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Design and Fabrication of Portable PPE Kit Sterilization

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Abstract: ***Medical demands during the COVID-19 pandemic have triggered a grave shortage of medical-grade personal protective equipment (PPE), especially, N95 respirators. N95 respirators are critical for the personal protection of medical providers and others when being exposed to individuals with infections caused by the SARS- CoV-2 coronavirus. To address the shortage of PPE Kit & N95 respirators, innovative methods are needed to decontaminate coronaviruses from N95 respirators & PPE Kit, allowing them to be safely reused by healthcare workers. For this research, we use a commercial ozone disinfecting cabinet to examine the efficacy of ozone-based disinfection of a conservative surrogate virus for SARS-CoV-2/Ultra Violet radiation, Chlorination, washing with soap and heating are some methods of sterilizing. Ultra Violet light is the best sterilizing and disinfectant agent, used for domestic as well as clinical purpose. Food packets, books, stationery, medical equipment's, toys, electronic gadgets like mobile phones, laptops, wrist watches, etc. can be sterilized with UV radiation whereas other methods of sterilization cannot be used. UV light does not release any waste and is eco-friendly, if used in a controlled manner. UV radiation is a range of electromagnetic waves with shorter wavelength (high frequency and energy). The wavelength from 100-280 nm known as UV-C is the best disinfectant used for purifying water, air, sterilizing vegetables and surgical equipment's. Research has shown that UV-C wavelength can kill harmful fungi, protozoa, bacteria and viruses like SARS- CoV-2 Virus. The article describes the construction of a low-cost UV-C Sterilizer Box where UV radiation is taking place in a closed environment. Safety features are also incorporated to prevent humans from UV light exposure. The germicidal property of ultraviolet-C is well known. This review will cover the most commonly described methods for sterilization of PPE Kit, namely, ultraviolet germicidal irradiation. These techniques have been tested previously and have demonstrated efficacy in reducing or inactivating viral and bacterial pathogens, although testing against SARS-CoV-2 specifically has not been done. Moreover, it must be emphasized that proper disposal after a single use is still ideal under normal circumstances.***

Keywords: UV, UV-C LED, Sterilize, Ultraviolet-C; decontamination; N95 respirator; peracetic acid; SARS-CoV-2, ozone

I. INTRODUCTION

Personal protective equipment (PPE) is essential for protection of personnel and patients in healthcare settings. The pandemic of coronavirus disease 2019 (COVID-19) caused by severe asucute respiratory syndrome coronavirus 2 (SARS-CoV-2) has resulted in shortages of critical supplies, including PPE. These shortages have led many facilities to consider strategies to extend or reuse PPE, particularly N95 filtering facepiece respirators. The Centres for Disease Control and Prevention and the National Institute for Occupational Safety and Health (NIOSH) have provided guidance the acceptability of extended use or limited reuse of N95 respirators & PPE Kit. The guidance document includes a discussion of potential concerns regarding these practices,particularly the risk for contact transmission from touching a contaminated respirator. There is an urgent need for evidence regarding the effectiveness of decontamination strategies for PPE. The goal of the current study was to examine the effectiveness of UV-C light and a high-level disinfection cabinet for decontamination of PPE Kit & N95 respirators. For UV-C light, we studied a 1-minute cycle delivered by a UV-C decontamination box that could potentially be used for rapid decontamination. According to the Institute of Medicine (IOM), simple decontamination techniques mustbe evaluated based on several factors. These include efficiency in removing or inactivating pathogens, potential hazard to the wearer from chemical residues ornoxious fumes (off-gassing), cost, and ease of implementation in the workplace. In many cases, the efficiency of decontamination does not depend on the utilized method alone but also on the surface or material being sterilized. In addition, the ability of the target pathogen to survive on surfaces is an important consideration. SARS-CoV-2, the causative agent of COVID-19, has been found to remain viable on stainless steeland plastic surfaces for up to 72 hours, on copper for up to 4 hours, and on cardboard for up 58 to 24 hours. Another important element to consider is the effect of the decontamination procedure on the integrity of the PPE Kit. Certain sterilization techniques may degrade the polymers in PPE Kit thereby decreasing its ability to filter out aerosols. Still, others may leave filtration capacity intact but cause loosening of the elastic bands. This is nonetheless significant as proper fit is key in PPE Kit.

