DISINFECTION OF WATER BY ULTRAVIOLET LIGHT

INTERNATIONAL
WATER-GUARD
INDUSTRIES INC.
THE WATER KNOWLEDGE COMPANY

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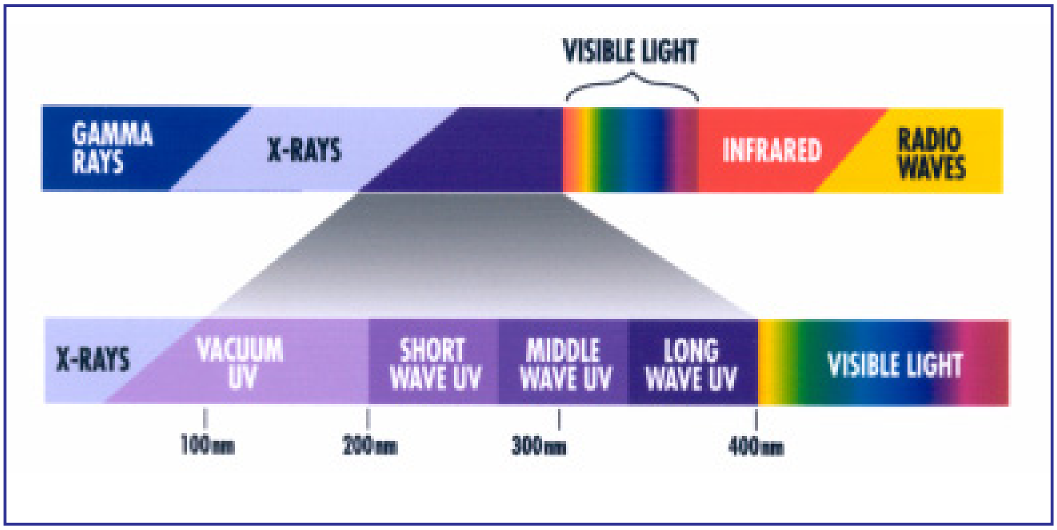
DISINFECTION BY ULTRAVIOLET LIGHT

Scientists have known for nearly a century that ultraviolet light of certain wavelengths is an effective germicidal agent. However, production of ultraviolet light in the proper range was expensive. With the development of high-intensity, long-life lamps came renewed interest in the use of ultraviolet as a disinfection agent for a variety of liquids, but primarily water.

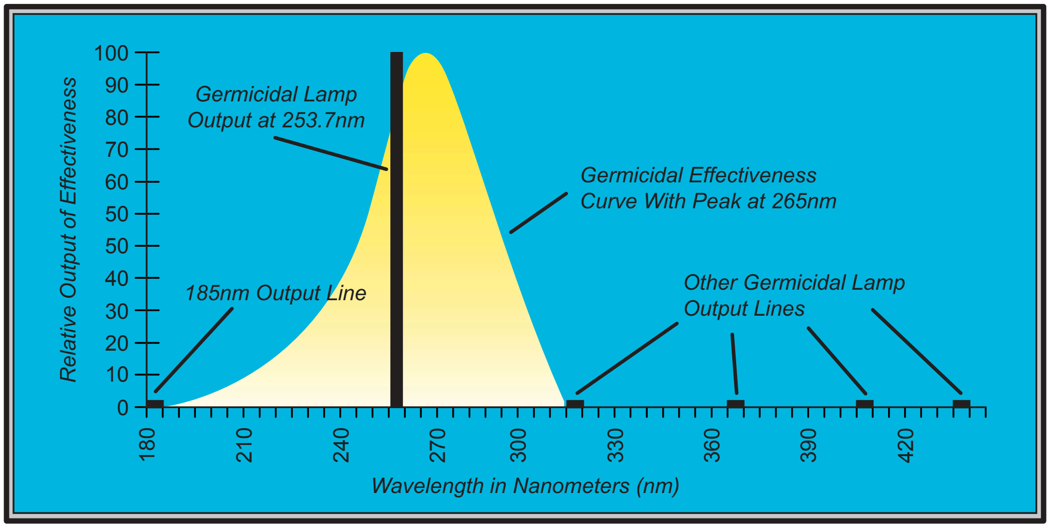
Over the past thirty years, researchers seeking to establish lethal ultraviolet dosages for a variety of micro-organisms have carried out extensive experimental work. Pathogenic microbes were generally the number one target. As a result of this research, it is now possible to design ultraviolet irradiation equipment to meet virtually any disinfection requirement.

