Analyzing the Effectiveness Of UV-C Emitters For The Decontamination Of Emergency Vehicles

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Abstract

The purpose of this research paper is to review the current research that supports the proposal that UV-C emitters can be used for decontamination purposes. Furthermore, we will analyze our UV-C emitter and the expected time of irradiation and NM wavelengths required to decontaminate a standard emergency vehicle. We will also go into detail on the latest technology our product incorporates such as a voice attenuator feature and failsafe measures. It is our goal to demonstrate the effectiveness of our UV-C emitter for the decontamination viruses, including coronaviruses.

Keywords: UV-C Emitters, Coronavirus, Decontamination

Introduction

UV light covers a wavelength spectrum from 100 to 380 nm and is subdivided into three regions: UVA (320 to 400 nm), UVB (280 to 320 nm) and UVC (200 to 280 nm). UVC has the strongest germicidal effect with UV light emitting diodes showing to have the quickest germicidal inactivation times. (Kim et al., 2015, 11) UV-C light deactivates the DNA of bacteria, viruses and other pathogens which prevents them from replicating. Specifically, UV-C light causes damage to the nucleic acid of microorganisms by forming covalent bonds between certain adjacent bases in the DNA. The formation of such bonds prevent the DNA from being unzipped for replication, and the organism is unable to reproduce. In fact, when the organism tries to replicate, it dies. Ultraviolet technology is a non-chemical approach to disinfection. In this method of disinfection, nothing is added which makes this process simple, inexpensive and requires very low maintenance. Ultraviolet purifiers utilize germicidal lamps that are designed and calculated to produce a certain dosage of ultraviolet (usually at least 16,000 microwatt seconds per square centimeter but many units actually have a much higher dosage.) Numerous research studies have been conducted on the germicidal effect of UV-C light. We will review research studies that have used UV-C light to inactivate SARS viruses and various forms to bacteria.

Supporting Research

Inactivation of the Coronavirus that Induces SARS

Severe acute respiratory syndrome (SARS) is a life-threatening disease caused by a novel coronavirus termed SARS-CoV. In 2002, a life-threatening virus of unknown etiology began in Guangdong Province, China. This virus was determined to be a novel coronavirus termed

SARS-Cov. SARS-Cov infected over 8,000 people and 773 people died from the virus during the 2003 outbreak. The World Health Organization (WHO) biosafety level 3 as the appropriate containment level when conducting research with the live virus. Darnell et al. examined the efficiency of several methods of viral inactivation including methods that may inhibit viral replication or entry (Darnell et al., 2004, 95). Successful inactivation of the virus would allow for the transport from a biosafety level 3 laboratory to a biosafety level 2 laboratory without the risk of accidental infections. Since the end of the SARS epidemic in July 2003, there have been three known cases of SARS in laboratory researchers due to accidental exposure to the virus (Darnell et al., 2004, 95).

