Application Note #12

Ultraviolet Light Disinfection Data Sheet

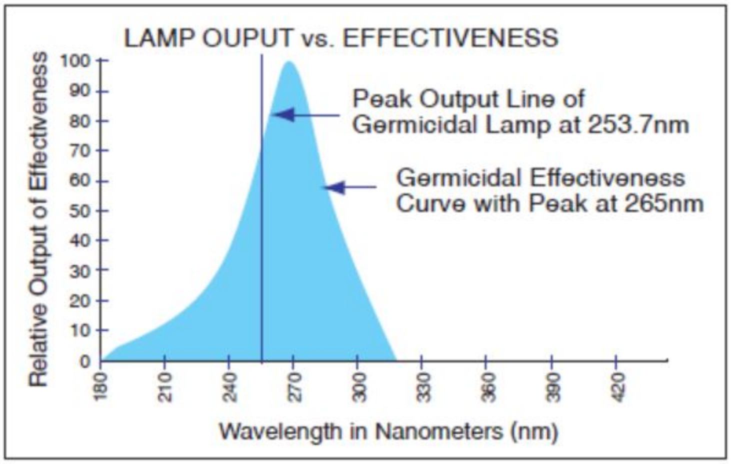
UV has been used for disinfection since the mid-20th century, with beginnings even earlier when sunlight was investigated for bactericidal effects in the mid-19th century. It's used for drinking and wastewater treatment, air disinfection, the treatment of fruit and vegetable juices, as well as a myriad of home devices for disinfecting everything from toothbrushes to tablet computers. Within research facilities, UV has been an option when purchasing biological safety cabinets for years, and can also be used within ductwork.

UV technology has advanced in recent years to become more reliable. Ballasts being used today are able to maintain the power output of UV bulbs for far longer than in the past. UV bulbs today have rated lifespans in the thousands-of-hours. This has allowed UV systems to become more viable for wide ranging use.

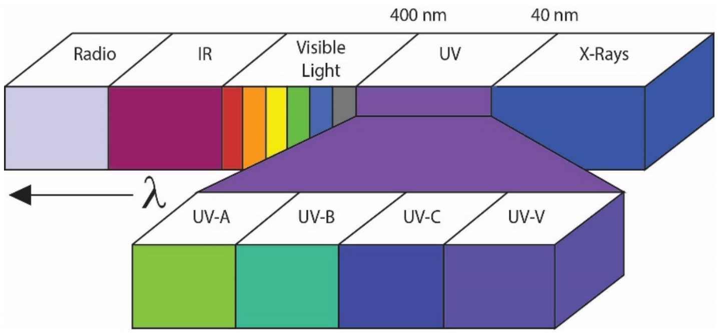
The use of UV has recently grown within the healthcare industry to provide disinfection of room surfaces in addition to existing cleaning methods. The use of ultraviolet light for surface disinfection within research facilities has started to increase as well due to its ease of use, short dosage times, and broad efficacy.

How Does UV Work?

Ultraviolet light exists within the spectrum of light between 10 and 400 nm. The germicidal range of UV is within the 100-280nm wavelengths, known as UV-C, with the peak wavelength for germicidal activity being 265 nm. This range of UV light is absorbed by the DNA and RNA of microorganisms, which causes changes in the DNA and RNA structure, rendering the microorganisms incapable of replicating. A cell that can't reproduce is considered dead; since it is unable to multiply to infectious numbers within a host. This is why UV disinfection is sometimes called ultraviolet germicidal irradiation (UVGI).



Our UV systems use low-pressure, mercury-arc germicidal lamps which are designed to produce the highest amounts of UV radiation - where 90% of energy is typically generated at 254nm. This radiation is very close to the peak of the germicidal effectiveness curve of 265nm, the most lethal wavelength to microorganisms.



What is UV Effective Against?

UV has been proven effective against a broad spectrum of microorganisms. Viruses contain RNA or DNA and are thus susceptible to irradiation. Bacteria and fungi both contain DNA and are similarly vulnerable to UV light. Spores are also susceptible to UV. With the longstanding use of UV for disinfection, there is a plethora of information regarding dosages necessary to inactivate different microorganisms. Bacteria are generally easier to inactivate than viruses, with fungi and spores being even harder to inactivate with UV. **Please see Appendix 2 for a list of microorganisms against which UV-C is effective.**

Safety

As UV-C provides radiation, it is not safe to be in the room while UV-C disinfection is taking place. UV-C is classified as "reasonably anticipated to be a human carcinogen" by the National Toxicology Program. It presents a hazard to skin and eyes, so direct exposure to UV-C is always to be avoided. UV-C is blocked by a number of materials, including glass (but not quartz glass) and most clear plastics, so it is possible to safely observe a UV-C system if you are looking through a window. UV-C provides residue free disinfection, so there is no concern over dangerous residues that need to be wiped down or neutralized after the disinfection occurs. The process is environmentally friendly in that there are no dangerous or toxic chemicals that require specialized storage or handling. Since no chemicals are added to the air/water, there are no process byproducts to be concerned with. The UV bulbs do not require special handling or disposal either, making the system a green alternative to chemical disinfectants.