THE MECHANICS OF DISINFECTION

Ultraviolet radiation is actually high energy light. The wavelengths in the ultraviolet spectrum are too short for the human eye to resolve and ultraviolet light is therefore invisible. The ultraviolet spectrum ranges



Ultraviolet rays are invisible to the human eye and, at the right intensity, are fatal to bacteria and viruses in water. The most effective ultraviolet wavelength is around 254 nanometers.

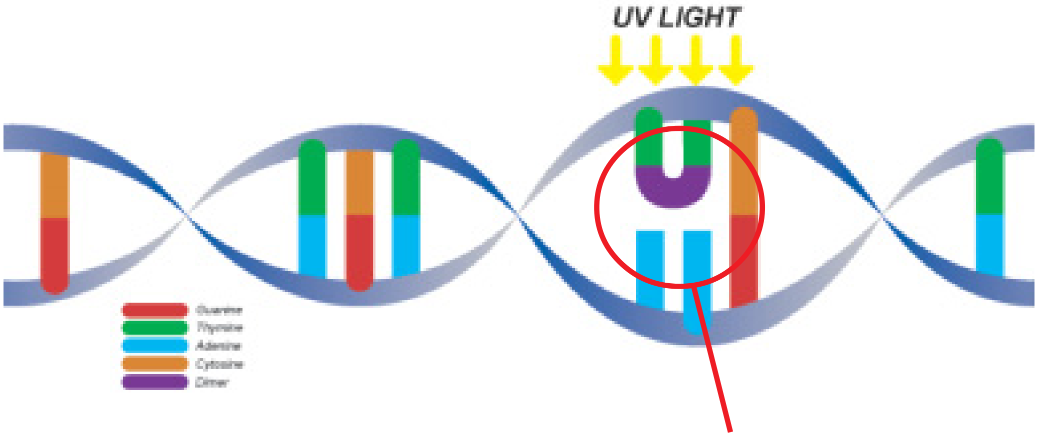


from 40 to 400 Nanometers (nm), with the most effective spectral region for germicidal purposes being between 250 and 265 nm. At the proper level of intensity, ultraviolet light is fatal to all micro-organisms known to inhabit water. Mercury arc lamps generate the ultraviolet radiation for water disinfection, with low pressure lamps being the most common and effective type. Since normal glass blocks ultraviolet, the lamp and its protective sleeve are generally made of fused silica or quartz, which readily transmit the germicidal ultraviolet rays. Low pressure mercury arc lamps are efficient producers of ultraviolet rays in the range lethal to microbes. About 50% of the input energy is converted to ultraviolet rays having a wavelength of 254 nm. This wavelength is very effective in the destruction of all known micro-organisms.

Studies show that DNA molecules in the nucleus of the organism absorb ultraviolet light. The organism is inactivated when sufficient dosage has been absorbed to modify the molecular structure in the DNA. This results when exposure to ultraviolet light causes two thimine molecules to form an inappropriate bond, or dimer. The effect of numerous thymine dimers forming along the DNA chain inhibits replication of the organism. It may not be killed instantly, but the scrambling of the genetic in the nucleus prevents reproduction, rendering it non-viable and harmless to humans. The amount of energy required to produce this effect in a given organism is referred to as the lethal dosage.

The term ‘dosage’ is used to describe the total amount of energy absorbed by the micro-organism. Dosage is the product of intensity and time, and as such, allows the capacity of any ultraviolet treatment unit to be calculated. There are some limits to the two factors involved. Neither exposure at low intensity for extremely

DNA before ultraviolet disinfection - all bonds required for replication are intact.



DNA after ultraviolet disinfection - broken bonds and Thymine Dimer formation prevent replication - and therefore prevent the organism from causing illness in humans.

long periods of time, nor very high intensity exposure for short time spans are useful, even though the product of the two may be greater than the lethal dosage.

