BUREAU OF INDIAN STANDARDS

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PART 17 SCIENCE OF ULTRA VIOLET AND ULTRA VIOLET GERMICIDAL IRRADIATION APPLICATIONS FOR HOSPITALS

[First Revision of SP 72 (Part 17)]

Illumination Engineering and Luminaries Sectional Committee, ETD 49

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FOREWORD

Ultraviolet Germicidal Irradiation (UVGI) technology is a proven methodology in killing and deactivating germs, viruses, and molds. It is emerging as a crucial and efficient tool for disinfecting and sterilizing surfaces in hospitals, offering a contactless and rapid solution at a lower cost. UVGI has also proven effective in sterilizing the air within hospital settings. However, it is essential for users to have a thorough understanding of UVGI technology before implementing it, as improper use can pose risks to human health and may render the treatment ineffective against the targeted pathogens, potentially leading to serious infections.

1 SCOPE

This chapter covers the following aspect of UVGI in hospitals:

a) The science behind UVGI technology,
b) Sources for generating UVGI.
c) UVGI for Surface and Air decontamination applications.
d) UVGI effectiveness in eradication of pathogens.
e) Human Safety from UVGI
f) Applications for UVGI in Hospitals
g) Luminaires/ fixtures for UVGI
h) UVGI Dosage to kill pathogens.
i) UVGI Metrology and measurement devices
j) Monitoring Effectiveness of UVGI

2 NORMATIVE REFERENCES

IS No / Other Standard No	*Title*
IS 1885(Part 16): 2023	Electrotechnical Vocabulary Part 16: Lighting
IEC 60050-845: 2020	International Electrotechnical Vocabulary: Lighting

3 TERMINOLOGY

All the definitions given in IS 1885(Part 16) are applicable to this standard.

4 HOW DOES UVC RADIATION KILL /INACTIVATION OF PATHOGENS

While almost all three, UVA-UVB-UVC- can inactivate Pathogens (Sunlight which contains UVA, UVB has been used by Indians for Centuries to sanitise beds and mattresses), the best killing/ inactivation has been found to be at 265nm UVC (see Inactivation Curve in Fig. 1 below).