Benefits

While there are definite limitations to UV-C disinfection technologies, there are many benefits as well. Disinfection times are fast, with a typical disinfection cycle lasting about 15 minutes. This allows for extremely fast turnover times for rooms or other spaces being disinfected. Due to its simplicity, UV-C disinfection is extremely easy to understand. All surfaces within a certain distance will observe an assured level of disinfection in a certain amount of time as long as the light is not blocked from shining on that surface. It becomes very easy to plan the use of a UV-C disinfection system when the parameters and limitations are easily established and understood.

There is no need to establish air flow patterns with UV-C as you would with a fogging system. Nor is there a need to isolate rooms from HVAC systems or seal doors. This, along with the lack of chemical mixture, makes the preparation time quick to setup and start a UV-C disinfection cycle.

The cost to run UV systems is very low, as systems are powered by regular wall outlets. With that, a typical UV-C treatment costs under two cents. UV systems also require little maintenance and upkeep due to their simplistic nature. UV bulbs last thousands of hours at their peak output, limiting the need for routine consumable change out and maintenance.

Drawbacks

While UV is effective at inactivating a wide range of microorganisms, there are limitations for its use. As it involves light waves, UV operates in a "line-of-sight" fashion, only irradiating surfaces within its sightlines. Surfaces can be blocked from the light if objects are in the way, much like a beach umbrella offering protection from the sun. These areas that become blocked from the UV light are commonly referred to as shadow areas. Surfaces in these shadow areas do not receive adequate disinfection as UV light does not have the ability to reflect well off surfaces. Shadow areas are typically dealt with by moving the UV light source to a second position to accommodate disinfection of the surfaces blocked from UV disinfection the first time.

Distance also plays a factor into the efficacy of UV light. The strength of the UV-C light decreases the further away it gets from the light source, following the inverse square law. This means that at twice the distance, the UV-C will have ¼ of its power that was present at the original reference point. This relationship limits how far a single source of UV light is effective before it is too weak to provide adequate disinfection. Most systems deal with this by quantifying their UV-C output at a given distance, and using that distance to generate treatment times. Sensors are available which can measure the UV-C output of the UV systems at any location, such that adequate treatment times can be interpreted for that specific location.

UV light does not penetrate well into organic materials, so for best results UV-C should be used after a standard cleaning of the room to remove any organic materials from surfaces.

Applications

UV light can safely be used for a variety of disinfection applications. Systems are available to disinfect rooms and high touch areas, ambulances and other emergency service vehicles, ductwork, tools equipment inside a disinfection chamber, continuous UV-C pass-through conveyors, and many other applications. It has long been available for biological safety cabinet disinfection and home water treatment as well. It provides a chemical free method of disinfecting soundproofing materials that are traditionally chemically incompatible.

Appendix 1 – Historical Use of UV Light for Disinfection

For the past 100 years science has recognized the bactericide effects of the ultraviolet area of the electromagnetic spectrum. Below are some key contributions over the years:

1855 Arloing and Daclaux demonstrated sunlight killed Bacillus anthracis and Tyrothrix scaber

1877 Downes and Blunt reported bacteria were inactivated by sunlight – violet blue spectrum most effective

1889 Widmark confirmed UV rays from arc lamps were responsible for inactivation

1892 Geisler used a prism and heliostat to show sunlight and electric arc lamps are lethal to Bacillus Typhosus

1903 Banard and Morgan determined UV spectrum 226-328 nm is biocidal

1932 Ehris and Noethling isolated biocidal spectrum to 253.7 nm

1957 Riley proves effectiveness for Tb control

1994 CDC acknowledges UV effectiveness for Tb control

1999 WHO recommends UVGI for Tb control

Appendix 2 – Ultraviolet Light Exposure Dosage

The degree of inactivation by ultraviolet radiation is directly related to the UV dose applied. The UV dose is the product of UV intensity [I] (expressed as energy per unit surface area) and exposure time [T].