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II. AUTHOR WRITES

A. *Effectiveness of an Ozone Disinfecting and Sanitizing Cabinet to Decontaminate a Surrogate Virus for SARS-CoV-2 on N-95 Masks | Megan S. Beaudry (4 April 2020)*

Effectiveness of an Ozone Disinfecting and Sanitizing Cabinet to Decontaminate a Surrogate Virus for SARS-CoV-2 on N-95 Masks that the COVID-19 pandemic has dramatically reduced the availability of PPE. During this global emergency, decontamination and reuse of FFRs may be necessary when access to PPE is limited. We have demonstrated that ozone sterilization is an effective method for the decontamination of N95 mask materials. Decontamination of N95 mask materials with ozone sterilization cabinets resulted in > 3-log10 reduction in MS2, a conservative surrogate virus for SARS-CoV-2. Further research is needed to ensure that the integrity and performance of FFRs is maintained, even after decontamination with ozone.

B. *Ultraviolet-c and other methods of decontamination of 2 filtering facepiece n-95 respirators during the covid-19 pandemic | Henry W. Lim (24 April 2020)*

The current COVID-19 pandemic, extreme measures are needed to keep those on the front line protected. UVC, hydrogen peroxide, microwave, and dry heat systems are all viable options to kill microorganisms on N95 FFRs to enable their reuse. These options are cost-effective, quick to employ, and have the potential to save many lives and valuable resources. These methods have demonstrated good biocidal activity against many viruses including influenza, SARS-CoV and MERS-CoV however, their efficacy against the novel coronavirus SARS-CoV-2 specifically has not been tested. Given their novel use and development, further studies on these methods are needed. Additionally, many unverified variations of these techniques are being considered by health care institutions and individual providers, which can yield catastrophic results if incomplete decontamination is rendered to contaminated FFRs. Lastly, it must be emphasized that such measures should be employed only when absolutely necessary, and that proper discarding of disposable PPEs after a single use is still ideal.

III. METHODOLOGY AND UVC RADIATION APPLICATION

Ultraviolet Radiation is an electromagnetic wave with low wavelength and high energy lying between X-ray and Visible Light spectrum. The wavelength of UV rays is 400 nanometers to 100 nanometers. This spectrum is dividedinto UV-A, UV-B and UV-C bands. The wave length of UV-A is from 400nm to 315nm, UV-B is from 315nm to 280nm. UV-C radiation covers wavelength spectrum from 280 nm to 200 nm. The UV radiation below 200nm does not propagate in air andcan only pass-through vacuum, so this band is called Vacuum-UV. Ultraviolet germicidal irradiation (UVGI) with wavelength of 254 nm can kill or destroy the DNA of bacteria or virus like SARS-CoV-2 more efficiently, but this particular wavelength radiation can penetrate into human skin and eye and causes damage to both. But the far UV-C with wavelength between 222nm to 207nm, have almost similar germicidal properties and very less impact on human body. So, the disinfectant UV-C radiators are designed to operate in this spectrum.

UV-C Radiation can be generated using low-pressure mercury lamp or UV-C LED. After applying high voltage across it, the specially made UV-C lamp creates an electricarc inside and excites mercury atoms to vaporize. Wavelength of radiated UVC depends on the quantity of mercury and vapor pressure inside the tube.

Ultraviolet germicidal irradiation (UVGI) is a method to disinfect disposable PPE Kit for reuse. This technique employs the germicidal property of ultraviolet-C (UVC), which has been utilized in the decontamination of water, air, and various surfaces. In the hospital setting, UVC systems are often used to disinfect objects which cannot be immersed in liquid biocides as well as for disinfecting high touch surfaces. The mechanism underlying UVGI is the absorption of photons by microbial nucleic acids, causing formation of pyrimidine photoproducts which subsequently damage deoxyribonucleic acid (DNA), prevent replication, and inactivate microorganisms.

