DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Use of Ultraviolet Germicidal Irradiation (UVGI) as a COVID-19 Disinfectant

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MAIN OFFICE
4695 Millennium Drive
Belcamp, MD 21017-1505
443-360-4600

REPORT PREPARED BY:
Travis J. Kneen
Office: DSIAC

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14. ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) was asked to determine if there was any relevant research and data on the efficacy of ultraviolet germicidal irradiation light to effectively disinfect touch surfaces exposed to SARS-CoV-2. In particular, DSIAC was asked to determine if there are applications of the same ultraviolet C (UVC) wavelength that are being used in aircraft, subway, and other transit interiors. UVC light was one of four methods of National Institutes of Health-approved decontamination for N95 masks and has been used previously to inactivate similar viruses (SARS-CoV-1 and MERS-CoV). However, there are no current published dosage parameters for UVC light to disinfect surfaces, although an industry-academia collaboration claims to have inactivated SARS-CoV-2 using 254-nm UVC light. Even so, there are multiple companies that have developed or adapted UVC devices to decontaminate personal protective equipment, air, and touch surfaces. UVC light and a selection of devices are summarized from open sources in this report.

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A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) was asked to determine if there was any relevant research and data on the efficacy of ultraviolet germicidal irradiation light to effectively disinfect touch surfaces exposed to SARS-CoV-2. In particular, DSIAC was asked to determine if there are applications of the same ultraviolet C (UVC) wavelength that are being used in aircraft, subway, and other transit interiors. UVC light was one of four methods of National Institutes of Health-approved decontamination for N95 masks and has been used previously to inactivate similar viruses (SARS-CoV-1 and MERS-CoV). However, there are no current published dosage parameters for UVC light to disinfect surfaces, although an industry-academia collaboration claims to have inactivated SARS-CoV-2 using 254-nm UVC light. Even so, there are multiple companies that have developed or adapted UVC devices to decontaminate personal protective equipment, air, and touch surfaces. UVC light and a selection of devices are summarized from open sources in this report.

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1.0 TI Request

1.1 INQUIRY

Is there relevant data regarding the efficacy of 254-nm germicidal ultraviolet C (UVC), including dosage required, to effectively disinfect touch surfaces exposed to the novel coronavirus SARS-CoV-2? Does that data contain any applications of the same UVC wavelength to surfaces of aircraft or other transportation interiors?

1.2 DESCRIPTION

This inquiry is related to the research performed by the Henry Ford Medical Center on the decontamination of respiratory masks.

2.0 TI Response

The Defense Systems Information Analysis Center (DSIAC) used open sources to search for research involving ultraviolet germicidal irradiation (UVGI) for COVID-19 disinfection and commercial off-the-shelf (COTS) technologies for surfaces and aircraft interiors.

2.1 INTRODUCTION TO UVC DISINFECTION

Ultraviolet (UV) disinfection technologies have become an option for small-scale (personal protection equipment [PPEs]) and industrial-scale (planes and commercial areas) SARS-CoV-2 disinfection. UV light, specifically UVC (200–280 nm) light energy, has been known for its disinfection properties for over 140 years and used for more than 40 years to disinfect air, drinking water, wastewater, pharmaceutical products, and surfaces against many hundreds of human pathogens, including other coronaviruses. It can help mitigate the risk of contracting an infection in contact with the COVID-19 virus when applied correctly. This method of disinfection is known as UVGI [1, 2].

Typically, artificial UVC energy is produced by ionizing low-pressure mercury vapor, which emits a predominantly discreet wavelength of 254 nm in the UVC band that is an ideal wavelength for destroying the DNA of single-celled organisms (Figure 1). These lamps are similar to fluorescent, household lighting fixtures but do not have the phosphorescent coating which imparts the soft white light [3]. UVGI can disinfect by irradiating air, surfaces, or objects. Applications can be used with either natural or mechanical ventilation for airborne disinfection or as stand-alone or mobile systems for surfaces or objects. The disinfectant effect is determined by the dose of UV-C applied, the configuration of the lamp array, the duration of exposure, the level of shadowing, and the characteristics of the target microorganism(s) [4].

