USE OF UV-C DISINFECTION CHAMBERS AND AIR PURIFIERS IN THE HEALTH CARE SECTOR

Technical Brief prepared by Murray Ward
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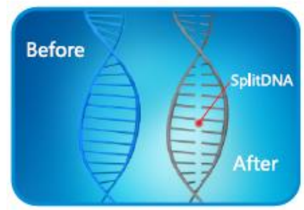
1. General science

Ultraviolet germicidal irradiation (UVGI) is a disinfection method that uses UV-C light to kill or inactivate microorganisms by destroying nucleic acids and disrupting their DNA, leaving them unable to perform vital cellular functions.



Schematic diagram of UV disinfection

UV-C radiation has been scientifically proven in hundreds of studies to kill and deactivate harmful microbiological pathogens including, most recently, the SARS-CoV-2 virus. The *Ultraviolet Germicidal Irradiation Handbook* lists data for over 600 microorganisms (bacteria, viruses and fungi) studied under various UV radiation sources.[1]

The critical parameter to determine the efficacy of UV-C for a given pathogen is the dose of UV-C radiation received (measured in millijoules per cm^2). The extent of the kill or deactivation is measured in %. The term 'log reduction' is regularly used. 99.9% is called 3-log. 99.9999% is called 6-log. Different pathogens will require different doses of UV-C to achieve the same %. The nature and condition of the surface also matters greatly. For example, the dose required to sanitize a porous multi-layer surface like that of an N95 mask can be 1,000-2,000 times greater than that required to sanitize a non-porous hard surface.

For the SARS-CoV-2 virus, on hard surfaces a 3 log reduction (99.9% deactivated) can be achieved with a UV-C dose of 3.7-7.6 mJ/cm^2. A 6-log reduction (99.9999% deactivated) can be achieved with a dose of 16.7-22.0 mJ/cm^2.[2]

Another term related to dose is "fluence" which also is measured in units of mJ/cm^2. Technical literature will often use the term fluence. The difference is described in these definitions:

> **UV Dose**: The amount of UV irradiation absorbed by an exposed population of microbes, typically in units of mJ/cm^2 (mJ/cm^2 = 1,000 $\mu W/cm^2$ per second). Often assumed to implicitly represent total absorbed dose.
>
> **UV Fluence**: The total radiant energy incident on an infinitesimal sphere. Technically, this term is more accurate than the more commonly used term "UV dose."

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[1] A useful summary list drawn from this handbook can be found at https://clordisys.com/pdfs/misc/UV%20Data%20Sheet.pdf

[2] Source: Biasin, M et al. UV-C irradiation is highly effective in inactivating SAR-CoV-2 replication. https://www.nature.com/articles/s41598-021-85425-w

2. History of UVGI in the health sector


Upper-Air UV-C Devices in TB Facility

Early applications of UVGI systems include their use in 1936 to reduce postoperative infections and their use in 1937 in the ventilation system of a school to reduce the incidence of measles. In the late 1950s and early 1960s, Riley et al. conducted a series of animal experiments that showed conclusively that intense UVGI in air ducts kills or inactivates virulent M. tuberculosis in droplet nuclei.[3]

Modern applications of UVGI in health care facilities include:

- high output UV-C emitters in recirculating central air handling systems
- upper-air systems which emit UV-C into the unoccupied zone of the room, without air movement (as the photo above of the TB facility)
- upper-air systems which emit UV-C into the unoccupied zone of the room and include fans that draw air through the units (increasing the effectiveness versus old style passive emitters)
- upper-air systems which include fans that draw air through the unit and an internal UV-C chamber, where the UV-C light is not visible (these may also include other filter material, e.g. medical grade HEPA filters)
- ceiling, wall mounted or portable units (including moving robots) that emit UV-C to disinfect room surfaces, and operate when the room is **not** occupied
- UV-C disinfection chambers that disinfect objects placed into the chamber, and which operate on a timed cycle
- wall mount or portable air purifiers that can be placed into a space in a room that draw air through the unit and an internal UV-C chamber, where the UV-C light is not visible (these may also include other filter material, e.g. medical grade HEPA filters)
- special application UV-C systems designed for situations not covered above, e.g. irradiating the inner bore of a CT machine