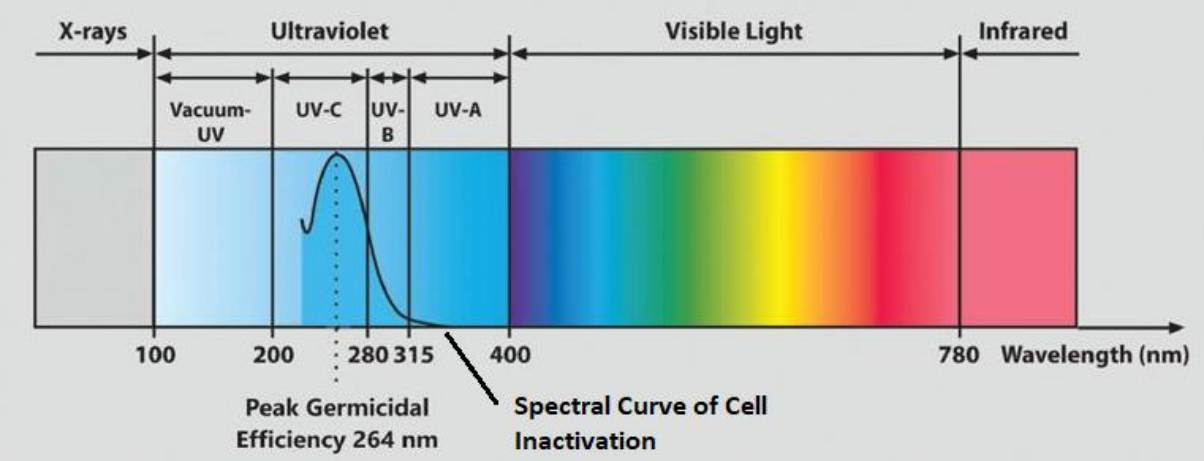

Fig. 1 Cell Inactivation Curve

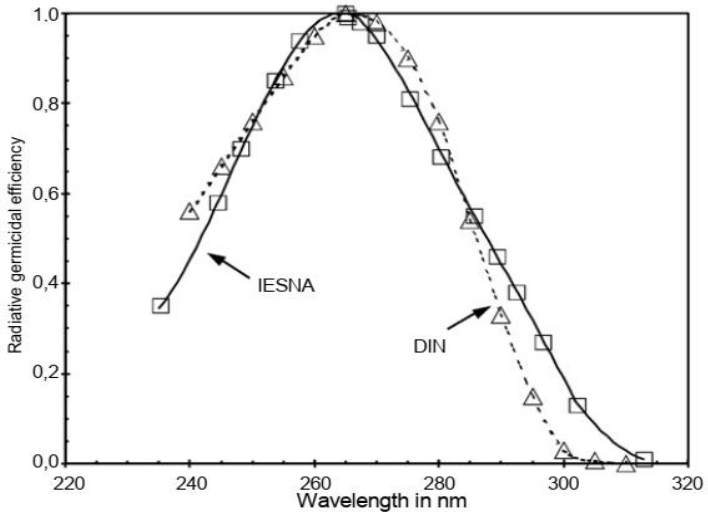

Fig. 2 UV Spectrum

The wavelength range around 264-265 nanometers in the UV spectrum as shown in Fig. 2 is indeed highly effective for cell inactivation. UVC light within this range is particularly efficient at disrupting the DNA and RNA in pathogens. Specifically, it targets the thymine bases in DNA (or uracil bases in RNA), causing two consecutive thymine bases to bond together and form dimers. This bonding disrupts the normal structure of the DNA or RNA, rendering it incapable of replicating properly and essentially useless.

While cells and pathogens do possess some mechanisms to repair minor disruptions in their DNA or RNA, when the damage is extensive and numerous, the DNA becomes irreparably destroyed. In such cases, the pathogen loses its ability to replicate, effectively inactivating it.

This process represents the standard mode of inactivation for many types of pathogens, including bacteria. Refer Fig. 3.

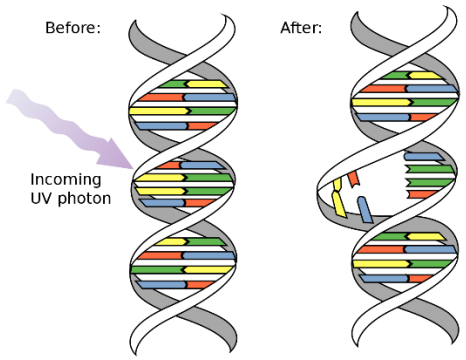

Fig. 3 Effect of UV Photon on DNA or RNA

Indeed, the formation of thymine dimer lesions in DNA is a crucial mechanism by which UVC radiation disrupts the normal structure of genetic material. This process involves two consecutive thymine bases on one strand of DNA binding together due to the UVC photon's energy, resulting in the destruction of the regular base-pairing double-strand structure in that specific region.

Viruses are not considered living organisms in the traditional sense, as they lack the cellular machinery necessary for independent life processes. Instead, they consist of genetic material (either RNA or DNA) encased in a protective protein coat. When a virus infects a living cell, it relies on the host cell's machinery to replicate its genetic material and create more copies of itself. UVC radiation can irreparably damage the viral RNA or DNA, effectively destroying the virus and preventing it from replicating or infecting other cells. This is a critical aspect of using UVC technology for disinfection and sterilization, as it helps eliminate viral contamination. Similarly UVC Radiation is able to inactivate a pathogen such as a parasites, plasmodium (malaria), Fungus also by damaging its DNA.

Viruses, given their microscopic size and thin protective layer, are swiftly penetrated and damaged by UVC energy, making them highly susceptible to rapid inactivation.

Bacteria, on the other hand, with their larger and more intricate structures, require a more substantial dose of UVC, necessitating higher intensity or longer exposure to achieve effective inactivation.

Bacterial spores, such as those produced by Anthrax, pose a formidable challenge due to their robust and dense protective shells. Nonetheless, with a sufficient dose of UVC, these spores can also be rendered inactive.

Molds, fungi, and their spores, being relatively large organisms, demand a significant amount of UVC energy for successful disinfection. Nevertheless, UVC can effectively eliminate them as well.

Another mechanism by which ultraviolet light (UVA, UVB, and UVC) combats pathogens is by breaking down molecules to generate free radicals and oxidants. These chemical agents attack germs by oxidizing their components, further contributing to their inactivation.