The configuration of the surface being treated is also an important factor that influences UVC dosage. Since UVC is primarily a surface decontaminant, shadowed areas may not be adequately reached by the light source thereby receiving suboptimal doses of UVC. Accordingly, any obstruction between the radiation source and the target can absorb UVC and decrease the effective dose received by the target. The dose received by the target also decreases with increasing distance from the source.

Because UVC radiation degrades polymers, there exists the possibility for UVGI to decrease the efficacy of PPE Kit and therefore the afforded protection. A study in which four different PPE Kit underwent UVGI doses of 120-950 J/cm2 revealed a small increase in particle penetration (up to 1.25%) with little effect on flow resistance. In addition, at higher doses, the respirator material strength was significantly reduced (sometimes >90%), but this varied greatly between the different models. At a dose of 2360 J/cm2, 100-1000x higher than the dose known to disinfect H1N1, the breaking strength of the straps were reduced by 20-51%

The ongoing COVID-19 pandemic and imminent threat to PPE Kit supplies has triggered a rapid emergence of many different

UVGI devices and manufacturers. Some involve hanging of the PPE Kit in an enclosed UVC unit (Orbitform Mask Sanitizer, Orbitform Medical, Michigan), while others utilize a tray to irradiate PPE Kit under a desktop UVC unit and require flipping of the PPE Kit in order to expose both exterior and interior surfaces (Daavlin Desktop UVC Germicidal Lamp, Daavlin, Ohio). It is important to emphasize that only UVC units with validated dosimetry should be used. As not all devices are built the same, incorrect dosing may confer the risk of inadequately killing viral pathogens and pose serious hazards to health care workers. The effects of UVC on human health must also be considered. Unlike UVA and UVB, UVC does not penetrate deep into the tissue, hence, adverse effects are confined to the superficial layers of the skin and eyes. These include erythema, photokeratitis, and conjunctivitis. Although the long-term effects of excessive UVC exposure has not been fully established, the possibility of UV-induced carcinogenesis, cataract formation, and photoaging should be emphasized.

IV. OZONE PRODUCTION

When oxygen comes in the contact with UVC Lamp it slips into single molecule of ozone, that single molecule combine with O_2 and forms ozone.

V. CHOICE OF UVGI EXPOSURE DOSE

We chose 1.0 J/cm2 as a minimum UV-C dose formask decontamination, which is also consistent with recently released guidance from governmental and non-governmental agencies. The UV-C unit used at the VA Portland Health Care System delivers 1.0 - 2.0 J /cm2 to each PPE Kit.

VI. DESIGN AND CONSTRUCTION

First of all, wooden cabinet of (lxbxh)=(50x50x80) with one side door opening with hinges and door opening and locking with the help of doormagnetic catcher and one more wooden box of (lxbxh)=(14x14x50) for circuitry and dc fan. Now cover the edges with the help of sealing rubber and add 4 wheels on the cabinet and place hook on under the top of the cabinet drill the cabinet with suitable holes for circuitry and now place UVC lamp with adapter and attach to the cabinet with the help of UVC light holder in left right and middle of the cabinet attach a wiring to the adapter to connect to the circuitry also make a drill for a bulb holder make a connection up to the circuitry.

Now add ozone sensor to the cabinet for sensing the ozone level now at the second wooden box add circuitry and the wires of the cabinet and attach lcd display to it withozone sensor once the circuitry complete and aluminum foil inner surface of the cabinet and from outer add wall paper for better design.

And now hang the PPE Kit and start the process of sterilization wait for 240 seconds to sterilize and now PPE kit is free from all types of viruses and bacteria.

