EFFECTIVENESS AND SAFETY OF ULTRAVIOLET GERMICIDAL IRRADIATION LAMPS USED FOR AIR AND SURFACE DISINFECTION

TIP No. 24-103-1020

PURPOSE

To provide information on the usefulness and limitations of Ultraviolet Germicidal Irradiation (UVGI) lamps used for air and surface disinfection and to provide guidance on the safe use of these lamps.

REFERENCES

References are provided in Appendix A.

FACTS

UVGI Lamps for Disinfection—Effectiveness and Limitations

The 2014 outbreak of the Ebola virus and the coronavirus disease 2019 (COVID-19) pandemic have renewed interest in the use of UVGI lamps for disinfection. Ultraviolet (UV) radiation was first used for disinfecting surfaces in 1877, for water in 1910, and for air in 1935.[1-4] Examples of UVGI application at Army facilities include surface disinfection to help reduce the incidence of healthcare associated infections[5-6] (Figures 1 and 2); water purification[7-8]; and disinfection of equipment at biomedical research laboratories.[9]

The Centers for Disease Control and Prevention (CDC) has published guidelines for using UVGI lamps in upper rooms and air-handling units (AHUs) as a supplemental control measure for air disinfection.[10-14] The CDC's COVID-19 guidance includes UVGI among recommended methods for disinfecting face-piece respirators to address equipment shortages[13] and for upper-air disinfection in schools.[14] Sample images of an upper-room lamp and tabletop lamps are shown in Figures 3 and 4, respectively.

UVGI lamp technologies for air and surface disinfection include low-pressure mercury lamps; krypton-chlorine excimer lamps (sometimes informally referred to as "far UV-C" lamps); pulsed-xenon arc lamps; and light-emitting diode (LED) lamps using 255 nanometer (nm) LEDs and 365 nm LEDs. Studies have shown that continuously emitting low pressure mercury lamps and pulsed xenon lamps are comparably effective for disinfection. However, pulsed xenon sources may be more practical when rapid disinfection is required.[15]

UVGI is an excellent method for surface disinfection. However, UVGI cannot penetrate surfaces, disinfect soiled surfaces, reach nooks and crannies of surfaces, nor penetrate coverings like dust and other matter. These limitations will negatively impact broader applications for disinfection.

Figure 1. Pulsed Xenon Ultraviolet Germicidal Irradiation Lamp at William Beaumont Army Medical Center
Note: Photograph by U.S. Army

Figure 2. Low Pressure Mercury Ultraviolet Germicidal Irradiation Lamp at Brian Allgood Army Community Hospital
Note: Photograph by U.S. Army

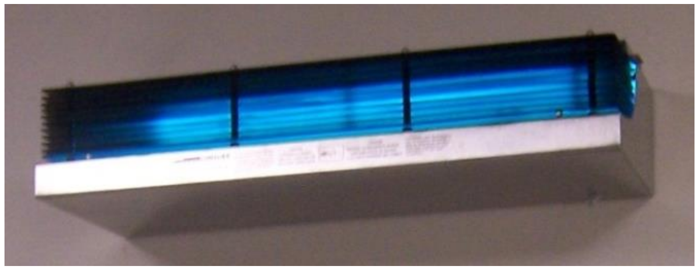

Figure 3. Upper Room Ultraviolet Germicidal Irradiation Lamp for Air Disinfection
Note: Photograph by U.S. Army Public Health Center (APHC);
Nonionizing Radiation Division (NRD)

Figure 4. Tabletop Ultraviolet Germicidal Irradiation Lamps
Note: Photograph by U.S. Army Public Health Center (APHC);
Nonionizing Radiation Division (NRD)

UVGI can augment other germicidal disinfection methods (e.g., chemical),[10-12] but UVGI is not a "stand-alone" solution to replace the need for other types of infection control.[16] Reviews of past research illustrate the challenge of controlling contagious disease in general populations:[17-20]

- Studies of UVGI effectiveness in military barracks showed consistent reductions in contagious disease where UVGI lamps were used. However, the reductions were deemed insufficient to recommend general UVGI use when considering overall cost and anticipated benefit. The authors recommended more research to improve understanding of disease transmission.[18-20]