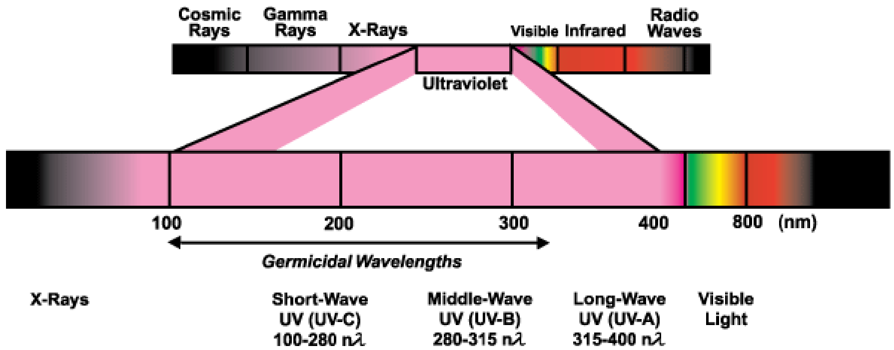

Figure 1: A Closer Look at the Ultraviolet Wavelength Band, With a Focus on UVC Light *(Image Used With Permission From the Atlantic Ultraviolet Corporation).*

Oftentimes, UVC disinfection is used in tandem with other technologies to form a multibarrier approach to ensure that whatever pathogen is not “killed” by one method (e.g., filtering or cleaning) is inactivated by another. This is especially true since the germicidal effectiveness of UVC is influenced by the UVC-absorbing properties of the suspension (the surface or aerosol that the virus is in), the type or action spectra of the microorganism, and a variety of design and operating factors that impact the delivered UV dose to the microorganism. The ability of the UVC light reaching the affected areas is key to disinfection [1, 2]. However, UVC rays can be harmful to humans, causing skin and eye damage. This means that typical UVC disinfection should not occur with humans present unless properly attired [1, 2, 4, 5].

2.2 USING UVC LIGHT TO DISINFECT

The flexibility of regulatory approval during this pandemic has accelerated the development of research and clinical testing of approaches to diagnose, control, prevent, and treat COVID-19, such as UV technologies. UVGI has been proven to be a possible alternative to the vapors of hydrogen peroxide and ethylene oxide for respirator decontamination [6]. However, decontaminating surfaces poses some different challenges. Viral particles can be directly deposited and resuspended due to natural mechanical airflow patterns or other sources of turbulence in the indoor environment, such as foot fall, walking, and thermal plumes from warm human bodies. Individuals have direct and indirect contact with surfaces as they move through an area in which a transfer of viruses from that person can transfer to a surface or vice versa [7].

Previous studies have demonstrated UVC light inactivating SARS-CoV-1 in 2004 and MERS-CoV at 1.22 m within 5 min in 2016. However, there has been no peer-reviewed, published data on UVC light inactivating SARS-CoV-2, but those prior studies suggest that it will also be susceptible to UVC [8]. However, in June 2020, the National Emerging Infectious Diseases Laboratories (NEIDL) at Boston University and the lighting company Signify assessed and reported on SARS-CoV-2 inactivating under various conditions. The team applied a 5 mJ/cm^2 dose that resulted in a 99% reduction in 6 s and extrapolated the data to determine that a 22 mJ/cm^2 dose would result in a 99.9999% reduction in 25 s [9].

To better understand the possibility of using UVGI against SARS-CoV-2, there are three classes of viruses regarding levels of resistance to disinfection:

1. Class 1 viruses are small, nonenveloped viruses (<50 nm); considered "highly resistant to disinfection; and the hardest class to kill (e.g., norovirus).
2. Class 2 viruses are large, nonenveloped viruses considered "less resistant" to disinfection and less hard to kill (e.g., reoviridae and adenoviridae).
3. Class 3 viruses are enveloped viruses considered to be the "least resistant" to disinfection and the easiest to kill (e.g., ebola, influenza, and coronavirus).

According to the Centers for Disease Control's emerging viral pathogen protocol, to be eligible for use against an emerging viral pathogen, a product or technology needs validation that it can inactivate at least one large or one small, nonenveloped virus [10].

While there are UVGI technologies focused on irradiating the air of viruses and pathogens, there are also a variety of technologies focused on disinfecting surfaces or objects, as seen in Table 1 [5]. These technologies are important, as SARS-CoV-2 is detectable up to 72 hr on plastic and stainless-steel surfaces while also detectable in shorter timeframes on copper (4 hr) and cardboard (24 hr) [11]. Examples of COTS technologies will be summarized in the next section.