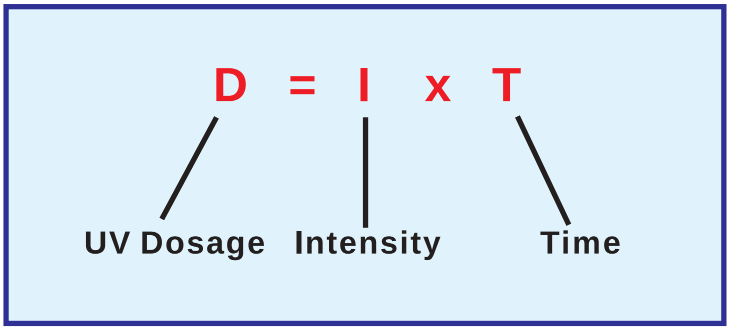
IS THERE A STANDARD FOR ULTRAVIOLET DISINFECTION OF WATER?

The industry benchmark for ultraviolet drinking water disinfection equipment design is the ***NSF Standard 55-1991 Ultraviolet Microbiological Water Treatment Systems.*** NSF (National Sanitation Foundation) is a non-profit organization based in the United States and is best known for its role in developing standards and criteria for products and services bearing upon health. Under NSF 55, there are two classes of ultraviolet drinking water treatment systems: Class A and Class B.

- Class A systems are those designed to disinfect water contaminated by micro-organisms like bacteria and viruses, but not water with an obvious contamination source such as raw sewage, nor are they designed to convert wastewater to safe drinking water. The NSF failsafe set-point dosage for Class A systems is 40,000 μw-sec/cm^2. International Water-Guard designs its Class A units to operate at a *minimum* dosage of 40,000 μw-sec/cm^2.

- Class B systems are intended to provide supplemental treatment of drinking water that has been tested by health authorities and deemed acceptable for human consumption. These systems are targeted at non-pathogenic and nuisance organisms. The NSF dosage requirement for Class B systems is 16,000 μw-sec/cm^2.

HOW IS ULTRAVIOLET DOSAGE ESTABLISHED?



Ultraviolet dosage is the product of ultraviolet intensity (expressed as μ w/cm^2) and the time of exposure (in seconds).

INTENSITY

Two main factors affect ultraviolet intensity:

- water quality, and
- the output of the ultraviolet lamps.

WATER QUALITY - Water quality refers to the clarity of the water to be treated and the degree to which it allows ultraviolet light to pass through it unobstructed (hereafter referred to as the ultraviolet transmission of the water). For optimum performance, ultraviolet disinfection units may require upstream filtration to remove suspended solids, dissolved organics, etc., and generate water with acceptable transmission qualities.

LAMP OUTPUT - Proper lamp output is easily maintained by regular cleaning of the quartz sleeve that encases the lamp (generally every six months) and by lamp replacement once per year. Ultraviolet level monitoring and alarm/shutoff equipment can also be placed on the unit to provide a fail-safe indication of lamp output.

TIME

The time of exposure to ultraviolet light (retention time) is directly related to the flow rate of water passing through the disinfection chamber. By changing the retention time for a given ultraviolet intensity, the dosage can be increased or decreased as needed. That is, higher or lower dosage rates can be achieved by either decreasing or increasing the flow rate. The longer the water is in the ultraviolet disinfection chamber the higher the dosage, and vice-versa.

For example, consider the effect upon ultraviolet dosage that changing the flow rate has for an IWG-1-S unit:

Flow Rate (US GPM)	Ultraviolet Dosage
5.0	16,000 µw-sec/cm^2
3.0	40,000 µw-sec/cm^2
1.3	90,000 µw-sec/cm^2

FACTORS AFFECTING THE USE OF ULTRAVIOLET DISINFECTION SYSTEMS

A number of substances can inhibit the passage of ultraviolet rays through water. Dissolved organics are a primary concern. All natural water contains some humic acids, i.e.; tannins and lignins. These substances have very high ultraviolet absorption coefficients. Water containing any significant amounts of these substances requires pre-filtration.

Iron also affects the use of ultraviolet systems. Some of its organic complexes absorb ultraviolet rays, but its major nuisance effect is the coating of the quartz sleeves. This can increase maintenance since the sleeves must be cleaned regularly, but again, in most cases the iron can be removed from the water by appropriate pre-treatment.

Contrary to common belief, inorganic suspended solids are not a major concern. Large clumps could have a shielding effect, but particles of this size would not be tolerated in potable water, and would be removed by filtration. Since levels of both suspended solids and iron sufficient to degrade ultraviolet performance also render the water aesthetically unappealing, pre-treatment would be required in any case.