Therefore: DOSE = I x T

This dose, sometimes referred to as fluence, is commonly expressed as millijoule per square centimeter (mJ/cm^2). The units "J/m^2" are used in most parts of the world except for North America, where "mJ/cm^2" are used.

The reduction of micro-organisms is classified using a logarithmic scale. A single log reduction is a 90% reduction of organisms. A two log reduction is a 99% reduction of organisms, followed by a three log reduction (99.9%), etc. The UV-C exposure dosage needed for each level of reduction is shown in the table along with the published reference where the data came from.

UV Dose (Fluence) (mJ/cm2) for a given Log Reduction without photo-reactivation									
	Lamp Type	1	2	3	4	5	6	7	Reference
Spore									
Bacillus anthracis spores - Anthrax spores	N/A	24.32	46.2						Light Sources Inc. 2014
Bacillus magaterium sp. (spores)	N/A	2.73	5.2						Light Sources Inc. 2014
Bacillus subtilis ATCC6633	N/A	36	48.6	61	78				Chang et al. 1985
Bacillus subtilis ATCC6633	LP	24	35	47	79				Mamane-Gravetz and Linden 2004
Bacillus subtilis ATCC6633	LP	22	38	>50					Sommer et al. 1998
Bacillus subtilis ATCC6633	LP	20	39	60	81				Sommer et al. 1999
Bacillus subtilis WN626	LP	0.4	0.9	1.3	2				Marshall et al., 2003
Bacillus subtilis spores	N/A	11.6	22.0						Light Sources Inc. 2014
Bacillus anthracis – Anthrax		4.52	9.04	13.56	18.08				UV-Light.co.UK
Bacillus anthracis spores – Anthrax spores		24.32	48.64	72.96	97.28				UV-Light.co.UK
Bacillus magaterium sp. (spores)		2.73	5.46	8.19	10.92				UV-Light.co.UK
Bacillus magaterium sp. (veg.)		1.3	2.6	3.9	5.2				UV-Light.co.UK
Bacillus paratyphusus		3.2	6.4	9.6	12.8				UV-Light.co.UK
Bacillus subtilis spores		11.6	23.2	34.8	46.4				UV-Light.co.UK
Bacillus subtilis		5.8	11.6	17.4	23.2				UV-Light.co.UK
Clostridium difficile (C. difficile or C. diff)		6.0	12.0	18.0	24.0				UV-Light.co.UK
Clostridium tetani		13.0	26.0	39.0	52.0				UV-Light.co.UK
Bacterium									
Aeromonas salmonicida	LP	1.5	2.7	3.1	5.9				Liltved and Landfald 1996
Aeromonas hydrophila ATCC7966	LP	1.1	2.6	3.9	5	6.7	8.6		Wilson et al. 1992
Bacillus anthracis - Anthrax	N/A	4.52	8.7						Light Sources Inc. 2014
Bacillus magaterium sp. (veg.)	N/A	1.3	2.5						Light Sources Inc. 2014
Bacillus paratyphusus	N/A	3.2	6.1						Light Sources Inc. 2014
Bacillus subtilis	N/A	5.8	11.0						Light Sources Inc. 2014
Campylobacter jejuni ATCC 43429	LP	1.6	3.4	4	4.6	5.9			Wilson et al. 1992
Citrobacter diversus	LP	5	7	9	11.5	13			Giese and Darby 2000
Citrobacter freundii	LP	5	9	13					Giese and Darby 2000
Clostridium tetani	N/A	13.0	22.0						Light Sources Inc. 2014
Corynebacterium diphtheriae	N/A	3.37	6.51						Light Sources Inc. 2014
Corynebacterium diphtheriae		3.37	6.74	10.11	13.48				UV-Light.co.UK
Ebertelia typhosa	N/A	2.14	4.1						Light Sources Inc. 2014V
Ebertelia typhosa		2.14	4.28	6.42	8.56				UV-Light.co.UK
Escherichia coli O157:H7 CCUG 29193	LP	3.5	4.7	5.5	7				Sommer et al. 2000
Escherichia coli O157:H7 CCUG 29197	LP	2.5	3	4.6	5	5.5			Sommer et al. 2000
Escherichia coli O157:H7 CCUG 29199	LP	0.4	0.7	1	1.1	1.3	1.4		Sommer et al. 2000
Escherichia coli O157:H7 ATCC 43894	LP	1.5	2.8	4.1	5.6	6.8			Wilson et al. 1992
Escherichia coli	N/A	3.0	6.6						Light Sources Inc. 2014
Escherichia coli ATCC 11229	N/A	2.5	3	3.5	5	10	15		Harris et al. 1987
Escherichia coli		3.00	6.0	9.0	12.0				UV-Light.co.UK
Escherichia coli ATCC 11229	N/A	3	4.8	6.7	8.4	10.5			Chang et al. 1985
Escherichia coli ATCC 11229	LP	<5	5.5	6.5	7.7	10			Zimmer et al. 2002
Escherichia coli ATCC 11229	MP	<3	<3	<3	<3	8			Zimmer et al. 2002
Escherichia coli ATCC 11229	LP	7	8	9	11	12			Hoyer 1998