Assessments and Measures

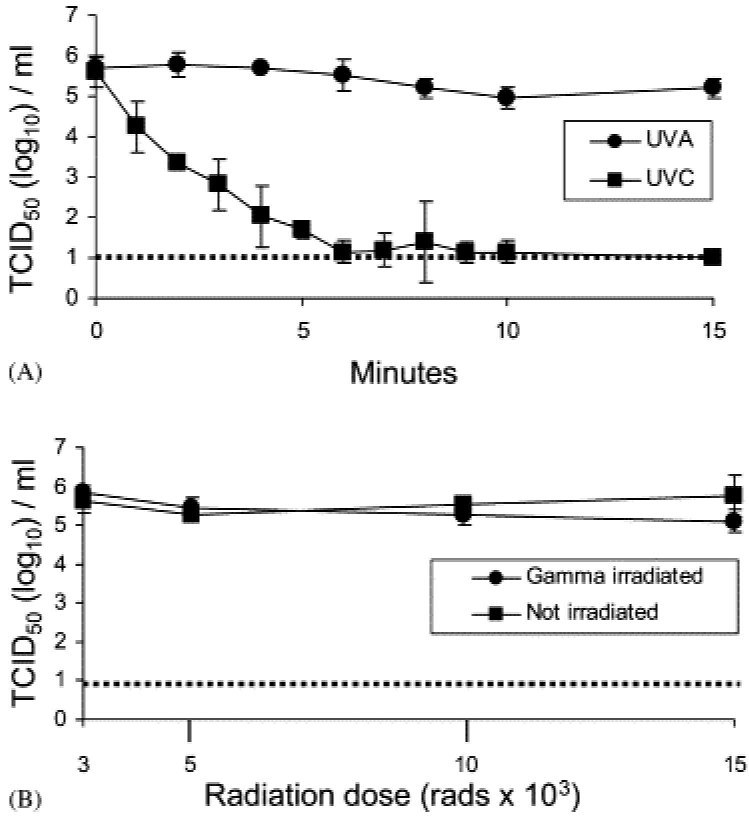
Darnell et al. assessed the SARS-Cov strain by infecting African green monkey kidney cells. Serial dilutions of virus samples were incubated at 37 °C for 4 days and subsequently examined for cytopathic effect (CPE) in infected cells (Darnell et al., 2004, 96). The research study tested the effectiveness of various inactivation methods; UV light, gamma radiation, formaldehyde, pH treatment and detergent. Ultraviolet light was performed on various sample sizes of the virus at a distance of 3cm. The UV-C light source (254 nm) emitted 4016 µW/cm2 and the UV-A light source (365 nm) emitted 2133 µW/cm2. Samples containing 400 µl were exposed to gamma radiation.Test samples were subjected to gamma radiation (3000, 5000, 10,000, and 15,000 rad) from a 60Co source, while control samples were protected from exposure (Darnell et al., 2004, 97). Furthermore, a heating block was used to achieve different temperatures to heat the virus at various temperatures (56, 65 and 75 °C). Diluted aldehydes (formaldehyde and glutaraldehyde)were added to virus samples in order to achieve final dilutions of 1:1000 and 1:4000 respectively. Virus aliquots were adjusted to the desired pH using 5 M and 1 M HCl or 5N and 1N NaOH. Subsequently, they were divided into three aliquots, incubated at the desired temperature (4, 25, and 37 °C), neutralized to a pH 7 (Darnell et al., 2004, 98).The infectivity of detergent disrupted virus was determined by washing infected Vero cells with trypsin/versene followed by PBS.

Results

Inactivation of SARS-Cov can be achieved by various methods given sufficient time and appropriate temperatures. Darnell et al. demonstrated that the virus being exposed to fifteen minutes of UV-C light had the most effective inactivation of the virus.

Effect Of Radiation on SARS-Cov

The inactivation potential of UV-C and UV-A was examined by exposing the virus to the respective irradiation types at different time intervals . Exposure of virus to UVC light resulted in partial inactivation at 1 min with increasing efficiency up to 6 min, resulting in a 400-fold decrease in infectious virus. No additional inactivation was observed from 6 to 10 min. After 15 min the virus was completely inactivated to the limit of detection of the assay (Darnell et al., 2004, 98). The data showed that UVC light inactivated the SARS virus at a distance of 3cm and a time interval of 15 minutes.



Gamma Radiation

No effect of viral inactivation was detected at the respective gamma radiation levels of 3000, 5000, 10,000, and 15,000 rad.

Heat Treatment

Heat inactivates viruses by denaturing the secondary structure of proteins thus preventing the attachment and replication in a host cell. To test the ability of heat to inactivate the SARS-CoV, they incubated a virus in 1.5 ml polypropylene cryotubes at three temperatures (56, 65 and 75 °C) for increasing periods of time (Darnell et al., 2004, 89). It was discovered that at 56 °C, after 20 minutes, most of the virus was inactivated. However some of the virus particles were still stable at this temperature, suggesting that a temperature increase was required. While virus was incompletely inactivated at 56 and 65 °C even at 60 min, it was completely inactivated at 75 °C in 45 min (Darnell et al., 2004, 90). Overall viral inactivation by pasteurization proved to me effective.