Dissolved minerals have very little effect on the efficiency of ultraviolet disinfection. This fact makes ultraviolet irradiation the premier method of seawater disinfection. Filtered seawater is readily disinfected by ultraviolet systems.

MYTHS ABOUT ULTRAVIOLET DISINFECTION

One of the most common negative comments about the use of ultraviolet irradiation in water treatment is the lack of a residual disinfection agent. However, pumps, distribution lines, etc., downstream from an ultraviolet installation can be chemically disinfected prior to installation. The disinfected water then flowing through the system will either keep it clear thereafter, or greatly reduce the need for ongoing chemical cleansing.

It has also been said that ultraviolet irradiation is not a feasible disinfection method for high flow rates. Although as yet there are no large municipal installations, some very large capacity systems do exist. Several fish hatcheries in the U.S. are disinfecting water at up to 16,000 US gpm using ultraviolet irradiation.

The capital costs of ultraviolet systems have been cited as excessive compared to chlorination, but almost invariably, the comparisons are invalid. A chemical feed pump injecting some form of disinfectant cannot be compared to an ultraviolet sterilizer. A true comparison must add at least a carbon filter for dechlorination. When all factors are considered, UV light is by far the most economical and reliable method of disinfection.

ULTRAVIOLET VS. CHLORINATION AND OZONATION

Ultraviolet light at sufficient dosage levels has proven to be an extremely effective means to destroy bacteria, mold, viruses and algae. In fact, all micro-organisms are susceptible to the effects of ultraviolet radiation. With major technological improvements made in the past few decades, ultraviolet irradiation has emerged as a leading water treatment contender with significant advantages over chlorination and ozone disinfection.

DISINFECTION METHODS COMPARISON

	Ultraviolet	Biocides*	Ozone
Destruction	Physical	Chemical	Chemical
Capital Cost	Low	Medium	High
Operation Cost	Low	Medium	High
Maintenance Cost	Low	Medium	High
Maintenance Frequency	Low	Medium	High
Disinfection Performance	Excellent	Good	Unpredictable
Contact Time	1 - 5 seconds	15-45 min.	5-10 min.
Staff Hazards	Low	Medium	High
Toxic Chemicals	No	Yes	Yes
Water Chemistry Changes	No	Yes	Yes
Residual Effect	No	Yes	Yes

*Biocides considered are gaseous chlorine, sodium hypochlorite, calcium hypochlorate, chlorine dioxide, and bromine.

Ultraviolet is a more effective viricide than chlorine, but does not add to or alter the composition of water, does not produce toxic by-products or other potentially harmful residual materials, and has no danger of overdose from added chemicals. Nothing is added that would have to be removed by other downstream systems. No dangerous chemicals must be used or stored, and staff need no specialized hazardous materials knowledge or training.

Ozonation systems work well to remove color, odor, and taste, but have disadvantages as a disinfecting process compared to ultraviolet irradiation. Ozone dosage levels are difficult to control and therefore this method is unpredictable as a disinfectant. For this reason, ozone treatment is usually backed up by chlorination, with the accompanying drawbacks of chemical addition and removal outlined above. In addition, overdose concentrations of the ozone gas generated by this form of water treatment can harm not only downstream water distribution systems, but humans as well, and must be carefully monitored. The ozonation process also leaves a residual ozone level that could be harmful and must be removed for operator/user safety.

Both ozone water treatment and chlorination can present the user with higher capital and operating costs than comparable ultraviolet systems. This is particularly so when added chlorine or high ozone levels must be removed prior to end use. Once installed, an ultraviolet system requires very little operator involvement beyond periodic cleaning and minor maintenance. Again, no specialized knowledge or training is required.

In some applications, a combination of the chlorination, ozone, and ultraviolet methods of water treatment is called for. But in most instances, ultraviolet irradiation alone provides the most effective and economical approach to disinfection.

DESIGN CRITERIA FOR ULTRAVIOLET DISINFECTION SYSTEMS

It is essential that the final design of an ultraviolet disinfection system eliminate laminar, or smooth, water flow through the disinfection chamber. The lethal dosage is calculated using a nominal dwell time in the chamber, based upon the flow rate of the unit. If water is allowed to pass directly from inlet to outlet, the micro-organisms will not be exposed to sufficient ultraviolet irradiation. Baffles and other flow control devices are required in treatment chambers to not only keep the water exposed to ultraviolet for the required time, but also to cause turbulence and thereby prevent laminar flow. Any suspended solids remaining after pre-treatment are whirled about, and cannot act as shields for microbes.