UV Dose (Fluence) (mJ/cm2) for a given Log Reduction without photo-reactivation									
	Lamp Type	1	2	3	4	5	6	7	Reference
Escherichia coli ATCC 11229	LP	3.5	4.7	5.5	6.5	7.5	9.6		Sommer et al. 2000
Escherichia coli ATCC 11229	LP	Gff6	6.5	7	8	9	10		Sommer et al. 1998
Escherichia coli ATCC 11303	LP	4	6	9	10	13	15	19	Wu et al. 2005
Escherichia coli ATCC 25922	LP	6	6.5	7	8	9	10		Sommer et al. 1998
Escherichia coli C	LP	2	3	4	5.6	6.5	8	10.7	Otaki et al. 2003
Escherichia coli K-12 IFO3301	LP & MP	2	4	6	7	8.5			Oguma et al. 2002
Escherichia coli K-12 IFO3301	LP & MP	2.2	4.4	6.7	8.9	11.0			Oguma et al. 2004
Escherichia coli K-12 IFO3301	LP	1.5	2	3.5	4.2	5.5	6.2		Otaki et al. 2003
Escherichia coli O157:H7	LP	1.5	3	4.5	6				Tosa and Hirata 1999
Escherichia coli O157:H7	LP	<2	<2	2.5	4	8	17		Yaun et al. 2003
Escherichia coli O25:K98:NM	LP	5	7.5	9	10	11.5			Sommer et al. 2000
Escherichia coli O26	LP	5.4	8	10.5	12.8				Tosa and Hirata 1999
Escherichia coli O50:H7	LP	2.5	3	3.5	4.5	5	6		Sommer et al. 2000
Escherichia coli O78:H11	LP	4	5	5.5	6	7			Sommer et al. 2000
Escherichia coli Wild type	LP	4.4	6.2	7.3	8.1	9.2			Sommer et al. 1998
Halobacterium elongate ATCC33173	LP	0.4	0.7	1					Martin et al. 2000
Halobacterium salinarum ATCC43214	LP	12	15	17.5	20				Martin et al. 2000
Klebsiella pneumoniae	LP	12	15	17.5	20				Giese and Darby 2000
Klebsiella terrigena ATCC33257	LP	4.6	6.7	8.9	11				Wilson et al. 1992
Legionella pneumophila ATCC33152	MP	1.9	3.8	5.8	7.7	9.6			Oguma et al. 2004
Legionella pneumophila ATCC 43660	LP	3.1	5	6.9	9.4				Wilson et al. 1992
Legionella pneumophila ATCC33152	LP	1.6	3.2	4.8	6.4	8.0			Oguma et al. 2004
Leptospiracanicola - infectious Jaundice	N/A	3.15	6.0						Light Sources Inc. 2014
Leptospiracanicola – infectious Jaundice		3.15	6.3	9.45	12.6				UV-Light.co.UK
Microccocus candidus	N/A	6.05	12.3						Light Sources Inc. 2014
Microccocus candidus		6.05	12.1	18.15	24.2				UV-Light.co.UK
Microccocus sphaeroides	N/A	1.0	15.4						Light Sources Inc. 2014
Microccocus sphaeroides		1.0	2.0	3.0	4.0				UV-Light.co.UK
Mycobacterium tuberculosis	N/A	6.2	10.0						Light Sources Inc. 2014
MRSA		3.2	6.4	9.6	12.8				UV-Light.co.UK
Mycobacterium tuberculosis		6.2	12.4	18.6	24.8				UV-Light.co.UK
Neisseria catarrhalis	N/A	4.4	8.5						Light Sources Inc. 2014
Neisseria catarrhalis		4.4	8.8	13.2	17.6				UV-Light.co.UK
Phytomonas tumefaciens	N/A	4.4	8.0						Light Sources Inc. 2014
Phytomonas tumefaciens		4.4	8.8	13.2	17.6				UV-Light.co.UK
Proteus vulgaris	N/A	3.0	6.6						Light Sources Inc. 2014
Proteus vulgaris		3.0	6.0	9.0	12.0				UV-Light.co.UK
Pseudomonas stutzeri	UVB	100	150	195	230				Joux et al. 1999
Pseudomonas aeruginosa	N/A	5.5	10.5						Light Sources Inc. 2014
Pseudomonas fluorescens	N/A	3.5	6.6						Light Sources Inc. 2014
Pseudomonas aeruginosa		5.5	11.0	16.5	22.0				UV-Light.co.UK
Pseudomonas fluorescens		3.5	7.0	10.5	14.0				UV-Light.co.UK
RB2256	UVB	175	>300						Joux et al. 1999
Salmonela paratyphi - Enteric fever	N/A	3.2	6.1						Light Sources Inc. 2014
Salmonella anatum (from human feces)	N/A	7.5	12	15					Tosa and Hirata 1998