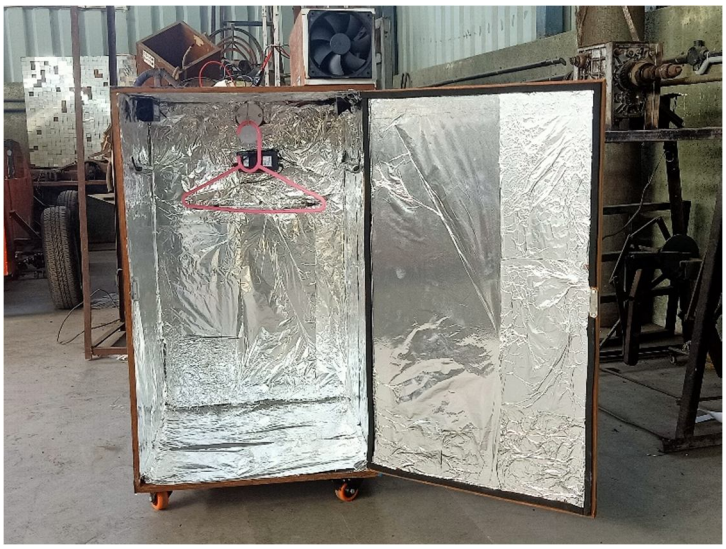


Fig. Model

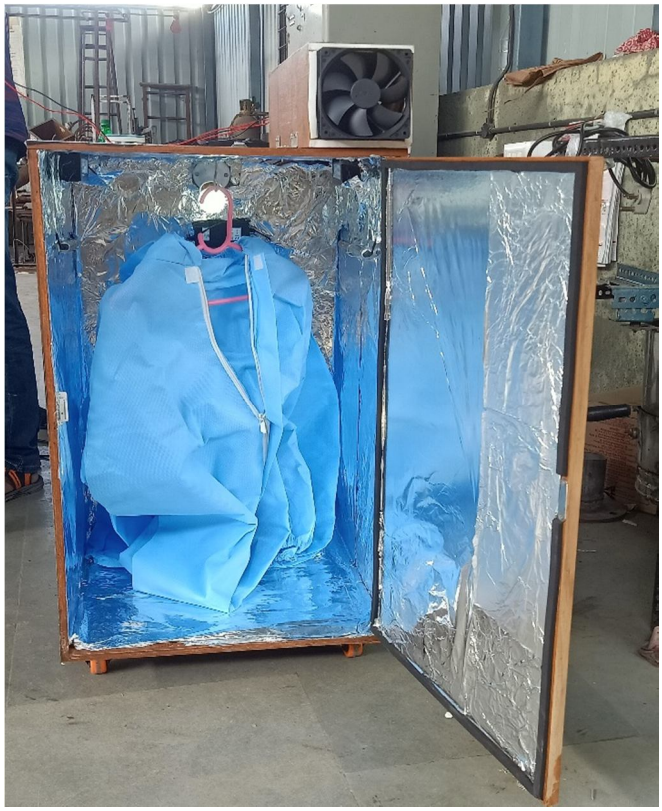


Fig. Testing with PPE Kit



Fig. Side view of the cabinet

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VII. COMPONENTS

A. UVC Lamp

UVC lamps used for disinfection purposes may pose potential health and safety risks depending on the UVC wavelength, dose, and duration of radiation exposure. UVC emits short wave UV radiation with a radiation peak at 253.7nm for germicidal Application.



Fig. UVC Lamp

B. LCD Display

An electronic device that is used to display data and the message is known as LCD 16×2. As the name suggests, it includes 16 Columns & 2 Rows so it can display 32 characters (16×2=32) in total & every character will be made with 5×8 (40) Pixel Dots.
16 X2 displays mostly depend on multi-segment LEDs. There are different types of displays available in the market with different combinations such as 8×2, 8×1, 16×1, and 10×2, however, the LCD 16×2 is broadly used in devices, DIY circuits, electronic projects due to less cost, programmable friendly & simple to access.