In addition to UVC disinfection, another widely employed method involves the use of mercury vapor lamps emitting UV radiation at a wavelength of 185nm, which generates ozone gas (O3) from oxygen molecules. Ozone is an unstable gas that promptly releases an extra oxygen atom to revert to its stable O2 state. This nascent oxygen (atomic oxygen, distinct from O2 molecules) is exceptionally reactive and serves as a potent oxidizing agent, surpassing the oxidizing power of chlorine. It damages pathogens by oxidizing their protective shells or by infiltrating cell membranes and oxidizing their proteins, DNA, and RNA, ultimately destroying them.

Since ozone can disperse throughout enclosed spaces, it is employed for disinfecting areas that may not be accessible to direct UVC exposure, which primarily operates through line-of-sight disinfection.

Nevertheless, it's crucial to underline that ozone is a hazardous gas, and even small quantities can pose risks to human health. Therefore, its use must be strictly regulated and accompanied by appropriate safety measures to safeguard individuals from potential harm.

5 UVC RADIATION SOURCES

5.1 UVC energy can be generated through various methods. Some of the most commonly used are as follows:

a) *Hot Cathode Low-Pressure Mercury Vapour Discharge Lamps* — These lamps are similar to fluorescent tubes but lack the fluorescent coating and use UVC-transmitting glass. UVC energy is emitted when an electric discharge ionizes the mercury vapor in the tube. A significant portion of the emitted energy is at 253.7nm, with up to 35% efficiency. These lamps also emit some energy at 185nm, which ionizes and produces ozone. They are sensitive to temperature changes and have a lifespan of around 9000 hours, extendable to 12000-16000 hours with special coatings. There are several versions of these lamps, including those using UVC transparent soft glass, quartz glass, or pure quartz glass with ozone production.

b) *Cold Cathode Low-Pressure Mercury Vapour Lamps* — These lamps generate UVC radiation similar to hot cathode lamps but are less efficient and produce lower UVC output. They are not widely used except in small portable applications due to their lower efficiency.

c) *Medium and High-Pressure Mercury Vapour Lamps* — These lamps are used for applications requiring very high power but are less efficient at generating UVC compared to low-pressure lamps. They find use in large water treatment plants.

5.2 Non-mercury UVC generation solutions are also used due to their environmental and safety benefits over mercury UVC. Some of these alternatives include:

a) *Xenon Lamps*— These lamps filled with low-pressure xenon gas emit high-intensity flashes of arc discharge, producing a broad spectrum of wavelengths, including UVC.

b) *UVC LEDs (Ultraviolet-C Light Emitting Diodes)* — UVC LEDs are developed as a viable UVC light source. They have lower efficiency, typically around 2 % to 5%, with higher efficiency toward 275-280 nm. UVC LEDs can have long lifespans exceeding 50,000 hours, making them suitable for continuous applications with low maintenance. However, they emit a narrow band of UVC radiation centered around wavelengths like 265nm or 275nm. Special precautions are needed when using UVC LEDs, such as providing secondary warning lights since they are not visible to the human eye. Additionally, UVC LEDs operating at 275-280nm have a higher corneal absorption rate, which can cause eye damage at lower energy levels compared to 254nm UVC sources. The cost of UVC LEDs is expected to decrease over time, making them a more cost-effective alternative to mercury-based light sources.

c) *Excimer Lamps* — These lamps used in industrial UV generation applications, generate UV radiation based on transient excited dimer (excimer) molecules. There is a new type of UVC lamp known as the KeCL (Krypton Chlorine) Excimer lamp that emits UVC radiation at 222nm. This wavelength is lethal to germs but does not penetrate the upper layer of human skin, making it potentially safe for use around humans. Ongoing tests are being conducted to evaluate its safety and effectiveness.

These various UVC generation methods offer different advantages and considerations, and their choice depends on specific application requirements and safety concerns.

6 UVGI SAFETY REUIREMENTS

6.1 UVC radiation, ranging from 200-280nm, is high-energy and potentially harmful to humans. Unlike UVA and UVB radiation, which can penetrate deep into the skin's dermis, UVC's shorter wavelength and higher frequency restrict its ability to penetrate the skin. UV-C radiation can be a hazard to exposed humans and materials if proper safety measures are not observed.