- Studies of UVGI application in schools were inconclusive. Some studies showed significant reductions in contagious disease transmission, but other studies showed little or no improvement compared to control groups.[18,19] In two studies, the authors determined that some UVGI benefit was negated because students congregated in close contact on school busses and during extracurricular play times. This behavior facilitated the spread of contagious disease among the students.[17]

For these reasons, UVGI is typically used as part of a multi-tiered approach for disinfection, rather than as the sole means of disinfection.[10-12] In addition, UVGI is appropriate for use where disease transmission is more likely to occur. Examples of high-risk locations for the spread of contagious disease include: medical waiting rooms, intensive care wards, homeless shelters, correctional facilities, and other high-occupancy locations where potentially infected persons may share the same space with uninfected persons.[21,22]

The CDC has stated the following regarding COVID-19 transmission (with emphasis added in bold)[23]:

> **Airborne transmission is infection spread through exposure to those virus-containing respiratory droplets comprised of smaller droplets and particles that can remain suspended in the air over long distances (usually greater than 6 feet) and time (typically hours)…"Close contact" refers to transmission that can happen by either contact or droplet transmission while a person is within about 6 feet of an infected person.**
>
> **The epidemiology of SARS-CoV-2 indicates that most infections are spread through close contact, not airborne transmission**…Diseases that are spread efficiently through airborne transmission tend to have high attack rates because they can quickly reach and infect many people in a short period of time. We know that a significant proportion of SARS-CoV-2 infections (estimated 40-45%) occur without symptoms and that infection can be spread by people showing no symptoms. **Thus, were SARS-CoV-2 spread primarily through airborne transmission like measles, experts would expect to have observed considerably more rapid global spread of infection** in early 2020 and higher percentages of prior infection measured by serosurveys. **Available data indicate that SARS-CoV-2 has spread more like most other common respiratory viruses, primarily through respiratory droplet transmission within a short range (e.g., less than six feet).**

Circumstances under which airborne transmission of SARS-CoV-2 appears to have occurred include:

- Enclosed spaces within which an infectious person either exposed susceptible people at the same time or to which susceptible people were exposed shortly after the infectious person had left the space.
- Prolonged exposure to respiratory particles, often generated with expiratory exertion (e.g., shouting, singing, exercising) that increased the concentration of suspended respiratory droplets in the air space.
- Inadequate ventilation or air handling that allowed a build-up of suspended small respiratory droplets and particles.

Existing interventions to prevent the spread of SARS-CoV-2 appear sufficient to address transmission both through close contact and under the special circumstances favorable to potential airborne transmission. Among these interventions, which include social distancing, use of masks in the community, hand hygiene, and surface cleaning and disinfection, ventilation and avoidance of crowded indoor spaces are especially relevant for enclosed spaces, where circumstances can increase the concentration of suspended small droplets and particles carrying infectious virus. **At this time, there is no indication of a general community need to**

use special engineering controls, such as those required to protect against airborne transmission of infections, like measles or tuberculosis, in the healthcare setting.

This CDC guidance has implications for how to use UVGI as an intervention for COVID-19. Recent Illuminating Engineering Society (IES) guidance accordingly recommends upper-room UVGI lamps as the preferred method for UVGI air disinfection of COVID-19.[21] Regarding in-duct UVGI lamp installations, the IES guidance states:

> "When UV is used in ducts, although it ensures that recirculated air does not have viable pathogens, it unfortunately does relatively little to prevent person-to-person transmission in a room where both an infectious source and other susceptible persons share the same air. For effective interruption of transmission, air disinfection has to occur in the same room where transmission is occurring." [21]

The CDC recognizes that UVGI has several potential applications for preventing COVID-19 transmission, but also has limitations and potential hazards.[11] The American Society of Heating, Refrigeration, and Air Conditioning Engineers recommends that the decision whether or not to use UVGI should be based on a complete analysis that considers overall performance goals for air quality, impact on energy use, safety, and economic factors.[22]

UVGI Lamp Safety

UVGI lamp emissions can pose a workplace safety and health hazard if the lamps are improperly used or installed. For example, some UV overexposures have occurred when workers did not recognize that the lamps posed a hazard, in part because some UVGI lamps appear to be visibly dim. However, these lamps can be used safely, provided that workers are informed regarding the hazards and follow appropriate precautions.[17]

Low-pressure mercury lamps, krypton-chlorine lamps, and LED lamps emit UV radiation that poses a hazard to the cornea and skin.