Fig. LCD Display

C. I2C Module

This chip converts the I2C data from an Arduino into the parallel data required by the LCD display.

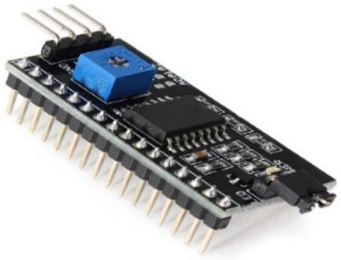


Fig. I2C Module

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D. UV Adapter

Use only for 240V AC, 11W Output Power Only.



Fig. UVC Lamp

E. Ozone Sensor

MQ131 **ozone gas sensor** has high sensitivity to ozone, and also has sensitivity to strong oxide such as Cl2, NO2 &etc. Use for sensing ozone in the cabinet.



Fig. Ozone Sensor

F. W1209 Digital Temperature Controller Thermostat Module

The W1209 Digital Temperature Controller Thermostat Module W1209 thermostat module has a temperature sensor, keys, LED display, relay and requires DC 12V power supply. It is an affordable, good quality thermostat controller.



Fig. DHT 11

G. Arduino UNO

Arduino UNO is a low-cost, flexible, and easy-to-use programmable open-source microcontroller board that can be integrated into a variety of electronic projects. This board contains a USB interface i.e., USB cable is used to connect the board with the computer and Arduino IDE (Integrated Development Environment) software is used to program the board.



Fig. Arduino UNO

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H. Jumper Wires

A jump wire (also known as jumper, jumper wire, DuPont wire) is an electrical wire, or group of them in a cable, with a connector or pin at each end (or sometimes without them – simply "tinned"), which is normally used to interconnect the components of a breadboard or other prototype or test circuit, internally or with other equipment or components, without soldering.

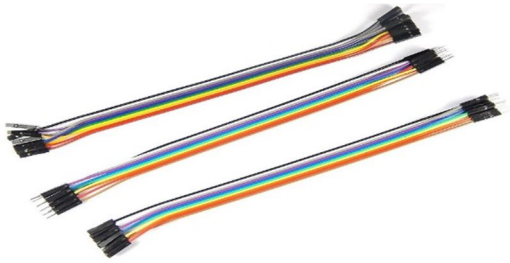


Fig. Jumper Wires

I. Breadboard

A breadboard is used to build and test circuits quickly before finalizing any circuit design. The breadboard has many holes into which circuit components like ICs and resistors can be inserted. The bread board has strips of metal which run underneath the board and connect the holes on the top of the board. The metal strips are laid out as shown below. Note that the top and bottom rows of holes are connected horizontally while the remaining holes are connected vertically.

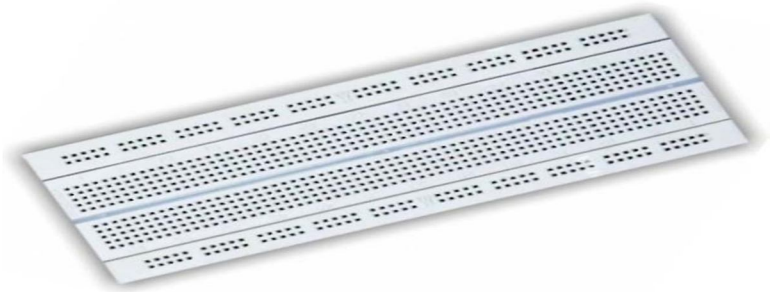


Fig. Breadboard

VIII. IMPLEMENTATION

1) *STEP 1:* Connect the instrument in mains
2) *STEP 2:* Switch on the mains
3) *STEP 3:* Hang the PPE kit inside it
4) *STEP 4:* On the UV lamp
5) *STEP 5:* On the air flow (DC fan)
6) *STEP 6:* Shut the door properly
7) *STEP 7:* Wait for 120-240 seconds
8) *STEP 8:* Switch off the airflow
9) *STEP 9:* Switch off the UV lamp

IX. VERIFICATION

Following are the steps involved in verification:

1) *STEP 1:* We will take sample cloth (Sample cloth is full of virus & bacteria).
2) *STEP 2:* Switch on the mains
3) *STEP 3:* Then we will put that sample cloth in the sterilizer.
4) *STEP 4:* We will make sure that process of sterilizer should take place for 120-240 seconds.
5) *STEP 5:* After 240 seconds we will check the sample cloth.
6) *STEP 6:* Comparing conditions of sample clothes before and after sterilization

Sample cloth is free from all type of viruses and bacteria.

