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Occupational Safety and Health Guide for Surface Disinfection Practices using Germicidal Ultraviolet Radiation

White Paper

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Overview

In the midst of a global SARS-CoV-2 pandemic one strategy being used to reduce virus surface contamination of public spaces is disinfection with germicidal ultraviolet radiation. The method has been shown to be effective in reducing germ loads for a variety of infectious agents, including coronavirus (Duan, 2003). In the past two decades, germicidal UV light has been used in microbiology laboratories, water treatment facilities, healthcare ventilation systems, upper room spaces of surgical suites, and even treatment areas of healthcare facilities. Recently, with the current global pandemic, there is an interest in expanding the use of germicidal UV technology to such areas as office building, hotel, retail, or school ventilation systems, and public transportation vehicles such as subway cars and city buses.

This White Paper addresses only occupational exposures to UV light from artificial sources. UV radiation exposure of the public should be in accordance with applicable environmental and public health regulations. In the absence of state or federal limits, public exposures should be held to below ten percent of recommended occupational limits.

Ultraviolet radiation falls in the spectrum of light between 100 and 400 nanometers (nm). The wavelength range of greatest germicidal action is between 100 and 280 nm. (IARC, 2020) At these wavelengths UV light is absorbed by the genetic strands of DNA and RNA in microorganisms and viruses, which causes changes in the structure, rendering the death of the agent, or nonviability in the case of viruses.

Health Effects

All wavelengths of ultraviolet radiation are considered Class 1 Known Human Carcinogens as rated by the International Agency for Research on Cancer of the World Health Organization. (IARC, 2006) In addition, the US National Toxicology Program rates all UV wavelengths (UVA, UVB, and UVC) as “Known carcinogens to humans”. (NTP, 2002) The 254 nm mercury vapor emission line within the UV spectrum has historically been the most widely used germicidal wavelength. At the power levels of UVC that can effectively kill germs in the air or on surfaces, safe durations of exposure to humans is typically limited to a few minutes per day.

Excessive UV radiation absorbed in the outer layer of the eye, the cornea or conjunctiva can lead to pain, inflammation, and photokeratitis. Eye exposure can lead to ocular cataracts. Excessive UV radiation to the skin can lead to reddening (erythema) or more severe burning. UV wavelengths shorter than 242 nm are sufficiently energetic to produce harmful ozone (O_3) through photolysis of molecular oxygen (O_2); however, photolysis of ozone itself at UV wavelengths longer than 200 nm makes net accumulation of ozone unlikely unless the UV source emits wavelengths shorter than 200 nm. (Horowitz et al., 1988, ASHRAE 2018)

Exposure Assessment

The American Conference of Governmental Industrial Hygienists (ACGIH) publishes recommended levels of worker exposure to ultraviolet radiation in their annual Threshold Limit Values® (TLVs). For a given wavelength with an ACGIH TLV_λ (radiant exposure, measured in millijoules per square centimeter, mJ/cm^2), the maximum exposure time (t_{max} in seconds) for a work shift is given by the following equation:

$$t\_max = \frac{TLV_\lambda \frac{mJ}{cm^2}}{E_\lambda \frac{mW}{cm^2}}$$

where E_λ is the power per unit area (irradiance, measured in milliwatts per square centimeter, mW/cm^2) measured at that wavelength with a 100% efficient detector. The TLV_λ for 254 nm UV radiation is 6.0 mJ/cm^2. The TLV can be considered the dose of germicidal radiation to the skin or eye – or to any other exposed tissue – that should not be exceeded in a work shift (ACGIH, 2020). The limits do not apply to photosensitive workers, nor to those concomitantly exposed to photo-sensitizing agents.

Using the equation provided, it is possible to estimate the maximum exposure time for a variety of effective irradiances shown in Table 1.

Table 1. Maximum exposure times allowed for various effective irradiances at the 254 nm wavelength

Maximum Exposure Time (hours)	Irradiance ($\mu W/cm^2$) at 254 nm
8	0.2
4	0.4
2	0.8
1	1.7
1/2	3.3
1/4	6.7
1/60 (1 minute)	100

As can be seen from these calculations above, an occupational exposure to a power level of just 0.1 mW/cm^2* leads to a very short allowable worker exposure time of one minute. The ACGIH TLVs represent conditions under which nearly all healthy workers may be repeatedly exposed without acute adverse health effects of erythema and photokeratitis.

*NOTE VERSION CHANGE: In version 1 of this white paper, exposure to a power level was previously noted as 0.1 $\mu W/cm^2$. This has been changed to 0.1 mW/cm^2.

Sometimes irradiance levels or dose levels can be provided, or estimated, by a UV germicidal system manufacturer. It is important to understand that the irradiance depends on the distance from the germicidal UV source, and the dose depends on both the exposure time and the distance from the source. Therefore, the manufacturer's estimate is only valid for the exposure conditions used when they made that estimate. These exposure estimates may be for just one UV bulb and not an array of bulbs set up and operating at the same time in the same space, which would greatly increase the irradiance levels. It is important to note that other confounding factors such as, but not limited to, relative humidity, volumetric airflow and direction, and concentration of other airborne particulate can affect the irradiant UV exposure.