Some krypton-chlorine lamps use narrowband filters, so that 222 nm radiation is primarily emitted. Other UV wavelength emissions are reduced (filtered) to mitigate the potential skin hazard from exposure to these lamps.[24-27]

Pulsed xenon arc UVGI lamps emit UV and visible radiation that poses a hazard to the retina, cornea, and skin. Some pulsed xenon arc lamps are filtered, so that only the UV radiation for disinfection is emitted. This reduces the potential retina hazard, but skin and cornea hazards are still present.

UVGI exposure can theoretically increase long-term risk for UV-related health problems like skin cancer and cataract.[28] However, a 2010 report by the International Commission on Illumination indicated that incidental UVGI exposures in the workplace would not significantly increase one's lifetime risk for cataract or skin cancer when compared to the long-term risk from daily sunlight exposure (primarily UV-A and UV-B). This is especially the case if the UV exposures to workers are kept within the threshold limit values (TLVs) specified by the American Conference of Governmental Industrial Hygienists (ACGIH).[29,30]

Some manufacturers of krypton-chlorine lamps are marketing them as a safer alternative than other UVGI lamps. They claim that far UV-C may pose minimal risk of injury to human tissue. However, these lamps can pose a hazard to the cornea and skin if they are improperly used or installed.[24] Some lamps operate intermittently (on a timer) in order to prolong lamp life and ensure that UV exposures to room occupants are kept within safety limits.

Research studies on short-term exposure effects from krypton-chlorine lamps with narrowband filters have shown promising results that the UV emissions may be less hazardous than other UVGI lamps.[25-27] Studies have begun to examine the long-term effects of chronic exposure to 222 nm UV in mouse subjects, but similar long-term studies on human subjects have not yet begun. According to the Food and Drug Administration, “There is some evidence that excimer lamps, with peak wavelength of 222-nm may cause less damage to the skin, eyes, and DNA than the 254 nm wavelength, but long-term safety data is lacking.” [31]

UVGI lamps may pose other hazards in addition to optical radiation. For example, pulsed xenon lamps may use power supplies that pose electrical hazards to persons who repair or service the lamp. Also, some types of UVGI lamps emit UV wavelengths that generate ozone. In particular, some low pressure mercury lamps are made with a special type of bulb that transmits 185 nm (i.e., “ozone generating” type), while other low pressure mercury lamps block the 185 nm wavelength (i.e., “ozone free” type). Ozone can pose a workplace indoor air hazard. Therefore, ozone free low-pressure mercury lamps should be used indoors for disinfection instead of ozone generating low-pressure mercury lamps. Maintenance and service on UVGI lamps should be performed by authorized personnel only, and workers should dispose of these lamps according to local regulations.

To ensure the safe use of UVGI lamps for surface disinfection:

- **Low-pressure mercury and pulsed xenon lamps**. Workers should place temporary warning signs at access points to the area being disinfected. They should either vacate the area during disinfection, or place opaque barriers between the UVGI lamp and room occupants. If these areas must be occupied during disinfection, and exposures cannot be avoided (e.g., if using a handheld disinfecting UVGI “wand”), then personal protective equipment (PPE) should be used:

    - **Low-pressure mercury lamps and UVGI LED lamps**. Workers should wear plastic or glass face shields to protect the eyes and face, nitrile gloves or work gloves to protect the hands, and clothing with tightly-woven fabrics that covers other exposed skin.

    - **Pulsed xenon arc lamps**. Workers should wear welding or cutting goggles to protect the eyes if the lamp emits UV and visible radiation. If the lamp is filtered so that only UV radiation is emitted, then eye protection that protects against UV-A, UV-B and UV-C radiation should be worn. To protect the skin, wear nitrile gloves or work gloves to protect the hands, and clothing with tightly-woven fabrics that covers other exposed skin.

- **Filtered far UV-C lamps and UVGI LED lamps intended for use in occupied rooms**. These UVGI lamps should only be installed after careful consideration of the risks and potential benefits. For example, they may be installed in rooms with a higher risk of disease transmission, or when other disinfection protocols are inadequate.