The most common source of UV-C in these UVGI systems are low pressure mercury lamps that emit UV-C at 254 nm. Most scientific studies and data available are for this source. Recently there have been new technologies including UV-C LEDs (which emit at 260-280 nm) and excimer lamps in the Far UV-C range (which emit at 222 nm). Compared with the standard 254 nm lamps:

- LEDs have the benefit of being less fragile and breakable, but their electrical efficiency and UV output is very much less, and they are still relatively expensive
- The wavelength of Far UV-C is not dangerous to humans so these can emit into an occupied space, but the efficacy of inactivation of microbiological organisms is not as strong, and they are still relatively expensive

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[3] Source: CDC-NIOSH. Environmental Control for Tuberculosis: Basic Upper-Room Ultraviolet Germicidal Irradiation Guidelines for Healthcare Settings

The balance of this Technical Brief focuses on **UV-C disinfection chambers** and **air purifiers** (‘portable’ and ceiling mount) that utilize the standard 254 nm germicidal lamps.

3. UV-C Disinfection Chambers

These come in multiple shapes and sizes, a few of which are shown here (including the *UVY* brand units designed and manufactured by Greenlight Canada).

A common use of disinfection chambers in medical facilities has been to disinfect such things as personal electronics like cell phones and tablets, and other personal items such as glasses and pens. The key point is that these have not been intended for disinfecting items classed as medical devices as this would require the disinfection chambers themselves to have regulatory approval (by US FDA or Health Canada) as a medical device.

In the early stages of the COVID-19 pandemic when there was great concern about the shortage of PPE, in particular N95 masks, there was a flurry of activity to use UV-C disinfection chambers to disinfect PPE. These were often custom made systems by hospitals and medical technology service providers. However, it was soon discovered by a range of studies worldwide that N95 masks were not an easy item to disinfect due to their porous and multi-layer nature. It was shown they could be disinfected to 99.9% (3 log) levels with a dose of 2,000 – 4,000 mJ/cm^2 applied to each side, but a 6 log reduction (99.9999%) necessary to meet sterilization protocols was not practically achievable. Moreover, masks showed physical degradation from the effects of multiple cycles, and failed physical integrity test requirements.

The outcome of these studies was that while FDA did allow a temporary use authorization for the use of such UV-C disinfection of N95 masks, it only was associated with a 3 log reduction and required the used masks to also go through the exact same multi-day handling requirements as if the masks were not disinfected at all. Health Canada did not provide even this level of authorization. By the time these studies had happened, and the FDA and Health Canada positions were firmly established, the concern about the COVID-19 pandemic had shifted more to airborne aerosols. The PPE supply problem had also mostly passed, in North America anyway.

This lesson does not detract from the scientific fact that UV-C is a powerful non-chemical means to disinfect objects that may be contaminated with pathogenic microorganisms that may be present in health care sector environments. Across the health care sector, including in elderly care facilities, when thinking about infection control and pandemic readiness, we expect there can be many applications of using UV-C disinfection chambers that do not involve disinfecting medical devices.

As noted in section 1, the science is well established to know the doses of UV-C needed to kill and inactivate such organisms, especially on hard non-porous surfaces. Taking the example of the SARS-CoV-2 virus, a 3 log reduction (99.9% deactivated) can be achieved with a UV-C dose of 3.7-7.6 mJ/cm^2. A 6-log reduction (99.9999% deactivated) can be achieved with a dose of 16.7-22.0 mJ/cm^2.

For a disinfection chamber the key parameter is the UV-C intensity (in mW/cm^2) present in the zone where the objects will be placed. The dose (in mJ/cm^2) it delivers is then this intensity times the number of seconds the chamber is operated. Put another way, the number of seconds to operate a chamber for a given object can be calculated by the formula: time = target dose / intensity.

In practice, depending on the size and shape of the objects the surfaces of the objects will be at different distances from the UV-C lamp(s) irradiating the space. Inside a mirrored surface cabinet, the mathematics of this is very complex. As a result, it is not practical to have precise calculations of how long to operate a chamber to deliver a precise dose. General average estimates can be calculated and conservative factors added in.