The Table 1 describes the maximum allowable dose of UVC radiation at 254nm that a human can be exposed to in a workday. It is crucial to ensure that these levels are not exceeded to protect against potential health risks.

Table 1 Maximum Allowable Dose of UVC Radiation
(*Clause* **6.1**)

Sl. No (1)	Units given (2)	Seconds (3)	Microjoule/sqcm (4)
i)	8 h	28,800	0.2
ii)	4 h	14,400	0.4
iii)	2 h	7,200	0.8
iv)	1 h	3,600	1.7
v)	30 min	1,800	3.3
vi)	15 min	900	6.7
vii)	10 min	600	10
viii)	5 min	300	20
ix)	1 min	60	100
x)	30 s	30	200
xi)	10 s	10	600
xii)	1 s	1	6,000
xiii)	0.5 s	0.5	12,000
xiv)	0.1 s	0.1	60,000

When exposures to UVC radiation exceed these established limits, it becomes necessary to utilize personal protective equipment to safeguard the skin and eyes.

In some case such as Pathology Laboratories, Pharma locations, continuous UVC Radiation may be allowed, however in such cases, Humans must be fully protected in full head covered personal protection equipment designed / checked for UVC protection.

6.2 Devices utilizing UVGI systems, particularly those that expose humans to potential risks, should incorporate automatic motion sensors capable of promptly shutting off the device upon detecting human presence or motion in hazardous areas.

6.3 Warning Signs and Training

6.3.1 In areas where exposed UVGI systems are deployed, such as locations with upper-room air UVGI lamps, it is imperative to install appropriate warning signs. These signs serve to alert maintenance personnel about the potential hazards of UVC light exposure, prompting them to switch off these lamps before conducting any maintenance or cleaning work.

6.3.2 For settings like operating theatres, where these devices are used to sterilize the area at night, warning signs, red warning lights, and, if necessary, audible warnings should be employed.

6.3.3 In the case of portable devices like handheld UVC wands and UVC tower trolleys, personnel must be trained to wear protective eye equipment and fully covered clothing, including face shields, when there is a risk of UVC exposure in these areas.

Comprehensive training should be provided to all personnel in such environments to raise awareness of the risks associated with UVC exposure and to ensure they understand the importance of wearing protective gear and following safety protocols when working with UVC devices.

7 APPLICATION GUIDELINES FOR USE OF UVGI

UVGI technology, while highly effective for sterilization and decontamination, comes with certain limitations and challenges that require careful consideration and mitigation:

a) *Line of Sight Inactivation* — UVGI operates in a line-of-sight manner, meaning it only disinfects surfaces that are directly exposed to the UV rays. Shadowed areas or surfaces hidden from direct UV exposure may not be effectively sterilized. To address this limitation, UV light devices are often strategically positioned or repositioned around objects to maximize surface coverage.

b) *Low UV Reflectivity* — UV light has poor reflectivity compared to visible light. Most objects do not reflect UV, except for materials like aluminum and stainless steel. Increasing the power and duration of UV exposure can compensate for poor reflectivity in partially shadowed areas.

c) *Sterilizing Contaminated Surfaces* — UVGI may not effectively sterilize dirt or contamination inside particles; it mainly sterilizes the surface of these particles. Therefore, thorough cleaning of surfaces in hospital rooms is essential before UVGI can achieve mass sanitation and disinfection.

d) *Monitoring UV Dosage* — Hospitals should monitor the dose of UVC energy delivered to ensure complete inactivation of all pathogens on room surfaces. This monitoring takes into account the UVC power of the UVGI luminaire and the duration of exposure. Hospitals are recommended to use UVC irradiance meters to establish the correct disinfection protocol for patient rooms.

e) *Luminaire Maintenance* — Regular cleaning of UVGI luminaires and lamps is critical, as dust accumulation can significantly reduce their power output and effectiveness. Regular maintenance and calibration may be required to ensure consistent performance.

f) *Lamp Life and Temperature* — UVGI lamps, like hot cathode mercury vapor lamps, have a limited lifespan of around 9000 hours, and their intensity diminishes over time. Additionally, low-pressure mercury vapor lamps may produce lower output at lower room temperatures. It is advisable to test lamp output using appropriate UVC meters at normal operating temperatures on-site.

g) *Regular Testing* — Hospitals should conduct documented swab tests of various locations to verify the effectiveness of the UVGI protocol. These tests can help indicate the need for protocol adjustments.

h) *Damage to Materials* — UVC radiation can damage plastics and organic materials over time. Therefore, it's important to use only the necessary amount of UVC energy required for disinfection to avoid unnecessary damage.