    - These lamps should be properly installed according to manufacturer instructions in order to prevent exposures in excess of ACGIH TLVs.[30] Following activation and prior to occupancy, a room commissioning survey must first confirm that UV exposures to workers in the lower room area are within ACGIH limits.[30]

    - Workers should place warning signs to instruct that unprotected personnel to avoid the upper room area while the UVGI lamps are operated. Activation switches should be clearly labeled and protected with switch guards to prevent accidental activation by unauthorized personnel. Installers and maintainers should deactivate all upper room UVGI lamps before ascending to the upper room for any purpose. If this cannot be avoided, workers in close proximity to these lamps for long periods should wear plastic or glass face shields to protect the eyes and face, and protect other exposed skin with tightly woven fabrics.

    - Only narrowband-filtered krypton-chlorine lamps should be used for this application.

To ensure the safe use of UVGI lamps for air disinfection:

- **All lamps**. Workers should place warning signs near upper room UVGI lamps, and on AHU access panels where internal UVGI lamps are installed. Activation switches should be clearly labeled and protected with switch guards to prevent accidental activation by unauthorized personnel. If exposures cannot be avoided, workers should wear plastic or glass face shields to protect the eyes and face, nitrile gloves or work gloves to protect the hands, and clothing with tightly-woven fabrics to protect all other exposed skin.

- **Upper room UVGI lamps**. These lamps should be properly installed according to manufacturer instructions in order to prevent exposures in excess of ACGIH TLVs.[30] Following activation and prior to occupancy, a room commissioning survey must first confirm that UV exposures to workers in the lower room area are within ACGIH limits.

- **AHUs with internal UVGI lamps**. Access panels for AHUs with internal UVGI lamps should be interlocked with automatic shutoff switches to prevent accidental exposure to UV radiation. CDC recommends lockout/tagout protocols for these devices[11]. The Occupational Safety and Health Administration guidance states that lockout/tagout protocols "…require, in part, that a designated individual turns off and disconnects the machinery or equipment from its energy source(s) before performing service or maintenance and that the authorized employee(s) either locks or tags the energy-isolating device(s) to prevent the release of hazardous energy and take steps to verify that the energy has been isolated effectively."[32] An inspection window that blocks germicidal UV radiation (e.g., plastic or glass) should be installed to allow workers to see if the UVGI lamp inside the AHU is operating.

Sunscreen lotions are not approved as PPE to protect the skin against UV radiation produced by UVGI lamps. Sunscreen lotions are made to protect against the UV radiation in sunlight (predominantly UV-A and UV-B), but their ability to protect against germicidal UV radiation (UV-C) has not been extensively studied.

Never use UVGI lamps to disinfect the hands or other skin areas unless recommended to do so as part of a treatment program by a medical provider.[33-34]

OTHER APHC GUIDANCE RELATED TO UVGI

The following Technical Information Papers (TIPs) provide further APHC guidance on possible UVGI applications:

- APHC TIP No. 98-105-0420, Cleaning and Disinfecting Buildings and Areas Previously Occupied by Coronavirus 2019 (COVID-19) Positive Personnel
- APHC TIP No. 98-108-042, COVID-19 Engineering Controls and Verification for Medical Treatment Facilities
- APHC TIP No. 98-113-0420, Measures to Modify Building HVAC for Occupant Health and Comfort During the COVID-19 Pandemic
- APHC TIP No. 98-128-0820, Considerations for the Use of Ultraviolet Germicidal Irradiation

QUESTIONS

Questions about the optical radiation hazards and protective measures for specific types of UVGI lamps should be directed to the APHC NRD at: 410-436-3932, or e-mail usarmy.apg.medcom-aphc.mbx.nonionizing@mail.mil

Questions about non-beam hazards for UVGI lamps (e.g., ozone, electrical) should be directed to the APHC Industrial Hygiene Field Services Program at: 410-436-3118, or email usarmy.apg.medcom-phc.list.org-ohs-ohs@mail.mil

Prepared by: APHC, Nonionizing Radiation Division, 410-436-3932
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APPENDIX A

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