The ultraviolet system should be designed such that it can handle the known pumping rate of the water system in an industrial or commercial application, or in a domestic situation, it should be sized to match the maximum expected peak flow. These measures would eliminate the possibility of inadequate treatment by preventing a flow rate through the treatment chamber that exceeds the disinfection capability of the unit.

A well-designed ultraviolet disinfection unit also incorporates quartz sleeves to isolate the ultraviolet lamps from the water. These sleeves protect the lamps, and also provide an air space that acts as an insulating barrier. This allows the lamps to maintain their optimum operational temperature of about 40 degrees Celsius (104 degrees Fahrenheit).

In some situations, monitoring devices should be an integral part of the ultraviolet system employed, since the effectiveness of an ultraviolet sterilizer is governed by the amount of radiation that actually penetrates the water. Most suppliers provide some form of a sensing circuit, but a Fail-Safe system is preferable and often required by regulation in critical applications.

A Fail-Safe system should include monitoring of ultraviolet levels in the treatment chamber, linked to audible or visual alarms and a water shut-off system. Lamp function/failure monitors should be part of the system, and should also be capable of activating alarms and shut-off switches. These systems ensure that only properly disinfected water leaves the treatment chamber. The wiring and electronic circuitry for monitoring systems should be protected from moisture and harsh environments. In many applications, a remote electrical enclosure is desirable or mandatory.

Although ultraviolet disinfection units require a minimum of care, design consideration should be given to ease of service. The lamps should be readily accessible, and the quartz sleeves should not require any special skills or tools for cleaning or replacement.

CONCLUSIONS

It is a well-established scientific fact that ultraviolet irradiation is highly effective at destroying waterborne pathogens. It can also be demonstrated that ultraviolet water treatment can present significant cost, safety, and health advantages over both chlorination and ozonation methods of water treatment.

However, several conditions must be met for the disinfectant quality of ultraviolet light to be reliably effective. Ultraviolet disinfection requires source water of sufficient clarity. While this does not always occur in nature, pre-filtration can provide a ready solution. In most cases, pre-treatment involving filtration would be required anyway to meet the aesthetic and other needs of the end user.

In addition, water must be subjected to a consistent lethal dosage of ultraviolet radiation for reliable destruction of micro-organisms. Long-life ultraviolet lamps provide the required dosage over their service lifetime, and can be backed up by fail-safe alarm, monitoring and water shut-off features.

Lethal dosage is also linked to the rate of water flow through the ultraviolet treatment chamber. The design criteria for modern ultraviolet treatment systems take this into account, and control the flow rate of water to be treated, as well as eliminate the laminar flow which can decrease micro-organism kill rates.

Ultraviolet irradiation is not suitable for all applications, and must sometimes be used in conjunction with pre-filtration and other disinfection processes. However, when all factors of germicidal effectiveness, ease of operation and maintenance, cost, and safety are considered, it clearly holds a leading position over traditional water treatment methods.

ULTRAVIOLET DOSAGE CALCULATIONS

Ultraviolet dosage is described as the total amount of energy absorbed by micro-organisms present in water. Dosage is the product of the effective intensity of the ultraviolet lamp(s) in the disinfection unit, multiplied by the retention time of the fluid within the unit's treatment chamber (D = I x T). Once the effective ultraviolet intensity and the retention time are known, the capacity of an ultraviolet treatment unit can be calculated.

EFFECTIVE INTENSITY

To calculate the effective intensity of ultraviolet light in a given disinfection chamber, the average lamp intensity is multiplied by the ultraviolet transmission quality of the fluid being irradiated.

The average lamp intensity is established by means of a formula applied to a reading taken at the mid-point on the arc length of the ultraviolet lamp to be used (arc length is the distance between the electrical filaments located at each end of the lamp).

From a body of experience gained through radiometer measurements of the average lamp intensity for a variety of ultraviolet lamps, International Water-Guard has determined that the average intensity across the arc length of a given lamp is approximately 90% of the mid-point value. As a safety measure, International Water-Guard reduces this to 85% and applies it to the mid-point values of production models.