Incorporating these considerations and precautions into UVGI protocols ensures that the technology is used effectively and safely in healthcare settings for sterilization and decontamination.

8 LUMINAIRES AND APPLICATION OF UVGI TECHNOLOGY IN HOSPITALS

UVGI technology can be applied effectively throughout various areas of a hospital where pathogens may be present. It can be employed for object decontamination, room surface decontamination, as well as air decontamination.

8.1 Object Decontamination/Sterilization

8.1.1 *UVGI Chamber* — In addition to sterilization methods like autoclaves, UVGI chambers offer an alternative for sterilization. Many items, including electronic instruments and PPE masks, cannot be subjected to traditional washing methods as it may compromise their integrity. UVGI sterilization chambers are suitable for surface sterilization of small equipment, instruments, and PPE masks, with the added convenience of timer controls. It is important to arrange objects undergoing disinfection/sterilization in such a way that they are not in the shadow of other items, allowing for adequate exposure to UVC light. Proper spacing is essential to ensure thorough sterilization.

The UVC intensity and time will decide the dosage to kill the pathogens.

8.2 Air Sanitation and Decontamination

In healthcare facilities, the need for air sanitation and decontamination is paramount, as patients continuously generate pathogens while coughing or speaking. Central air conditioning systems have the potential to circulate these pathogens throughout the facility, making effective air sterilization crucial. UVC is an effective method for air sanitation and decontamination, leveraging the germicidal properties of UVC light to inactivate airborne pathogens. This is particularly important in areas with high infection risks, such as operating rooms, intensive care units, and isolation wards. UVGI works by emitting UVC light, which penetrates and disrupts the DNA and RNA of microorganisms, rendering them inactive and unable to reproduce. This non-chemical, environmentally friendly method enhances overall air quality and creates a safer environment for both patients and healthcare workers.

8.2.1 *UVGI Localised Air Sanitisers* — UVGI Localized Air Sanitizers are deployed to target specific areas or surfaces, providing an added layer of protection against pathogens. These devices are particularly useful in high-risk areas such as operating rooms, isolation rooms, and waiting areas. UVGI Air Sanitiser units internally fitted with Powerful UVGI lamps and Suction Blowers installed at different locations on the walls, or in the Ceiling, quickly suck in the air and Sanitise it internally and return it back locally, thus preventing spread of the pathogen in the same Hall or Room. UVGI air sanitisers provide an improvement over conventional Hepa filter Air purifiers, because of their low air resistance, hence fast air flow.

8.2.2 *Upper-Room Air Disinfection Wall Mounted UVGI Luminaires*— Upper-Room Air Disinfection Wall Mounted UVGI Luminaires enhance air quality and reduce the transmission of airborne pathogens in hospitals. These devices are mounted on walls near the ceiling, allowing them to disinfect air in the upper portion of the room where pathogens are more likely to be found. The UVGI fixtures should be installed at the minimum height of 2.1 m. Refer Fig. 4.

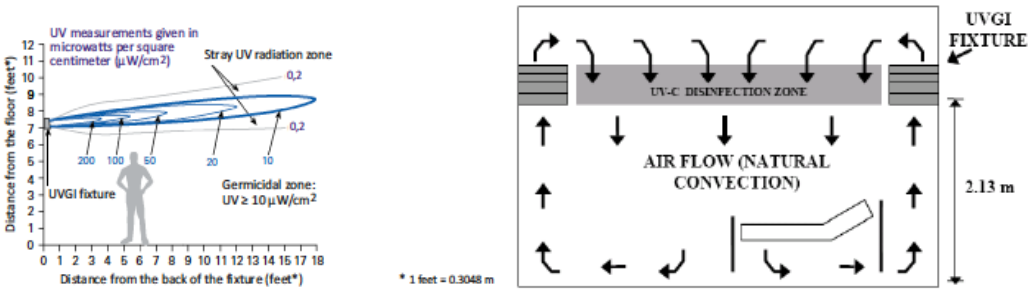

Fig. 4 UVGI Fixture

As a general guideline, a 30W lamp is typically recommended for every 18 square meters of surface area. However, the shape of the room may require additional fixtures to ensure a more uniform coverage of UVC coverage.