Table 1: Review of UGVI Applications [5]

UVGI Technology	Description	Effectiveness
Area disinfection systems	Portable or mounted units direct high levels of unshielded UVC irradiation over a large area for periodic disinfection of walls, floors, tables, chairs, equipment, or surfaces.	• Provides effective treatment of air and surfaces, depending on intensity and duration of exposure. • Shadowed or dirty surfaces or objects may receive less exposure. • It is not intended for use when there are occupants in the room and is more suitable for intermittent or routine after-hours disinfection in healthcare or industry settings.
Disinfection chambers	An enclosed chamber or room, which may include a conveyor or rotation system, to apply high levels of UVC to objects.	• This technology has been shown to be effective for disinfecting objects used in a range of applications, such as medical equipment, mail, and laundry. • Effectiveness is determined by UVC intensity, exposure time, and shadowing on object surfaces.
UVC wands	Handheld UV devices, which can be battery powered, are used to apply localized UVC to surfaces or objects that may be difficult to disinfect using traditional approaches.	• Effective for disinfecting objects or complex surfaces and has been used for disinfecting mattresses and surfaces in vehicles (e.g., buckle or latches in air ambulances). • May be more effective with a short target distance and direct (overhead) exposure but can present risks of UVC damage to skin or eyes to the user or those nearby.

In a paper by P. Arguelles [12], estimations for UVC sterilization doses for COVID-19 mitigation efforts are presented. Arguelles uses curve-fitting analysis on SARS-CoV-1, a close genomic relative of the novel coronavirus, and survivorship data to predict UVC dosages to inactivate SARS-CoV-2. The approximate dosage required for SARS-CoV-1 inactivation was determined to be 36,144 J/m^2. This was used as a benchmark for SARS-CoV-2 time exposure predictions, where the time, *t*, is determined by

$$t \approx (1.5\ x\ 10^6)\pi \cdot \left({r^2}/{P}\right),$$

where *r* is the distance of the UVC source to the surface, *P* is the wattage of the bulb, and *t* is expressed in seconds. Therefore, a minimum of 2 hr for a 15-W bulb placed 6 inches from the disinfecting surface was presented [12]. A subsequent web-based application called the UVGI Scientific Calculator, https://covid-19-clean.org/calculator-journal-report/, has been used to facilitate the engineering and design of air-purifying equipment being developed for hospitals, commercial, and residential applications [13].

2.2.1 Large-Scale Disinfection

Even though there is not an agreed upon dosage and exposure time to inactivate SARS-CoV-2 on surfaces, there are examples of UVC/UVGI technologies being utilized in large interior spaces to combat the pandemic. UV-wielding robots in hospitals and UVC germ zappers in airplanes and subways are examples of such technologies. Due to the health hazards, these systems cannot operate while people are present, although research into far-UVC light (222 nm) could change that. Other issues that design engineers must account for with these technologies include uneven/canyon geometries, unexposed areas, shadows, and unconfirmed power intensity (intensity and distance) requirements. For these reasons, many technologies either require using multiple systems or multiple bulbs in the design [14].

In mid-May 2020, the Metropolitan Transportation Authority (MTA) in New York City (NYC), following the example of Chinese subways, began using UV lamps to disinfect train cars during nighttime closures (from 1 a.m. to 5 a.m.). In June 2020, the MTA expanded the UV program, which uses the full UV spectrum for disinfection, to clean more than 6,500 train cars. The May pilot program used about 150 dual-headed mobile devices from Denver-based company PURO Lighting. The proof-of-concept was run by the director of Columbia University's Center for Radiological Research, Dr. David Brenner, who demonstrated the first-ever test of ultraviolet light that efficiently killed the virus on a NYC subway car [15, 16].

2.2.2 Small-Scale Disinfection

Early on in the COVID-19 pandemic, small-scale disinfection became a pressing need in order to reuse PPE like N95 masks and medical tools. Most of the early research into possibly using UVC light focused on safely disinfecting PPE for medical personnel, as masks and other required equipment became scarce. Companies like Cleanbox Technology have adapted previously developed technologies for the task, while other companies like PrescientX and research institutions like Rensselaer Polytechnic Institute developed technologies specifically with mask disinfection in mind [14]. Cleanbox Technology's CleanDefense decontamination product was originally developed for decontaminating virtual and augmented reality headsets. The Cleanbox claims that the CleanDefense can disinfect four masks in a 1–2-min cycle [17]. AtomicBlue and Signify also launched cabinet-style technologies to disinfect masks, while Genmega added UVC modules to the ATMs and kiosks they manufacture [18].

2.3 COTS TECHNOLOGIES

A selection of COTS UVC technologies developed for use in aircraft interiors or other surfaces are summarized in the subsections that follow. There are also other technologies explored in the A. Ringangaonkar and S. N. Kulkarni publication "A Comparative Study on UVC Light Devices to Inactivate Viruses" [19].

2.3.1 Honeywell

Honeywell announced a partnership in June 2020 with Dimer LLC to bring a UVC cleaning system to airlines that, when properly applied, can significantly reduce viruses and bacteria on cabin surfaces in under 10 min for less than $10 per flight for midsize-to-large airliners. The Honeywell UV Cabin System is roughly the size of an aircraft beverage cart and has UVC light arms that extend over the top of seats and sweep the cabin to treat aircraft surfaces. However, no specific testing had been done to inactivate COVID-19 [20]. In July 2020, JetBlue became the first airliner to test the UV Cabin System [21].