The ultraviolet transmission quality of the fluid to be irradiated is established relative to a dry (air only in chamber) test of the ultraviolet lamp. The test is conducted with a clean quartz sheath surrounding the lamp as would be the case in actual operation. International Water-Guard uses a radiometer manufactured by International Light (Model No. 1IL-1400A) for this test. The radiometer measurement is taken at the mid-point of the lamp.

International Water-Guard recommends subsequent tests with the chamber filled using a water sample from the customer to establish the sample's transmission quality, which is expressed as a percentage of the dry test values. In cases where the customer does not forward the recommended water sample, International Water-Guard assigns a standard ultraviolet transmission value to the disinfection unit.

For example, in the household waste water unit (model WG-1-LV-WW) calculations below, the transmission value for the anticipated fluid to be treated is set at 75% based on a flow rate of 5 US gpm. For this particular model, flow rates of 7 US gpm can also be accommodated, depending on the dosage required. A higher ultraviolet transmission value in the fluid results in a higher dosage for a given flow rate.

FLUID RETENTION TIME

The retention time of the fluid in a given ultraviolet water treatment unit is a product of the design flow rate in US gallons per minute (US gpm) for that unit and the net volume of its disinfection chamber. The pre-determined flow rate is governed by flow control devices that are usually chosen by the end user. The net volume of the chamber is calculated by the manufacturer after first determining the basic chamber volume and the effective chamber volume.

To determine the basic chamber volume (chamber volume without the quartz sleeve and lamp in place) the formula •r^2 x arc length is employed, with r = the radius of this unit's four inch diameter treatment chamber. The same formula is used to calculate the effective chamber volume, with r = the radius of the quartz sleeve for this model. An actual calculation of ultraviolet dosage levels for the International Water-Guard WG-1-LV-WW household wastewater treatment unit (not drinking water) is included below. The same basic method is employed to establish dosage levels for all International Water-Guard products, although the final dosage would be much higher for units disinfecting potable or industrial process water.

DOSAGE CALCULATION FOR MODEL NO: WG-1-LV-WW

Power supply specifications:

Voltage (VL) @ 120 VAC/60Hz	98V
Current (IL)	319mA
Power to Lamp	18.95W

After a three minute warm-up, an ultraviolet intensity measurement of the lamp (International Water-Guard Part No.GSL591T5VH/4C) taken at a distance of 2 inches from the mid-point resulted in an intensity reading of 4.07 milliwatts per square centimeter (mW/cm^2).

Intensity at mid point:	4.07 mW/cm^2	
Average Intensity:	4.07 x 85% = 3.46 mW/cm^2	
Effective Average Intensity	3.46 mW-sec/cm^2 x 75% = **2.60 mW/cm^2**	
Basic Chamber Volume	π (2")^2 x 20" (arc length)	= 251.33 cu in.
minus		
Effective Chamber Volume	π (0.493")^2 x 20"	= 15.27 cu in.
Net Chamber Volume		236 cu in.
Net Chamber Volume in liters:	236 cu in. x 16.41 = $\frac{3{,}872.76\ m^3}{1000}$ = 3.873 liters	
Flow Rate in liters:	5 US gpm x 3.785 = 18.925 liters per minute	
Retention Time:	$\frac{3.873\text{ liters}}{18.925\text{ liters/min.}}$ = 0.2046 minutes = **12.28 seconds**	

D = I x T (dosage = effective average intensity x retentoin time)

2.60 mW/cm^2 x 12.28 seconds = 31.93 mW-sec/cm^2 x 1000 = 31,930 µW-sec/cm^2

ESTIMATED LETHAL ULTRAVIOLET DOSAGES - MICROBIOLOGICAL ORGANISMS

(Using commonly accepted industry norms with extrapolation for Log reduction. Expressed in microwatt-seconds per square centimeter)