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X. WORKING

Main function of our project is sterilization of PPE kit for instant use in 240 seconds. And to meet this condition, we have designed a cabinet who is capable to sterile it in 240 seconds. In our cabinet a process take place. Process of ozone formation air inside the cabinet will interact with the UVC light and form ozone as we all know that ozone is disinfectant than ozone formed in cabinet will disinfect the PPE and make it ready for instant use. Ozone is a gas that can reach all areas of the PPE kit so that it is sterilized inside out. Ozone is a proven disinfection and has the ability to disinfect surfaces of bacteria and viruses. The system can generate ozone out of air and no need for water or chemicals or any other inputs. The system makes use of a UV based ozone generator. UV or ultraviolet light (185 to 200nm) can generate ozone gas from air.

When air comes in contact with this UV frequency, the oxygen in air is converted to Ozone. The ozone is then reverse passed through UV chamber this time with a different light frequency to convert it back to oxygen. The system uses ozone sensors in sterilization chamber to check for ozone levels ozone is a harmful gas if inhaled incertain quantity.

XI. MAINTENANCE

1) Clean the inner and outer surface of sterilizer cabinet with the help of lint free clothsoaked in disinfectant solution. Once in a month check the intensity of UV lamb by using LUX meter.
2) Replace UV lamp of the sterilizer cabinet after 2000 hours of burning.

XII. ADVANTAGES AND LIMITATIONS OF DECONTAMINATION METHODS

A. *Advantages*

1) Good germicidal activity
2) Short treatment duration
3) Has activity against coronaviruses

B. *Disadvantages*

1) Not readily available
2) Degrades polymers

XIII. DISCUSSION

Shortages of PPE are a grave concern for many healthcare facilities in the setting of the global COVID-19 pandemic. Our findings have important implications for facilities that are considering decontamination of PPE as a potential strategy to maintain adequate supplies. Using a rigorous test method, we found that UV-C reduced contamination of PPE Kit with E.Coli and MS2 bacteriophages and MRSA. However, there was considerable variability in reductions achieved on different respirator brands and on different locations on the respirators. The efficacy on the interior surface of the respirator was reduced in comparison to the outer surface, possibly due to the permeability of the inner surfaces to the liquid suspensions resulting in reduced access by UV-C. Our results suggest that facilities might consider use of the UV-C box or room decontamination devices to reduce contamination on respirators that will be reused by individuals. However, the levels of reduction did not meet our pre-established criteria for decontamination (i.e., >3-log10 reduction on inoculated respirators), and more over would not have met a >2-log10 reduction requirement for decontamination. Thus, the level of reduction would not be adequate to allow shared use of respirators by different individuals.

The high-level disinfection cabinet was more effective than UV-C and provided 2.1 or greater log10 reductions in bacteriophage MS2 on both outer and inner surfaces of the respirator with a single cycle. It is not able that this level of reduction is substantially lower than the 6-log10 reductions in bacteriophage MS2 achieved on solid carriers in previous studies with this technology. Moreover, the single cycle resulted in >6-log10 reductions in MRSA and C. difficile spores inoculated on the respirator, despite greaterUV-C resistance of these organisms on solid surfaces. Taken together, these data suggest that reduction in viral pathogens on PPE Kit might be challenging, in part because the small size of viral particles allows them to penetrate beneath the respiratorsurface to a greater extent than bacteria resulting in partial protection from technologiessuch as UV-C and aerosolized peracetic acid. These data also highlight the importanceof including viruses in the testing of technologies proposed for PPE Kit decontamination. With 3 consecutive cycles or an extended cycle, the high-level disinfection cabinet met criteria for disinfection, achieving >6-log10 reductions on PPEKit. The same technology is available as a room decontamination device that would provide additional space for larger quantities of PPE. On solid surfaces, the efficacy of the high-level disinfection cabinet is similar to that reported for hydrogen peroxide vapor, which has also been considered as an option for PPE decontamination.