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UV Dose (Fluence) (mJ/cm2) for a given Log Reduction without photo-reactivation	Lamp Type	1	2	3	4	5	6	7	Reference
Salmonella derby (from human feces)	N/A	3.5	7.5						Tosa and Hirata 1998
Salmonella enteritidis (from human feces)	N/A	5	7	9	10				Tosa and Hirata 1998
Salmonella infantis (from human feces)	N/A	2	4	6					Tosa and Hirata 1998
Salmonella spp.	LP	<2	2	3.5	7	14	29		Yaun et al. 2003
Salmonella typhi ATCC 19430	LP	1.8	4.8	6.4	8.2				Wilson et al. 1992
Salmonella typhi ATCC 6539	N/A	2.7	4.1	5.5	7.1	8.5			Chang et al. 1985
Salmonella typhimurium (from human feces)	N/A	2	3.5	5	9				Tosa and Hirata 1998
Salmonella typhimurium	UVB	50	100	175	210	250			Joux et al. 1999
Salmonella typhimurium (in act. sludge)	LP	3	11.5	22	50				Maya et al. 2003
Salmonella enteritidis	N/A	4.0	7.6						Light Sources Inc. 2014
Salmonella typhimurium	N/A	8.0	15.2						Light Sources Inc. 2014
Salmonella typhosa - Typhoid fever	N/A	2.15	4.1						Light Sources Inc. 2014
Salmonella enteritidis		4.0	8.0	12.0	16.0				UV-Light.co.UK
Salmonela paratyphi – Enteric fever		3.2	6.4	9.6	12.8				UV-Light.co.UK
Salmonella typhosa – Typhoid fever		2.15	4.3	6.45	8.6				UV-Light.co.UK
Salmonella typhimurium		8.0	16.0	24.0	32.0				UV-Light.co.UK
Sarcina lutea	N/A	19.7	26.4						Light Sources Inc. 2014
Sarcina lutea		19.7	39.4	59.1	78.8				UV-Light.co.UK
Serratia marcescens	N/A	2.42	6.16						Light Sources Inc. 2014
Serratia marcescens		2.42	4.84	7.26	9.68				UV-Light.co.UK
Shigella dysenteriae ATCC29027	LP	0.5	1.2	2	3	4	5.1		Wilson et al. 1992
Shigella dyseteriae - Dysentery	N/A	2.2	4.2						Light Sources Inc. 2014
Shigella flexneri - Dysentery	N/A	1.7	3.4						Light Sources Inc. 2014
Shigella paradysenteriae	N/A	1.68	3.4						Light Sources Inc. 2014
Shigella sonnei ATCC9290	N/A	3.2	4.9	6.5	8.2				Chang et al. 1985
Spirillum rubrum	N/A	4.4	6.16						Light Sources Inc. 2014
Spirillum rubrum		4.4	8.8	13.2	17.6				UV-Light.co.UK
Shigella dyseteriae – Dysentery		2.2	4.4	6.6	8.8				UV-Light.co.UK
Shigella flexneri – Dysentery		1.7	3.4	5.1	6.8				UV-Light.co.UK
Shigella paradysenteriae		1.68	3.3	5.04	6.72				UV-Light.co.UK
Staphylococcus aureus ATCC25923	N/A	3.9	5.4	6.5	10.4				Chang et al. 1985
Staphylococcus albus	N/A	1.84	5.72						Light Sources Inc. 2014
Staphylococcus albus		1.84	3.68	5.52	7.36				UV-Light.co.UK
Staphylococcus aureus	N/A	2.6	6.6						Light Sources Inc. 2014
Staphylococcus hemolyticus	N/A	2.16	5.5						Light Sources Inc. 2014
Staphylococcus lactis	N/A	6.15	8.8						Light Sources Inc. 2014
Staphylococcus aureus		2.6	5.2	7.8	10.4				UV-Light.co.UK
Staphylococcus hemolyticus		2.16	4.32	6.48	8.64				UV-Light.co.UK
Staphylococcus lactis		6.15	12.3	18.45	24.6				UV-Light.co.UK
Streptococcus viridans		2.0	4.0	6.0	8.0				UV-Light.co.UK
Streptococcus faecalis (secondary effluent)	N/A	5.5	6.5	8	9	12			Harris et al. 1987
Streptococcus faecalis ATCC29212	N/A	6.6	8.8	9.9	11.2				Chang et al. 1985
Streptococcus viridans	N/A	2.0	3.8						Light Sources Inc. 2014
Vibrio anguillarum	LP	0.5	1.2	1.5	2				Liltved and Landfald 1996
Vibrio cholerae ATCC25872	LP	0.8	1.4	2.2	2.9	3.6	4.3		Wilson et al. 1992
Vibrio comma - Cholera	N/A	3.375	6.5						Light Sources Inc. 2014
Vibrio natriegens	UVB	37.5	75	100	130	150			Joux et al. 1999

