USACHPPM
Readiness thru Health

25-020-1009

Just the Facts...

USACHPPM Consensus Statement on UV Germicidal Irradiation for Upper Air Disinfection in the Workplace

Background

The following consensus statement on UV Germicidal Irradiation (UVGI), and important issues regarding its use for air disinfection in the workplace was developed at an expert meeting held at the USACHPPM on 31 May 2007. The 15 attendees included government representatives from the USACHPPM, Edgewood Chemical and Biological Center, the Centers for Disease Control, the National Institute of Standards and Technology, the General Services Administration; industry representatives from Acuity Lighting, Osram Sylvania and Gigahertz Optik; academic researchers and field use specialists from St. Vincent's Hospital in New York, the University of Colorado and Harvard School of Public Health, and independent consultants.

Efficacy of UVGI for Air and Surface Disinfection

UVGI is a proven technique for inactivating bioaerosols, and UVGI lamps have been used to combat infectious airborne agents such as tuberculosis bacillus for decades. However, the efficacy depends upon the organism. Short-wavelength (UV-C; 100-280 nm) UV radiation is highly effective in damaging DNA. Once the DNA has been damaged (inactivated), the biological agent is no longer likely to be infectious, although some inactivated agents may remain allergenic, e.g., some fungal spores or bacterial endotoxins. UVGI does not generally affect endotoxins and allergens, and such substances must be removed by other means. The efficacy is greatest for exposed airborne viral agents, although when the DNA of the biological agent is buried inside sputum particles, the UV radiation may be attenuated and greater UV exposure doses are required. There are two types of in-room UVGI: (1) upper air disinfection, or (2) full room disinfection, e.g., with a UVGI lamp located in a central area of an unoccupied room. UVGI lamps can also be installed in air-recirculating enclosures, and in ducts for heating, ventilation and air conditioning (HVAC) systems. Upper air UVGI is more effective for immediate exposures.

UVGI for disinfection of surfaces can be highly effective, as demonstrated by its use during disinfection processes for food, as well as disinfection hoods for laboratory equipment. This technique can be less effective because the reach of UV photons into nicks and crannies of surfaces or a covering of dust and other matter may shield the agent being disinfected.

Dose Required to Inactivate Microorganisms

The required dose to achieve a given fraction of inactivation (e.g., 90% or 99%) will vary with humidity, organism type and the amount of extraneous material that might shield the microorganism. Exposure doses can vary between 30 and 200 J/m^2 (i.e., 3-20 mJ/cm^2) effective ultraviolet exposure. The "effective" exposure dose or "effective" irradiance is determined by spectrally weighting the UV spectral radiant exposure or spectral irradiance by the action spectrum for germicidal effectiveness.

Design and Safety Considerations, Prior to Installation of Upper Air UVGI Systems in the Workplace

The determination of the practical design for a UVGI installation is a judgment call that depends upon the determination of the risk and consequences of the biological agent and the percentage to which it should be reduced to achieve effectiveness.

Air mixing. Adequate air mixing in critical for effective upper-air disinfection. Room air must circulate within the irradiated zone for maximal efficacy. Ceiling fans are highly effective in moving air upward into the irradiated zone. UVGI employed within ductwork or plenums are designed to irradiate the entire cross-section of airflow, however ventilation system effectiveness and room "dead spots" must be considered.

Safety of bystanders, occupants, and maintenance workers. Internationally recognized health-protection standards exist for protection against adverse effects upon the eye and skin from UV-C and UV-B radiant energy. The daily exposure limit is 30 J/cm^2 (3 mJ/cm^2) effective exposure (spectrally weighted against the UV hazard spectrum defined by the American Conference of Governmental Industrial Hygienists). Thus, the installation must take into account the occupancy levels, durations for potential exposure, and the movement patterns of people in the room. This includes the possibility that maintenance personnel may use ladders to adjust lighting fixtures, and would need to be aware of the hazard and take appropriate precautions. Some in-room UVGI devices have been developed to activate only when a space is not occupied; if a UVGI lamp is to be operated in an occupied room, then only upper-air UVGI devices can be applied safely. UVGI installed in ventilation systems will not expose normal building occupants, but must not be operated when access is gained for servicing.

The production of ozone by short-wavelength UV-C (wavelengths less than 230 nm) from quartz-envelope lamps has been of health concern; hence, properly designed UVGI lamps employ a UV-transmissive envelope that blocks wavelengths below ~ 235 nm.