Effects Of Formaldehyde and Glutaraldehyde

Formalin and glutaraldehyde inactivation of SARS-Cov was examined over a three day period and at two dilutions (1:1000 and 1:4000). Both of the aldehydes exhibited temperature dependence in their ability to inactivate virus (Darnell et al., 2004, 90). After a period of three days, and a temperature of 4°C , complete virus inactivation was unsuccessful. At 25 and 37 °C, formalin inactivated most of the virus, close to the limit of detection of the assay, after 1 day, yet some viruses still remain infectious on day 3. However, glutaraldehyde completely inactivated the virus by day 2 at 25 °C and by day 1 at 37 °C (Darnell et al., 2004, 90). Results indicated that aldehydes can be effective but only at certain temperatures, dilutions and time intervals which removes the possibility of practical decontamination.

pH Changes

Data suggest that different pH conditions affect the spike proteins of coronaviruses, and the activity of the spike protein of the SARS-CoV may be sensitive to changes in pH, possibly by changing the infectious nature of the viral particles (Darnell et al., 2004, 90). The effect of different pH levels on the inactivity of SARS-CoV was investigated. Results demonstrated that the virus was sensitive to extreme pH levels. After exposing the virus to extreme alkaline conditions between pH12 and pH14 inactivated the virus. Furthermore, exposing the virus to highly acidic conditions between pH 1 and pH3 also inactivated the virus. The results support the date that the virus is sensitive to the extremes of the pH scale.

Overall the results indicated that while there are many ways to inactivate the SARS-CoV virus, UV-C proved to be the most effective.

Inactivation of Human Coronaviruses Used Far-UVC Light

Germicidal ultraviolet light (254 nm) is effective in inactivating coronaviruses but is harmful to human tissue. Far-UVC light (207-222nm) efficiently eliminates viruses without causing damage to exposed human tissues. Buonanno et al. investigated far-UVC efficacy against airborne human coronaviruses alpha HCoV-229E and beta HCoV-OC43. UVC light (207 to 222nm) has been shown to be as efficient as conventional germicidal UV light in killing microorganisms, and does not cause health issues associated with conventional germicidal UV light. This is due to the fact that far UVC light has a range of a few micrometers and cannot reach living human skin or eye cells. Contrarily, bacteria and viruses are extremely small, far-UVC light can still penetrate and kill the organisms. Thus demonstrating the equivalent effectiveness of far-UVC light without the associated health risks. Buonanno et al. investigation suggests that far-UVC light has the potential to be used in occupied public settings to prevent the airborne person-to-person transmission of pathogens such as coronaviruses (Buonanno et al., 2020, 2).

FDA Recommendations For the Decontamination Of Covid-19 Using UV-C

According to the FDA, UVC has been shown to destroy the outer protein coating of the SARS-coronavirus but is a different virus to the current SARS-CoV-2 virus causing an international pandemic. The FDA states that “UVC radiation may also be effective in inactivating the SARS-CoV-2 virus, which is the virus that causes the Coronavirus Disease 2019 (U.S. Food and Drug Administration, 2020). In order to leverage the full effectiveness of UVC radiation, the FDA recommends direct exposure to the surface and an effective duration. UV radiation may have a lesser effect on surfaces covered by soil or dust. The FDA recommends in order to analyze the effectiveness of UVC, the following should be considered:

> "The effectiveness of UVC lamps in inactivating the SARS-CoV-2 virus is unknown because there is limited published data about the wavelength, dose, and duration of UVC radiation required to inactivate the SARS-CoV-2 virus. It is important to recognize that, generally, UVC cannot inactivate a virus or bacterium if it is not directly exposed to UVC. In other words, the virus or bacteria will not be inactivated if it is covered by dust or soil, embedded in a porous surface or on the underside of a surface" (U.S. Food and Drug Administration, 2020).