ORGANISM	TYPE	LETHAL DOSAGE TO KILL:		
		99.990%	99.990%	99.999%
		LOG REDUCTION:		
		3 LOG	4 LOG	5 LOG
Tobacco Mosaic	Virus	440,000	586,666	733,333
Aspergillus niger	Mold Spores	330,000	440,000	550,000
Rhisopus nigricans	Mold Spores	220,000	293,333	366,666
Paramecium	Protozoa	200,000	266,666	333,333
Aspergillus flavus	Mold Spores	99,000	132,000	165,000
Nematode eggs	Protozoa	92,000	122,666	153,333
Aspergillus glaucus	Mold Spores	88,000	117,333	146,666
Penicillium digitatum	Mold Spores	88,000	117,333	146,666
Bacillus subtilus (spores)	Bacteria	58,000	77,333	96,666
Bacillus megaterium (spores)	Bacteria	52,000	69,333	86,666
Muscor racemosus A	Mold Spores		46,933	58,666
Muscor racemosus B	Mold Spores		46,933	58,666
Penicillium roquefort	Mold Spores			44,000
Sarcina lutea	Bacteria			44,000
Rotavirus	Virus			40,000
Muscor racemosus A	Mold Spores	35,200		
Muscor racemosus B	Mold Spores	35,200		
Penicillium roquefort	Mold Spores		35,200	
Sarcina lutea	Bacteria		35,200	
Rotavirus	Virus		32,000	
B. subtillus spores	Bacteria			36,666
Chlorella vulgaris (algae)	Protozoa			36,666
Clostridium tetani	Bacteria			36,666
Penicillium expansum	Mold Spores			36,666
Poliovirus (Poliomyelitus)	Virus			35,000
Penicillium roquefort	Mold Spores	26,400		
Sarcina lutea	Bacteria	26,400		
Rotavirus	Virus	24,000		
B. subtillus spores	Bacteria	22,000	29,333	
Chlorella vulgaris (algae)	Protozoa	22,000	29,333	
Clostridium tetani	Bacteria	22,000	29,333	
Penicillium expansum	Mold Spores	22,000	29,333	
Poliovirus (Poliomyelitus)	Virus	21,000	28,000	
Saccaromyces sp.	Yeast	17,600	23,466	29,333
Common yeast cake	Yeast	17,600	22,000	
Saccaromyces cerevisiae	Yeast		17,600	22,000
Saccaromyces ellipsoideus	Yeast		17,600	22,000
Micrococcus candidus	Bacteria		16,400	20,500
Vibrio cholerae	Virus			19,166
Bacillus subtilus (vegetative)	Bacteria			18,333

ORGANISM	**TYPE**	**LETHAL DOSAGE TO KILL:**		
		99.990%	99.990%	99.999%
		LOG REDUCTION:		
		3 LOG	4 LOG	5 LOG
Oospora lactis	Mold Spores			18,333
Pseudomonas aeruginosa (environmental strain)	Bacteria			17,500
Mycobacterium tuberculosis	Bacteria			16,666
Salmonella	Bacteria			16,666
Streptococcus faecalis	Bacteria			16,666
Common yeast cake	Yeast	13,200		
Saccaromyces cerevisiae	Yeast	13,200		
Saccaromyces ellipsoideus	Yeast	13,200		
Micrococcus candidus	Bacteria	12,300		
Vibrio cholerae	Virus	11,500		
Bacillus subtilus (vegetative)	Bacteria	11,000	14,666	
Oospora lactis	Mold Spores	11,000	14,666	
Pseudomonas aeruginosa (environmental strain)	Bacteria	10,500	14,000	
Mycobacterium tuberculosis	Bacteria	10,000	13,333	
Salmonella	Bacteria	10,000	13,333	
Streptococcus faecalis	Bacteria	10,000	13,333	
Bakers' yeast	Yeast	8,800	11,733	14,666
Streptococcus lactis	Bacteria	8,800	11,733	14,666
Bacillus anthracis	Bacteria	8,700	11,600	14,500
Agrobacterium tumefaciens	Bacteria	8,500	11,333	14,166
Neisseria catarrhalis	Bacteria	8,500	11,333	14,166
Phytomona tumefaciens	Bacteria	8,500	11,333	14,166
Hepatitus virus	Virus	8,000	10,666	13,333
Salmonella enteritidis	Bacteria	7,600	10,133	12,666
Escherichia coli	Bacteria	7,000	9,333	11,666
Staphylococcus aureus	Bacteria	7,000	9,333	11,666
Bacteriophage (E. coli)	Bacteria	6,600	8,800	11,000
Brewers' Yeast	Yeast	6,600	8,800	11,000
Influenza virus	Virus	6,600	8,800	11,000
Proteus vulgaris	Bacteria	6,600	8,800	11,000
Pseudomonas fluorescens	Bacteria	6,600	8,800	11,000
Corynebacterium diptheriae	Bacteria	6,500	8,666	10,833
Rhodospirillium rubrum	Bacteria	6,200	8,266	10,333
Serratia marcescens	Bacteria	6,160	8,213	10,266
B. paratyphosus	Bacteria	6,100	8,133	10,166
Salmonella paratyphi (Enteric Fever)	Bacteria	6,100	8,133	10,166
Leptospira interrogans (Infectious Jaundice)	Bacteria	6,000	8,000	10,000
Salmonella typhosa (Typhoid Fever)	Bacteria	6,000	8,000	10,000
Staphylococcus epidermidis	Bacteria	5,800	7,733	9,666