UVGI Equipment Quality Control

Several manufacturers produce UVGI lamps and fixtures. Such equipment must be properly installed to achieve the intended and expected efficacy as well as safety. Interchangeable lamps and replacement parts can impact efficacy and safety; hence, the UVGI components and fixtures should be certified and maintained as intended by the manufacturer.

Might UVGI Actually Increase the Pathogenic Potential of Mircrobes?

UVGI has been criticized on a hypothetical basis in the past for having the potential to induce genetic mutation in an airborne biological agent, which may in-turn increase its pathogenic potential. This is largely a myth. UVGI researchers are generally skeptical of the potential for UV-C radiation to have any serious mutation potential in terms of drug resistance in people or even virulence in human populations. The probability of increasing the virulence of airborne microbes by UV induced mutation of genes associated with antibiotic resistance, or other virulence factors, is immeasurably low – particularly in UVGI systems where relatively high energy doses are delivered to inactivate airborne microbes in time frames on the order of seconds. While UV irradiation has been used as a tool for inducing random mutagenesis in some bacterial cultures, spontaneous mutations happen at a slower rate in organisms all the time, and do not necessarily cause spontaneous drug resistance in people. In the case of tuberculosis, for example, it is believed that drug resistance either comes from bad treatment (the use of single agents) or by transmission of the agent from someone with drug resistance. It is uncommon to diagnose an instance of drug resistance without one of these factors. Further, the UV doses used for inducing mutation are orders of magnitude lower than those designed for UVGI, because survival is anticipated in such an approach.

What is key is that mutations are selected by environmental conditions to predominate in competition with wild-type organisms. A selection pressure drives the ecological success and progression of the mutant population. It is a general truism that mutations usually are less "fit" than wild type organisms. The only reason that spontaneous drug resistance mutations survive in a host is the presence of effective antibiotics that kill wild strains, allowing even less-fit mutants to survive. To argue that upper room UV-C radiation could cause mutations requires the following unlikely chain of events (using tuberculosis as an example):

a. A non-lethal DNA mutation in an airborne, presumably non-replicating, organism
b. Mutated organism must remain virulent against host defenses despite presumed loss in fitness
c. The mutation has some survival advantage in a host. For example, if by chance a random DNA mutation caused INH resistance (i.e., resistance to isoniazid, an anti-bacterial drug that has been used to prevent and to treat tuberculosis since 1952), and a person was infected, but an infected person was not taking INH, there would be no advantage to that mutation, only the loss in fitness.
d. Normal DNA repair mechanisms are ineffective in reversing the mutation, i.e., INH resistance, and restoring competitive fitness in any subsequent organisms. In the absence of treatment, drug resistant organisms can revert to drug susceptible and again dominate in an infection.

In general, aerosols are considered relatively hostile environments for microbial survival, and replication in an aerosol phase is limited because growth factors are limited, as is water. While airborne in a UVGI system, UV doses are purposely delivered such that massive DNA damage occurs in a de facto non-growth environment (air), where microbes have no sustained selection pressure. Thus successful mutagenic progression is unlikely.

UVGI Used with Air Filters, as Part of a Multi-Tiered Approach for Controlling Contagions

Hybrid systems are most effective for this purpose, that include high efficiency particulate air (HEPA) filtration in HVAC systems, in-duct UVGI within the HVAC system, and also upper-room UVGI with proper air mixing. A complete analysis of the potential threat and risk reduction requires consideration of all means to reduce the potential human exposure to aerosolized biological agents.

Future Needs

The following future areas of research and necessary activity were identified by the group:

- Standards for safety, including guidelines for proper installation of UVGI systems, guidelines for in-room workers, and recommendations on the use of proximity detectors, safety interlocks, or other protective measures to prevent accidental overexposures.
- Tests on reflectivity and degradation of in-duct materials and ceiling tiles.
- Definition of a scale or “grade” for UVGI systems. A Grade 1 UVGI system would be developed for improved indoor air quality; Grade 2 for public health and hospitals, and Grade 3 for bioterrorism defense.
- UVGI efficacy and efficiency studies on UVGI systems in “real-world,” less-ideal environments.

Questions?

Further questions or requests can be referred to the USACHPPM, Laser/Optical Radiation Program, DSN 584-3932 or Commercial (410) 436-3932.