HiViz UV-C Decontamination System

During the nationwide COVID-19 Pandemic response, HiViz LED Lighting has received feedback from dealers and end-users around the market requesting information related to "UV-C" decontamination lighting products for ambulances. The CEO of HiViz, who is an active NC EMT, is hyper-sensitive to the need for limiting the likelihood of their apparatus becoming a vector for communicable disease. The initial rapid-outbreak of this COVID-19 virus can be attributed to unaware carriers transmitting the disease when otherwise appearing healthy. As such, the likelihood exists that contamination of ambulances during routine calls for service could have inadvertently caused the vehicle to act as a high-value vector, which may have brought COVID-19 in to contact with immunosuppressed patients in facilities which rely heavily on ambulances for transport of patients (nursing homes).

Development Of Our Technology

HiViz LED Lighting is developing a system of light fixtures, coupled with a grouping of safety sensors and a system controller, which use high intensity UC-V LEDs to provide secondary decontamination in the patent module of an ambulance.The system will automatically activate when the vehicle is in-between calls. Physically, some number of light emitters will be installed in the patient module, shining on the surfaces of the truck. Early indications point to 2-4 emitters with 4 LEDs each over the patient compartment, and/or 1 mini-emitter over the action area. HiViz LED Lighting is actively exploring the design and manufacture of a high-intensity, short duration, retrofittable automated UV-C lighting system which can be installed in an ambulance. The goal of this technology would be to offer automated secondary decontamination using UV-C LEDs to inactivate pathogens in ”general” purpose ambulances (not only for specialty high-risk trucks).

Low Effectiveness	Use an array of high-powered UV-C LEDs, placed in the optimal location after detailed photometric analysis of interior compartment of ambulance, tied to an automated system to ensure it gets used after every call. Emitter on the roof shining down for primary zones, mini emitters for secondary zones (action area).
Low Perception of effectiveness	Do not use “visible light spectrum” (400-420nm) light emitters (illumination lighting). Rather, use UV-C 275 to 286nm wavelengths which are higher powered, and produce a distinctly different emission color (you can see them working)
High cost	Eliminate the middleman. Partner to develop technology from the ground up with pre-set expectation of reasonable operating margin and sale price. We own the entire manufacturing process (SMT lines, electrical engineering and design, production facilities, etc). Leverage volume and simplicity in relationship. Use systems that already exist in the truck to augment system controller. Go after federal money for pandemic-prevention. Highly likely after COVID-19. (long term strategy) Lobby DOT and medical directors for legislation mandating secondary decontamination technology for interfacility palliative care of immunosuppressed citizens. Tie to billing or ambulance certification. Offer sized solutions which can keep cost low (transport market). Effectiveness of the tech is a factor of time and intensity. A very small and inexpensive fixture will work well if given enough time. Need to find a balance. Preliminary market research indicates a sub 15 min decontamination time is preferred, with sub 5 minutes being ideal.
Too much complexity	Automate the system. Don’t require the operator to press a button.
Causes downtime of ambulance	Use lighting vs aerosol and permanently attach it to the truck. If a call comes in during deacon, system can immediately shut off and patent compartment becomes useable right away,

The UV-C System consists of two primary components: UV-C Emitter and a control interface. The emitters contain 8x Luminus XST-3535-UV LEDs and produce 275 (280 max) NM wavelengths. The system is designed to be installed in vehicles, particularly emergency vehicles and automatically senses when a passenger compartment has been occupied. When the compartment is vacated, an irradiation cycle begins. The irradiation time is a user-selectable parameter with its effectiveness dependent on intensity and duration. This user-selectivity allows the users to adjust the parameters dependent on the size and shape of the vehicle. We expect a standard ambulance to require 4-6 emitters and a 5-10 minute irradiation time interval.