ORGANISM	**TYPE**	**LETHAL DOSAGE TO KILL:**		
		99.990%	99.990%	99.999%
		LOG REDUCTION:		
		3 LOG	4 LOG	5 LOG
Staphylococcus albus	Bacteria	5,720	7,626	9,533
Legionella dumoffii	Bacteria	5,500	7,333	9,166
Streptococcus hemolyticus	Bacteria	5,500	7,333	9,166
B. megatherium sp. (spores)	Bacteria	5,200	6,933	8,666
Legionella gormanii	Bacteria	4,900	6,533	8,166
Shigella dysenteriae (Dysentery)	Bacteria	4,200	5,600	7,000
Eberthella typhosa	Bacteria	4,100	5,466	6,833
Pseudomonas aeruginosa (laboratory strain)	Bacteria	3,900	5,200	6,500
Legionella pneumophilia	Bacteria	3,800	5,066	6,333
Streptococcus viridian	Bacteria	3,800	5,066	6,333
Legionella bozemanii	Bacteria	3,500	4,666	5,833
Shigella flexneri (Dysentery)	Bacteria	3,400	4,533	5,666
Shigella paradysenteriae	Bacteria	3,400	4,533	5,666
Legionella micdadei	Bacteria	3,100	4,133	5,166
Bacillus megaterium (vegetative)	Bacteria	2,500	3,333	4,166

Ultraviolet Light vs. Cryptosporidium parvum and Giardia lamblia

What the research says:

“This study measured the effect of germicidal ultraviolet (UV) light on Giardia lamblia (the etiologic agent for giardiasis outbreaks associated with drinking water) and Giardia muris cysts (a more easily handled rodent parasite)… At >3 millijoules per square centimeter (mJ cm^{-2}), a dose significantly lower than what large-scale UV reactors would be designed to provide, more than 2 log$_{10}$ (99 percent) inactivation was observed. These results show that both organisms are significantly more susceptible to UV light than many bacteria and most viruses… Recently, analysis by animal and cell-culture infectivity assays demonstrated that Cryptosporidium parvum oocysts (another waterborne protozoan pathogen) are highly susceptible to low dosages of UV light.”

Extracted from:

Disinfection of *Giardia Lamblia* and *Giardia Muris* Cysts by UV Light

Alexander A. Mofidi, Associate Engineer, Connie I. Chow, Laboratory Technician, Bradley M. Coffey, Senior Engineer, Metropolitan Water District of Southern California, La Verne California USA 91750-3399.
Ernest A. Meyer, Professor, Oregon Health Sciences University, Portland, Oregon, USA 97201-3098.
Peter M. Wallis, President, Hyperion Research, Ltd., Medicine Hat, Alberta Canada T1A 3G8.

2001.

“Low doses of ultraviolet (UV) light are highly effective for inactivation of *Cryptosporidium parvum* oocysts in water. While used in the US for ground water disinfection of viruses and bacteria, the United States Environmental Protection Agency (USEPA) has now included UV as a technology for disinfecting surface waters to control *Cyrptosproridium.*”

Extracted from:

Susceptibility of Multiple Strains of Cryptosporidium parvum Oocysts to UV Light

J.L. Clancy, T.M. Hargy, J.P. Durda, D.G. Korich, and M.M. Marshall
Clancy Environmental Consultants Inc., POB 314, St. Albans VT 05478
U. of Arizona, Veterinary Science Department, Tucson AZ 85721

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