UVGI fixtures can also be ceiling-mounted, positioned as hanging ceiling fixtures about 300-400mm below the ceiling. They emit UVC energy upwards, targeting the ceiling for effective disinfection.

Measurement of UVGI level shall be done at installation at least once a year.

a) Lower Room UVGI Luminaires— Pathogenic microorganisms, including bacteria, spores, and viruses, tend to settle downward over time, accumulating near the floor. These pathogens can be stirred up and reintroduced into the air by foot traffic and footwear, potentially spreading contamination in critical areas such as operating theater (OT) corridors.

   To address this concern, Lower Room UVGI luminaires can be installed. These devices are designed to specifically target floor surfaces along the walls, ensuring that OT corridor floors remain sterile and minimizing the risk of infection spread. Lower Room UVGI luminaires are typically mounted at a height of 450-600 mm above ground level on the wall as shown in fig. 1.

   In areas equipped with Lower Room UVGI luminaires, standard protective measures such as wearing full-length pants and footwear are generally sufficient to safeguard occupants from any potential hazards.

Below Fig. 5 shows lower room UVGI luminaires installation for sterile zones and high risk.

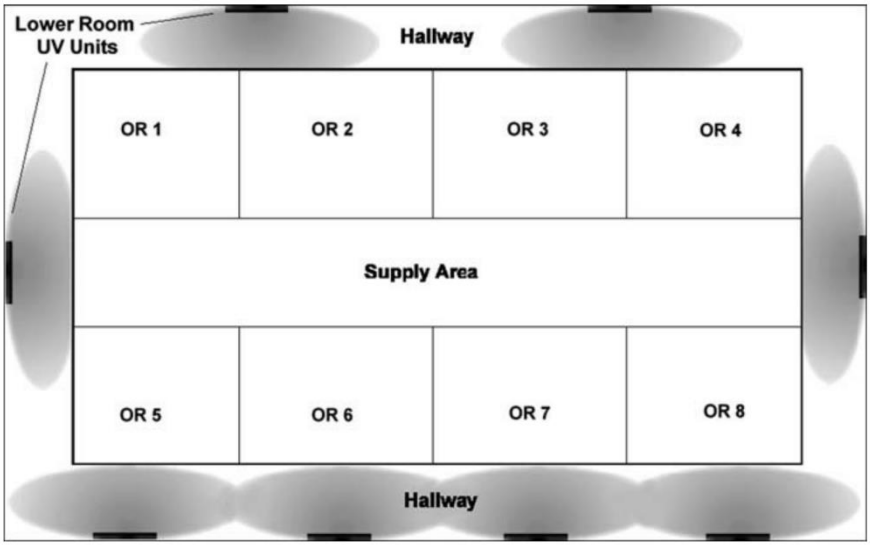

Fig. 5 Lower Room UVGI Luminaires Installation for Sterile Zones and High Risk

These are recommended for corridors leading to sterile zones such as Operation Theatres, and can be used in ICU, ITUs, and also corridors leading to Patient Rooms dedicated for infectious diseases.

8.3 UVGI for Water Disinfection

Hospitals require a reliable source of pathogen-free, sterile water for various purposes. Ultraviolet Germicidal Irradiation (UVGI) of water is a well-established method for water sterilization. In this process, water is passed through a steel cylinder that contains a central UV-transparent glass or quartz jacket housing a Hot Cathode Low Pressure Mercury Vapor UVC lamp.

The effectiveness of UVGI in water disinfection is determined by factors such as the speed of water flow, thickness of the water wall, and the intensity of the UVC lamp. Some systems create turbulence within the steel cylinder to ensure uniform irradiation of all water particles.

Regular monitoring of UVGI system performance is essential. Over time, the intensity of the UVC lamp may decrease, compromising disinfection quality. Sediment or scale deposits on the outer surface of the UV-transparent protection glass jacket can also block UVC light from reaching the water, reducing or eliminating disinfection.