A starting point is test data for the UV-C lamps used in the cabinets. The data below is for the 463 mm UV-C germicidal lamp used in the *UVY* product line chambers. The rating for this lamp is: Power 23W, UV output 8W, UV intensity at 1 metre 78 µW/cm^2. The table below shows the UV intensity measured at a selection of distances from the surface of the lamp.[4]

Distance from lamp, mm	UV-C intensity uW/cm^2	Time to achieve 25 mJ/cm^2, secs
10	7,600	3.3
50	3,040	8.2
100	1,940	12.9
150	1,480	16.9

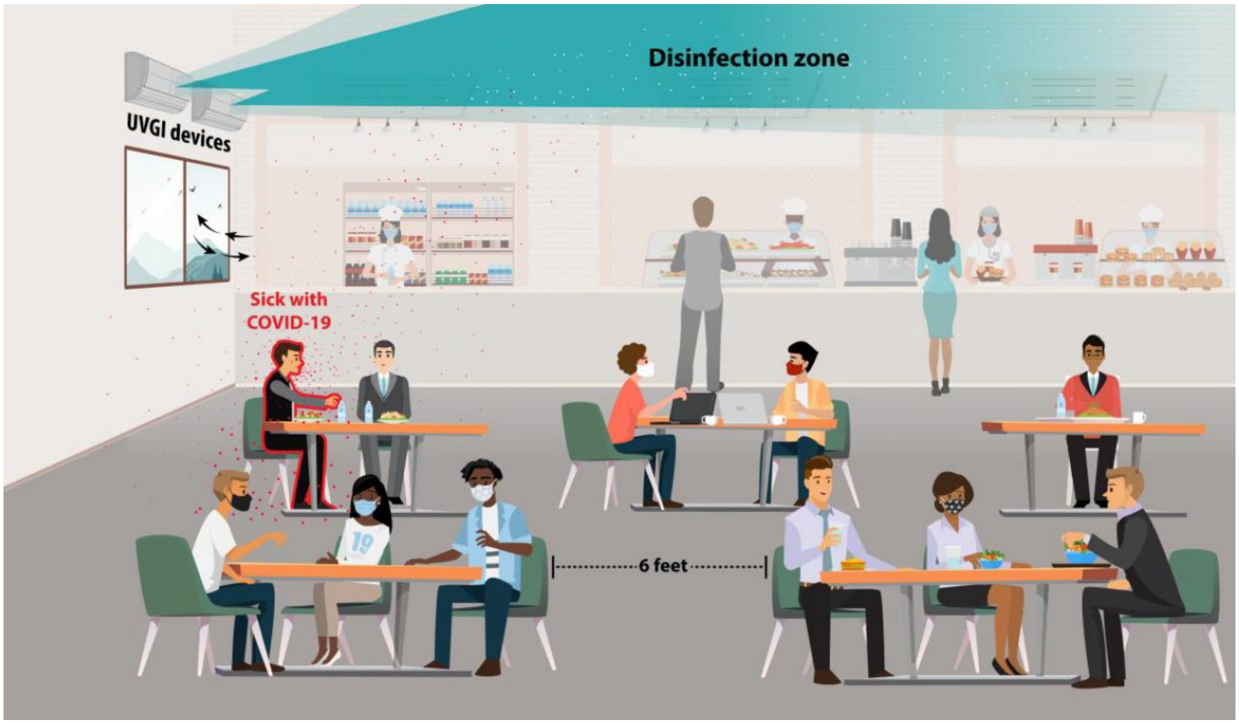
[4] Note that these UV-C intensity test values will be conservative when such a lamp is operated inside a mirror wall cabinet.

A key point from this data is that disinfection times to achieve target dose amounts for hard surfaces are comparatively short (so in seconds not minutes). What this means is that UV-C disinfection chambers can be used for rapid disinfection procedures where the loading and unloading times are more the limiting factor, not the disinfection cycle itself.

A practical example of how this is meaningful would be disinfecting personal electronic and other items as staff arrive for their shifts or take their breaks.