UV Measurements

In many workplaces it is most prudent to perform environmental assessments of irradiance levels using a hand-held radiometer to make accurate measurements at various locations. This could be even more important in locations where the public could be exposed to such UV germicidal light. For example, it may be clearly understood that the exposure levels inside a subway car are hazardous, but what happens to the power level of the beam as it passes through a closed subway window? It would not be prudent to just assume that the windows filter all the harmful rays down to negligible levels without making measurements to be sure.

In performing UVC measurements one must be sure that they have an appropriately calibrated radiometer, and a special probe that is calibrated for the germicidal wavelength (usually 254 nm). Using a regular radiometer that is not specific to the germicidal wavelength emitted by the device will not give accurate readings that are useful for the ACGIH TLV exposure assessment calculations. The operator of the radiometer should be well aware of the spectral response of the meter. The operator should also be aware of the angular response of the meter when taking field measurements. Generally, a "cosine response" of the detector is desired. It is also important that the UV system is operating at full power, and that all bulb arrays are operating in unison to determine the maximum irradiance levels and potential worker exposures.

Once UV measurements are taken using the appropriate equipment by a competent industrial hygienist, the values can be used in the TLV equations to determine allowable work locations and durations. Records of all field measurements and exposure analyses should be maintained for a period in accordance with other industrial hygiene monitoring results used at the workplace.

Controls

In locations or activities where hazardous levels of UVC are unavoidable to workers or the public, then appropriate controls must be undertaken to ensure the levels are kept within the limit values. The level of controls needed will be dependent on the results of potential worker exposure level calculations or measurements.

Engineering Controls

The first line of defense to prevent human exposure to hazardous UVC is the use of physical enclosures. Some devices allow the direction of the beam away from the operator, thus significantly reducing the power of the radiation that the worker may be exposed to because the beam is diffuse or scattered. Spectral reflective or mirror like surfaces on equipment or machinery should be considered as potential source of indirect irrandiant exposure. Operating the device at a greater distance can also be an effective means of reducing worker exposure as the irradiance falls off according to the inverse square law, and basically for each doubling of the distance, the UV irradiance is reduced by a factor of four. Other engineering controls can include the use of screens, curtains, or shields. System interlocks and safety controls are also need for these devices to ensure they can only be operated by trained and authorized personnel, and they shut off automatically when the protective enclosure is opened.

UV radiation should be contained or confined to a restricted area when practicable. UV radiation can be easily contained with opaque materials, such as cardboard or wood. Transparent materials, such as glass, PVC (polyvinylchloride), plexiglass and perspex, block UV radiation in varying degrees. Generally, carbonated plastics provide adequate UV protection. Some kinds of clear glass (including some kinds of window glass and optical glass) transmit significant amounts of UV-A radiation.

Administrative Controls

Policies, programs, and detailed Standard Operating Procedures must be created before any germicidal UV system is put into place. Special procedures for equipment maintenance must also be part of the initial program. Management, supervisors, workers using and maintaining the equipment, and ancillary bystander employees must all receive the appropriate level of operational or awareness training. Mechanisms for reporting incidents or accidents associated with malfunction or possible human exposures must be developed and disseminated.

In all cases the administrative controls used in combination with available and practical engineered controls should minimize or eliminate human exposure. Where this is not practical the exposures under administrative controls should be as low as reasonably achievable. Whenever UV radiation cannot be contained or confined, worker exposure should be minimized by limiting exposure times and increasing the distance between workers and the sources.

Administrative programs should include the use of consistent posting of warning signs and lights related to the operation and use of the UV system. Periodic audits and surveillance of programs should be conducted, and deficiencies corrected promptly. Administrative programs should include a list of all UV sources in the workplace and include their wavelengths and output power (if available) and determine their hazard potential. The list should be updated as new devices are added. Persons qualified to perform measurements and risk assessments should be identified. Control measures for each UV device should be developed and updated as necessary.

Personal Protective Equipment

In cases where workers must be in locations that exceed ACGIH TLVs then appropriate Personal Protective Equipment (PPE) must be provided at no cost to the employee. Protective clothing, including gloves and eyewear, should be analyzed and selected by a competent industrial hygienist to ensure that they each have the appropriate level of filtration of the hazardous UV radiation. Workers exposed to UV radiation in excess of the above guidelines should use the following personal protective equipment: UV-blocking safety eyewear (goggles, spectacles, face shields, welding shields, etc.) with side-shields where applicable, and sun-screen effective against all UV wavelengths on all exposed skin. It is recommended that the UV protective clothing be tested with actual radiometric filtration measurements either conducted in a laboratory, or onsite, or both. The reduction of UV filtering effectiveness for protective clothing with washing and normal wear should also be considered, if reusable PPE is utilized.

Protective eyewear must be evaluated to ensure that adequate Optical Density (OD) is provided to reduce radiation to the eye below the TLV. All protective eyewear should be labeled as ANSI approved and include the OD for the wavelength of interest. Eyewear should be inspected periodically, and workers should be trained on their use and care.

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