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UV Dose (Fluence) (mJ/cm2) for a given Log Reduction without photo-reactivation	Lamp Type	1	2	3	4	5	6	7	Reference
Vibrio comma – Cholera		3.375	6.75	10.125	13.5				UV-Light.co.UK
Yersinia enterocolitica ATCC27729	LP	1.7	2.8	3.7	4.6				Wilson et al. 1992
Yersinia ruckeri	LP	1	2	3	5				Liltved and Landfald 1996
Yeasts									
Brewers yeast	N/A	3.3	6.6						Light Sources Inc. 2014
Brewers yeast		3.3	6.6	9.9	13.2				UV-Light.co.UK
Common yeast cake	N/A	6.0	13.2						Light Sources Inc. 2014
Common yeast cake		6.0	12.0	18.0	24.0				UV-Light.co.UK
Saccharomyces carevisiae	N/A	6.0	13.2						Light Sources Inc. 2014
Saccharomyces carevisiae		6.0	12.0	18.0	24.0				UV-Light.co.UK
Saccharomyces ellipsoideus	N/A	6.0	13.2						Light Sources Inc. 2014
Saccharomyces ellipsoideus		6.0	12.0	18.0	24.0				UV-Light.co.UK
Saccharomyces spores	N/A	8.0	17.6						Light Sources Inc. 2014
Saccharomyces spores		8.0	16.0	24.0	32.0				UV-Light.co.UK
Molds									
Aspergillius flavus	N/A	60.0	99.0						Light Sources Inc. 2014
Aspergillius flavus		60.0	120.0	180.0	240.0				UV-Light.co.UK
Aspergillius glaucus	N/A	44.0	88.0						Light Sources Inc. 2014
Aspergillius glaucus		44.0	88.0	132.0	176.0				UV-Light.co.UK
Aspergillius niger	N/A	132.0	330.0						Light Sources Inc. 2014
Aspergillius niger		132.0	264.0	396.0	528.0				UV-Light.co.UK
Mucor racemosus A	N/A	17.0	35.2						Light Sources Inc. 2014
Mucor racemosus A		17.0	34.0	51.0	68.0				UV-Light.co.UK
Mucor racemosus B	N/A	17.0	35.2						Light Sources Inc. 2014
Mucor racemosus B		17.0	34.0	51.0	68.0				UV-Light.co.UK
Oospora lactis	N/A	5.0	11.0						Light Sources Inc. 2014
Oospora lactis		5.0	10.0	15.0	20.0				UV-Light.co.UK
Penicillium expansum		13.0	26.0	39.0	52.0				UV-Light.co.UK
Penicillium digitatum	N/A	44.0	88.0						Light Sources Inc. 2014
Penicillium digitatum		44.0	88.0	132.0	176.0				UV-Light.co.UK
Penicillium expansum	N/A	13.0	22.0						Light Sources Inc. 2014
Penicillium roqueforti	N/A	13.0	26.4						Light Sources Inc. 2014
Penicillium roqueforti		13.0	26.0	39.0	52.0				UV-Light.co.UK
Rhisopus nigricans	N/A	111.0	220.0						Light Sources Inc. 2014
Rhisopus nigricans		111.0	222.0	333.0	444.0				UV-Light.co.UK
Protozoan									
Chlorella Vulgaris	N/A	13.0	22.0						Light Sources Inc. 2014
Chlorella Vulgaris		13.0	26.0	39.0	52.0				UV-Light.co.UK
Cryptosporidium hominis	LP & MP	3	5.8						Johnson et al. 2005
Cryptosporidium parvum	LP & MP	2.4	<5	5.2	9.5				Craik et al. 2001
Cryptosporidium parvum	MP	<5	<5	<5	~6				Amoah et al. 2005
Cryptosporidium parvum	MP	<10	<10	<10					Belosevic et al. 2001
Cryptosporidium parvum	LP	1	2	<5					Shin et al. 2001
Cryptosporidium parvum	MP	1	2	2.9	4				Bukhari et al. 2004
Cryptosporidium parvum	LP	<2	<2	<2	<4	<10			Clancy et al. 2004
Cryptosporidium parvum	MP	<3	<3	3-9	<11				Clancy et al. 2000
Cryptosporidium parvum	LP	<3	<3	3-6	<16				Clancy et al. 2000
Cryptosporidium parvum	LP	0.5	1	1.4	2.2				Morita et al. 2002
Cryptosporidium parvum	LP	2	<3	<3					Zimmer et al. 2003