It is recommended that UVGI systems for water disinfection include built-in UVC sensors for online monitoring of the UVC energy level of the lamp. These sensors can provide warnings when the UVC intensity falls below a specified level, indicating the need to replace the UVC lamp before disinfection quality is compromised. Additionally, routine testing of the UVGI-disinfected water, both before and after UVGI treatment, should be conducted to verify the system's effectiveness in eliminating pathogens.

8.4 UVC Dosage/ Fluence

To effectively kill or inactivate pathogens, a minimum dose of UVC energy, also known as fluence, must be applied. Fluence is the UVC irradiance energy received from all angles that is incident on a small region of space in three dimensions.

The required UVC dose varies depending on the specific pathogen being targeted. Hospitals may also consider conducting their own tests in collaboration with microbiologists in their pathology labs to verify the efficacy of UVC treatment against specific pathogens.

The reduction of pathogens is measured on a logarithmic scale, where each log reduction represents a significant decrease in pathogen count:

1 log reduction corresponds to a 90% reduction in pathogens.

2 log reduction corresponds to a 99% reduction in pathogens.

3 log reduction corresponds to a 99.9% reduction in pathogens.

4 log reduction corresponds to a 99.99% reduction in pathogens.

To achieve a log reduction from 1 log to 2 log, a significantly higher dose is typically required.

Reference data of the Dose of UVC for inactivation of some common Pathogens given in Table 2.

Table 2 Lethal Fluence of UVC (254nm) for Various Bacterial Survival Levels

(*Clause* **8.4**)

Sl. No.	**Bacteria**	**$F_{-1\ log}$ Jm $^{-2}$**	**$F_{-4\ log}$ Jm $^{-2}$**	**Reference**
1)	2)	3)	4)	5)
i)	Bacilli			
a)	Vegetative: B. anthracis	12-45	26-110	(28.38)
b)	B. megaterium	56		(44)
c)	B. paratyphosus	32		(28)
d)	B. subtils	40-60		(41.42)
e)	Spores: B. anthracis	275	620	(47)
f)	B. megaterium	290	600	(44)
g)	B. subtilis	260	600	(43,47,48)
ii)	Other vegetative bacteria			
a)	Burkholderia cepacia	31	92	(54)
b)	Burkholderia pseudomallei	44	130	(39)
c)	Camplobacter jejuni	11	21	(30)
d)	Citrobbacter freundi		80	(37)
e)	Corynebacterium diptheriae	34		(28)
f)	Eberthella typosa	21		(28)
g)	Enterobacter cloacae		100	(37)
h)	Entercolitica faecium		170	(37)
i)	Escherichia coli	20-40	50-110	(28.30)
j)	Klebsiella pneuminiae		110	(37)
k)	Listeria monocytogenes	50	96	(14)
l)	Micrococcus cadidus	61		(28)
m)	M. piltonensis	81		(28)
n)	M. sphaeroides		100	(37)
o)	M. smegatis		200	(37)
p)	Neisseria catarrhalis	44		(28)
q)	Phytomonas tumefaciens	44		(28)

r)	Proteus vulgaris	26		(28)
s)	Pseudomonas aeruginosa	55	110	(28.37)
t)	P. fluorescenes	35		(28)
u)	Salmonella typimurium	80	130	(28.37)
v)	S. typhi	51	90-140	(28.59)
w)	Serratia marcescens	23	130	(28.37)
x)	Shigella paradysenteriae	17		(28)
y)	Shigella sonnei	40	75	(27)
z)	Spirillum rubrum	44		(28)
aa)	Staphylococcus albus	21		(28)
ab)	S. aureus	22-49		(28.37)
ac)	Streptococcus hemolyticus	22		(28)
ad)	S. lactus	62		(28)
ae)	S. viridans	20		(28)
af)	Vibrio cholera	11	25-50	(28)
ag)	Yersinia enterocolitica	13	36-110	(30.37)
ah)	“Dysentery” bacilli	22		(28)

9 MONITORING OF UVC SYSTEMS

Measuring devices for monitoring the functionality of UVC systems are essential tools to ensure that these systems are operating effectively and safely. These devices help in verifying that the UVC light intensity and coverage are sufficient to achieve the desired disinfection levels. Key measuring devices include UVC Radiometers, Dosimeters etc.