-germicidal-lamps>

Casini, B., & Tuvo, B. (2019, September 24). Evaluation of an ultraviolet C (UVC) light-emitting device for disinfection of high touch surfaces in hospital critical areas. International journal of environmental research and public health. Retrieved July 25, 2022, from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6801766/>

Ultraviolet (UV) radiation. American Cancer Society. (2019). Retrieved July 25, 2022, from <https://www.cancer.org/healthy/cancer-causes/radiation-exposure/uv-radiation.html>

FDA. (2020). Ultraviolet (UV) radiation. U.S. Food and Drug Administration. Retrieved July 25, 2022, from <https://www.fda.gov/radiation-emitting-products/tanning/ultraviolet-uv-radiation>

Staff. (2020, September 14). What is the difference between UVA UVB UVC? which is most dangerous? LED Lighting Distributor and Implementation Company. Retrieved July 24, 2022, from <https://www.stouchlighting.com/blog/uva-uvb-uvc-differences>

Baes, F. (n.d.). Hps.org. Health Physics Society. Retrieved July 24, 2022, from <https://hps.org/publicinformation/ate/q9450.html>

Heilingloh, C. S., Aufderhorst, U. W., & Schipper, L. (2020, August 4). Susceptibility of SARS-COV-2 to UV irradiation. American Journal of Infection Control. Retrieved July 24, 2022, from <https://www.ajicjournal.org/article/S0196-6553(20)30756-2/fulltext>

LightSources. (2022, January 2). Does UV light kill covid-19? LightSources. Retrieved July 24, 2022, from <https://www.light-sources.com/blog/does-uv-light-kill-covid/>

Griffiths, A. (2022, June 30). UV-C dose required to kill microorganisms. UV Light Technology. Retrieved July 24, 2022, from <https://uv-light.co.uk/uv-dosage-required-to-kill-microorganisms/>

Yang, J.-H., Wu, U.-I., Tai, H.-M., & Sheng, W.-H. (2019, September 18). Effectiveness of an ultraviolet-C disinfection system for reduction of healthcare-associated pathogens. Journal of Microbiology, Immunology and Infection. Retrieved July 24, 2022, from <https://www.sciencedirect.com/science/article/pii/S1684118217302001>