Establishing the Emotional Connection With Our Product

Our system uses a voice attenuator that communicates with the user and occupants. The system announces its various operational modes, and activates an emotional connection with the user. Hearing the system speak can prompt the user to ensure that it is being used correctly and to vacate the vehicle before the irradiation cycle begins. There are also numerous safety measures which ensures the vehicle is empty before the irradiation cycle begins. The system is connected to the seat sensors, seat belts, and door open switches along with a motion detector in order to ensure complete safety of the occupants. The system can also be cellular enabled with diagnostic reports frequently sent to a cloud server. This allows an ambulance fleet operator to correlate decontamination against run reports and could be used to limit liability. If the system is malfunctioning, it will notify the fleet manager to the issue. The fleet operator has the ability to change the parameters of irradiation intervals. If new medical research shows a different irradiation interval is desired, it is possible to update parameters on the fly remotely.The system is multi-zone compatible, which means it can operate the cab area and the patient module area separately from each other.

Decontamination Protocol

Our decontamination system has a motion occupancy sensor that will not allow irradiation of the vehicle compartment until there is 5 minutes of no activity. There is a door trigger input thus the doors must be closed in order for the system to begin operating. The emergency stop must not be engaged and the last irradiation time cannot be greater than 20 minutes.

1	Seatbelt Positive Trigger	Seatbelt Negative Trigger
2	Seatbelt Mode Active	Seatbelt Mode Disabled
3	Door Trigger Positive	Door Trigger Ground
4	Firmware Feature TBD	Firmware Feature TBD
5	Firmware Feature TBD	Firmware Feature TBD
6	Firmware Feature TBD	Firmware Feature TBD

Automatic Decontamination Mode

If all the doors in the vehicle are closed but the medic is not belted in, the system will not begin irradiation until there is no motion for a minimum of 5 minutes. The decontamination will automatically begin but will announce itself with an audio file "Decontamination commencing in 5, 4, 3, 2,1, ON". The irradiation cycle will be between 3 and 15 minutes. There are protection measures in place, where any motion detected will disable the system immediately. When the cycle is complete the green "decontamination complete" button will illuminate on the display.

If all of the doors are closed, and the medic is not belted in, and the motion sensor doesn't sense any motion for a minimum of five minutes, the decon system should automatically turn itself "on" and complete a cycle. If the decontamination is complete and the occupant opens the door to enter the vehicle, the system will announce that the vehicle has been irradiated and is safe to enter. Our system's display shows the last decontamination time, and a countdown to the next decontamination time.

Manual Decontamination Mode

Our system also has a manual mode that allows for the operator to manually operate the system. When finished the system returns to automatic mode. When the manual button is pressed on the system, an audio file announces the decontamination process and requires for the user to exit the vehicle. The yellow decontamination light will flash and there is a 1 minute countdown. If motion is detected or a seatbelt is buckled, the countdown is cancelled. If the timer reaches zero, and there has been no motion for 30 seconds, the system will begin the decontamination process. If there is any motion inside the truck there system will disable immediately. If the manual "system disable" button is pressed, the decontamination process stops immediately and "disabled mode" will display on the screen.

Purchase Options

Our decontamination system can be purchased as a whole, which is highly recommended. The controller and emitters can also be purchased separately.

Competitive Products

Standard decontamination processes are simply not enough to reassure passengers in emergency vehicles during a global pandemic. Secondary decontamination systems include Aeroclave systems, reactive oxygen species ultraviolet systems, and large UV-C decontamination systems. There are multiple barriers associated with the use of the aforementioned systems. Barriers include high cost, low-effectivity and the reduction of productivity for the vehicle operator. We believe that our product brings a unique opportunity of effectiveness and accessibility. While the technology of UV-C is already in use, we are bringing a viable product to the emergency vehicle market. We understand the culture of the public safety industry and specialize in connecting emotionally with the end-users of our products. For this technology to be adopted, it must be easy to use, integrated in the apparatus, moderate to low cost, and it must be visually-verifiable that it is working.

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