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UV Dose (Fluence) (mJ/cm2) for a given Log Reduction without photo-reactivation	Lamp Type	1	2	3	4	5	6	7	Reference
Cryptosporidium parvum	MP	<1	<1	<1					Zimmer et al. 2003
Cryptosporidium parvum, oocysts, tissue culture assay	N/A	1.3	2.3	3.2					Shin et al. 2000
Encephalitozoon cuniculi, microsporidia	LP	4	9	13					Marshall et al. 2003
Encephalitozoon hellem, microsporidia	LP	8	12	18					Marshall et al. 2003
Encephalitozoon intestinalis, microsporidia	LP & MP	<3	3	<6	6				Huffman et al. 2002
Encephalitozoon intestinalis, microsporidia	LP	3	5	6					Marshall et al. 2003
G. muris, cysts	MP	<5	<5	5					Amoah et al. 2005
G. muris, cysts, mouse infectivity assay	N/A	<2	<6		10 + tailing				Craik et al. 2000
Giardia lamblia	LP	<10	~10	<20					Campbell et al. 2002
Giardia lamblia	LP	<2	<2	<4					Mofidi et al. 2002
Giardia lamblia, gerbil infectivity assay	LP	<0.5	<0.5	<0.5	<1				Linden et al. 2002b
Giardia lamblia, excystation assay	N/A	40	180						Karanis et al. 1992
Giardia lamblia,excystation assay	N/A	> 63							Rice and Hoff 1981
Giardia muris	MP	1	4.5		28 + tailing				Craik et al. 2000
Giardia muris	MP	<10	<10	<25	~60				Belosevic et al. 2001
Giardia muris	LP	<1.9	<1.9	~2	~2.3				Hayes et al. 2003
Giardia muris	LP	<2	<2	<4					Mofidi et al. 2002
Giardia muris, excystation assay	N/A	77	110						Carlson et al. 1985
Nematode Eggs	N/A	45.0	92.0						Light Sources Inc. 2014
Nematode Eggs		45.0	90.0	135.0	180.0				UV-Light.co.UK
Paramecium	N/A	11.0	20.0						Light Sources Inc. 2014
Paramecium		11.0	22.0	33.0	44.0				UV-Light.co.UK

ClorDiSys

The following table shows the required UV-C exposure dosages necessary for various log reductions of viruses.