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Given the efficiency of the disinfection cabinet, this type of technology could potentially be used for disinfection of PPE that would be shared among different individuals in the settingof a crisis with inadequate supplies of PPE. We found that dry heat in an oven at 70°C for 120-240 seconds had limited effectiveness for decontamination of inoculated respirators. Previous reports suggest that heat can be very effective against viruses in liquidsuspension and heated droplets. The relative lack of efficiency of heat in our study may be attributable to the use of dry rather than moist heat, inoculation into respirators rather than hard surfaces or liquid suspensions, and characteristics of the viruses being tested. Lore et al. and Heimbuch et al. found that moist heat (65°C for 240 seconds) was effective for inactivation of influenza virus. Darnell et al. found that heating a liquid suspension with virus particles for 120 seconds at 75°C or 240 seconds at 65°C was effective for inactivation of SARS-CoV. Further studies are needed that include use of moist and dry heat for reduction of viruses inoculated onto respirators. Our study has several limitations. First, we did not address the concern that decontamination technologies could alter the level of protection provided by PPE. Further studies are currently being conducted to evaluate the impact of multiple different decontamination methods on PPE Kit performance such as filtration efficiency. Second, we applied the test organisms in a liquid suspension directly onto the surface of the PPE Kit and spread them over a relatively small surface area with a loop. We cannot exclude the possibility that the technologies would have been more effective if the inoculum was spread out over a larger surface area; spreading of an organism inoculum over a larger surface area has been shown to increase the efficacy of UV-C light. It has also been suggested that the method of deposition may influence results, and that methods that more closely mimic droplet and aerosol deposition on respirators should be used. Third, the testing was conducted as a laboratory simulation. Additional studies are needed to evaluate decontamination of PPE Kit used in clinical settings. Fourth, UV-C was less effective in our study than has been reported in previous investigations of UV-C for decontamination of influenza virus on respirators. This may be related to differences inmethodology or to greater UV-C susceptibility of influenza virus than the bacteriophages studied. Previous studies suggest that viruses vary considerably in susceptibility to UV-C. Fifth, we cannot exclude the possibility that a higher UV-C dose might have resulted in greater efficacy. However, there is evidence that very high UV- C doses may adversely affect PPE Kit performance and structural integrity. Sixth, we only studied PPE Kit methods of decontamination. We are currently evaluating the effectiveness of several other technologies.

XIV. RESULTS

S.No.	Test Organism	Duration of Exposure to UV radiation		
		120 sec	180 sec	240 sec
1	E.coli MTCC 68 (bacterium)	99.99986	Not Applicable	Not Applicable
2	MS2 phage ATCC1559781 Surrogate Virus – MS2 phage	99.94 % Reduction	99.988 %	≥99.998%

Table: Microbial Reduction with Different Exposure Timing to UV Treatment

A Report was taken up to assess the efficacy Sample of PPE Kit's using E.coli MTCC 68 (Bacterium) and MS2 phage ATCC15597B1 (Surrogate Virus - bacteriophage). Different time of exposures were given in separate trials with reference to MS2 phage viz. 120 sec, 180 sec, 240 sec and only 120 seconds in case of E.coli organism. Tested Sample was found to be effective.

XV. OBSERVATION

Observed that UvC light is effective towards the viruses and bacteria's E.coli MTCC 68 (Bacterium) and MS2 phage ATCC15597B1 (Surrogate Virus - bacteriophage).