4. Air Purifiers utilizing UV-C germicidal technologies

The use of UV-C germicidal technologies is explicitly recommended in documents by the US CDC and ASHRAE related to COVID-19.[5] UV-C, along with high efficiency mechanical filtration technologies such as HEPA filters, can be seen as proven technologies given decades of experience. As noted in section 1, the use of upper-air UVGI systems includes its use to control tuberculosis (TB). The infographic below is from a recent CDC document[6]. This notes that UVGI has been used for over 70 years to eliminate airborne pathogens and that current guidance from CDC[7] and NIOSH on the design, installation, testing, and safe operation of upper-room UVGI systems is based on science and practice-based evidence to control TB.



This CDC document also notes that influenza viruses are more susceptible to UV energy than the bacteria that causes TB. Thus, any upper-room UVGI system installed to help during the COVID-19 pandemic will also be useful against seasonal flu, if it is properly maintained.

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[5] See https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation.html#print
and https://www.ashrae.org/file%20library/about/position%20documents/pd_infectiousaerosols_2020.pdf
[6] See https://www.cdc.gov/coronavirus/2019-ncov/community/ventilation/uvgi.html
[7] See https://www.cdc.gov/niosh/docs/2009-105/pdfs/2009-105.pdf?id=10.26616/NIOSHPUB2009105

ASHRAE includes a whole chapter (19) on UVGI systems in its 2019 ASHRAE Handbook. The recent publication on Filtration and Disinfection from the ASHRAE Epidemic Task Force[8] also provides a detailed summary on applications of UVGI.

Air purifier systems utilizing UVGI technologies that are intended to supplement buildings' existing HVAC systems can be ceiling mounted, wall mounted or floor mounted. Modern upper-air systems (so intended to operate and treat air in the unoccupied upper-air zone) can also include fans that move air through the zone, so increase the effectiveness by drawing air across their internal UV-C lamps (example right).

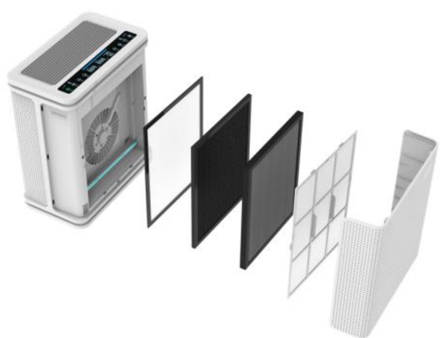
Floor mounted 'portable' air purifiers utilizing UVGI technologies are also available in a range of shapes and sizes. These can be of three general types:

(i) UV-C is the principal technology to control (inactivate) microorganisms

(ii) UV-C supplements high efficiency MERV or HEPA mechanical filters, which both play a role

(iii) The UV-C performs two functions; the regular inactivation of microorganisms role, plus the activation of a photocatalytic oxidation PCO filter. This latter technology is described as one of a number of "emerging technologies" in CDC and ASHRAE literature referenced in this Brief.

Some recent portable air purifiers take a multi-tiered approach that incudes multiple filtration and disinfection technologies. The example right includes medical grade HEPA, activated carbon and PCO filters, plus UV-C lamps.



Room air purifiers may or may not have high single pass efficiencies. HEPA filters will provide very high efficiencies (when operating and maintained correctly). For UV-C, the single pass efficiency will depend on the residence time of air passing through the UV-C chamber, the UV output of the lamps and the dose of UV-C that particles in the air stream will be subject to as they pass through. For HVAC in-duct UV-C systems intended to have high single-pass efficiency, ASHRAE recommends[9] a minimum UV exposure time of 0.25 seconds and minimum UV dose of 1,500 $\mu J/cm^2$.

In practice the efficacy of room air purifiers, whether upper-air (with fans) or whole room, depends on multiple passes of air through the device. It can also be affected by how it operates in conjunction with the existing air flow patterns established by mechanical AC systems or natural ventilation.

FOR MORE INFORMATION OR HELP: email contact@greenlightcan.ca

[8] See https://www.ashrae.org/file%20library/technical%20resources/covid-19/ashrae-filtration_disinfection-c19-guidance.pdf

[9] Source https://www.ashrae.org/technical-resources/filtration-disinfection