2.3.2 UV Light Technology

UV Light Technology, based in the UK, used the Signify and NEIDL-released information for UVC dose levels required to inactivate SARS-CoV-2 to calculate the required exposure times for each of their UV disinfection lamps based on a specific distance/area from the source. This information is shown in Table 2 [22].

Table 2: SARS-CoV-2 Inactivation Conditions for UV Light Technology UVC Disinfection Lamps [22]

UV Lamp	Distance/Area	Time Exposure (s)	Reduction (%)
LightSaverUV disinfection trolley	3-m radius	600	99.9999
UVC germicidal hand lamp	0.20 m	1.33	99
		5.87	99.9999
UVC 150-W germicidal unit	2.5-m ceiling height 4- x 4-m area	600	99.9999

The LightSaverUV disinfection trolley is a tablet-controlled, mobile decontamination unit that includes eight UVC germicidal tubes and has a 700-W power output. As with similar technologies, UV Light Technology notes that multiple positioning and cycles may be required to reduce shadow areas, depending on the size and layout of the room or area [23]. The UVC germicidal hand lamp is a more flexible tool that uses a UV 400-W mercury bulb to disinfect surfaces and difficult-to-reach areas. It has a maximum center irradiance value of 50 W/m^2 and an average A4 area value of 37.5 W/m^2 [24]. The UVC germicidal units are aluminum, dual-bulb ceiling-hung lamps that come in three power options—34 W, 72 W, and 150 W. Hung 2.5 m above a surface, the two larger units cover a 4- x 4-m area, while the 34 W units cover a 2- x 2-m area [25].

2.3.3 Israel Aerospace Industries (IAI)

IAI fast tracked the deployment of a UVC light system that would be available to disinfect aircraft interiors. The robot-based system is suitable for use in any size aircraft, having been tested in wide-body cargo airliners and helicopters. The 12-in-wide robot can move between seats in straight lines in larger airliners using the 254-nm lights mounted on electronically controlled arms to disinfect exposed surfaces, such as seats and other cabin fittings. In smaller aircraft, stationary units, like those designed for hospital rooms, can be deployed. Unexposed surfaces would still need to be manually cleaned. IAI claims that a wide-body cargo airliner can be disinfected using the robotic system in between “30 and 40 minutes” [26].

2.3.4 Seoul Semiconductor

In early April 2020, University of California Santa Barbara’s Solid State Lighting and Energy Electronics Center member company Seoul Semiconductor reported a "99.9% sterilization of coronavirus (COVID-19) in 30 seconds" with their UV light-emitting diode (LED) products [27]. At that time, the technology was being adopted into UV LED lamps that sterilize the interior of unoccupied vehicles.

2.3.5 Aeronautica SDLE and Grupo Rias

Spanish companies Aeronautica SDLE and Grupo Rias began developing a microdrone that would emit UVC light to disinfect both indoor and outdoor surfaces. The drone would incorporate sensors that allow it to perform disinfection duties remotely to avoid human contact. The microdrone is being developed to have 15 min of endurance [28].

2.4 CONCLUSIONS

UVC light was highlighted as one of four decontamination methods by the National Institutes of Health back in April 2020 and has since been proven by Signify and NEIDL to inactivate SARS-CoV-2. Since the beginning of the 2020 pandemic, there have been research institutions and companies that have focused on advancing and developing UVC technologies to disinfect PPE, air, and surfaces, particularly for mass transit interiors (planes, trains, and automobiles). However, even with that focus, there are no agreed-upon parameters (dosage, time exposure, and power) for UVC use against SARS-CoV-2 in peer-reviewed publications, although it has been used successfully against similar viruses and bacteria. Additionally, since UVC light is harmful to humans, it cannot be utilized without proper protection and can only be used in off hours. There is, however, research into safe-for-humans, far-UVC (222 nm) research ongoing at Columbia University. For these reasons, it is imperative to continue advancing research and development of UVC technologies for a variety of disinfection applications to combat the COVID-19 pandemic.

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BIOGRAPHY

Travis Kneen is a research analyst at DSIAC. Prior to joining DSIAC, he was an intern at America Makes. His graduate research focused on the mechanical properties of additively manufactured stainless steel 316L. Mr. Keen holds a B.S. in physics and astronomy and a B.A. in history from the University of Rochester and an M.S. in mechanical engineering from Youngstown State University.