XVI. CONCLUSION

After sterilization found that the its effectively sterilize the PPE kit and kill all type of viruses and bacteria with the help of ozone and UVC light.

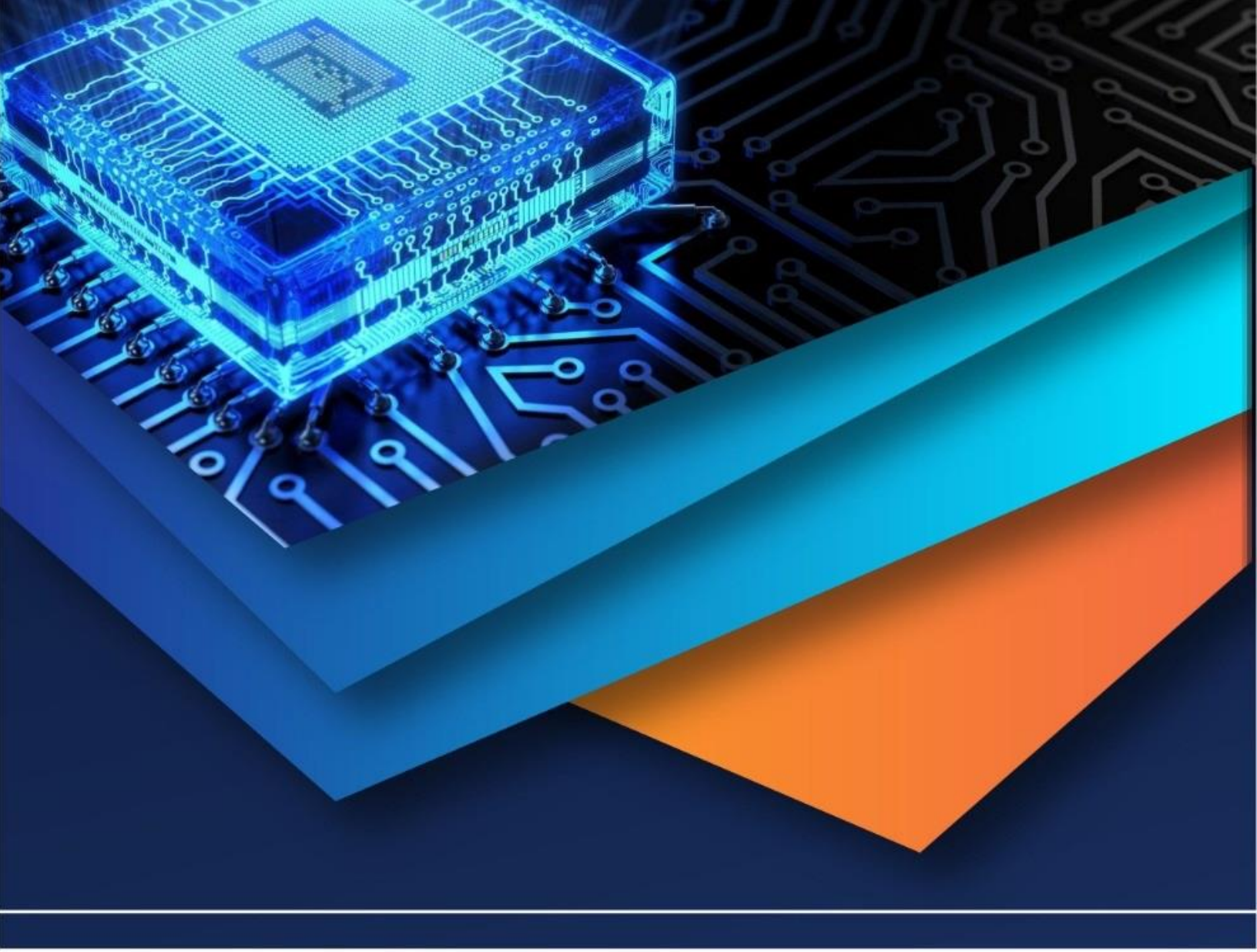
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