UV Dose (Fluence) (mJ/cm2) for a given Log Reduction without photo-reactivation									
Virus	Host	Lamp	1	2	3	4	5	6	
Adenovirus type 15	A549 cell line (ATCC CCL-185)	LP	40	80	122	165	210		Thompson et al. 2003
Adenovirus type 2	A549 cell line	LP	20	45	80	110			Shin et al. 2005
Adenovirus type 2	Human lung cell line	LP	35	55	75	100			Ballester and Malley 2004
Adenovirus type 2	PLC / PRF / 5 cell line	LP	40	78	119	160	195	235	Gerba et al.
Adenovirus type	PLC / PRF / 5 cell	LP	55	105	155				ston-Enriquez
Adenovirus type	PLC / PRF / 5 cell	LP	30	ND	ND	124			Meng and Gerba
Adenovirus type	PLC / PRF / 5 cell	LP	23.6	ND	ND	111.8			Meng and Gerba
B40-8 (Phage)	B. Fragilis	LP	11	17	23	29	35	41	Sommer et al.
B40-8 (Phage)	B. fragilis HSP-40	LP	12	18	23	28			Sommer et al
Bacteriopfage - E. Coli	N/A	N/A	2.6	6.6					Light Sources Inc.
Bacteriophage – E. Coli			2.6	5.2	7.8	104.0			UV-Light.co.UK
Calicivirus canine	MDCK cell line	LP	7	15	22	30	36		Husman et al.
Calicivirus feline	CRFK cell line	LP	7	16	25				Husman et al.
Calicivirus feline	CRFK cell line	N/A	4	9	14				Tree et al. 2005
Calicivirus feline	CRFK cell line	LP	5	15	23	30	39		ston-Enriquez et al. 2003
Coxsackievirus B3	BGM cell line	LP	8	16	24.5	32.5			Gerba et al.
Coxsackievirus B5	Buffalo Green Monkey cell line	N/A	6.9	13.7	20.6				Battigelli et al. 1993
Coxsackievirus B5	BGM cell line	LP	9.5	18	27	36			Gerba et al.
Echovirus I	BGM cell line	LP	8	16.5	25	33			Gerba et al.
Echovirus II	BGM cell line	LP	7	14	20.5	28			Gerba et al.
Hepatitis A	HAV/HFS/GBM	N/A	5.5	9.8	15	21			Wiedenmann et
Hepatitis A HM175	FRhK-4 cell	LP	5.1	13.7	22	29.6			Wilson et al.
Hepatitis A HM175	FRhK-4 cell	N/A	4.1	8.2	12.3	16.4			Battigelli et al.
Infectious Hepatitis	N/A	N/A	5.8	8.0					Light Sources Inc.
Infectious Hepatitis			5.8	11.6	17.4	232.0			UV-Light.co.UK
Influenza	N/A	N/A	3.4	6.6					Light Sources Inc.
Influenza			3.4	6.8	10.2	136.0			UV-Light.co.UK
MS2 (Phage)	Sal monella typhimurium WG49	N/A	16.3	35	57	83	114	152	Nieuwstad and Havelaar
MS2 (Phage)	*E. coli* K-12 Hfr	LP	21	36					Sommer et al.
MS2 (Phage)	*E. coli* CR63	N/A	16.9	33.8					Rauth 1965
MS2 (Phage)	*E. coli* 15977	N/A	13.4	28.6	44.8	61.9	80.1		Meng and Gerba
MS2 (Phage)	*E. coli* C3000	N/A	35						Battigelli et al.
MS2 (Phage)	*E. coli* ATCC 15597	N/A	19	40	61				Oppenheimer et
MS2 (Phage)	*E. coli* C3000	LP	20	42	69	92			Batch et al. 2004
MS2 (Phage)	*E. coli* ATCC 15597	LP	20	42	70	98	133		Lazarova and

UV Dose (Fluence) (mJ/cm2) for a given Log Reduction without photo-reactivation									
Virus	Host	Lamp	1	2	3	4	5	6	
MS2 (Phage)	*E. coli* ATCC 15977	LP	20	50	85	120			Thurston-Enriquez et al., 2003
MS2 (Phage)	*E. coli* HS(pFamp)R	LP		45	75	100	125	155	Thompson et al.
MS2 (Phage)	*E. coli* C3000	LP	20	42	68	90			Linden et al.
MS2 (Phage)	*E. coli* K-12	LP	18.5	36	55				Sommer et al.
MS2 (Phage)	*E. coli* NCIMB 9481	N/A	14						Tree et al. 2005
MS2 ATCC 15977-B1 (Phage)	*E. coli* ATCC 15977–B1	LP	15.9	34	52	71	90	109	Wilson et al. 1992
MS2 DSM 5694 (Phage)	*E. coli* NCIB 9481	N/A	4	16	38	68	110		Wiedenmann et al. 1993
MS2 NCIMB 10108 (Phage)	*Salmonella typhimurium* WG49	N/A	12.1	30.1					Tree et al. 1997
PHI X 174 (Phage)	*E. coli* WG5	LP	2.2	5.3	7.3	10.5			Sommer et al.
PHI X 174 (Phage)	*E. coli* C3000	N/A	2.1	4.2	6.4	8.5	10.6	12.7	Battigelli et al.
PHI X 174 (Phage)	*E. coli* ATCC15597	N/A	4	8	12				Oppenheimer et
PHI X 174 (Phage)	*E. coli* WG 5	LP	3	5	7.5	10	12.5	15	Sommer et al.
PHI X 174 (Phage)	*E. coli* ATCC 13706	LP	2	3.5	5	7			Giese and Darby
Poliovirus - Poliomyelitis	N/A	N/A	3.15	6.6					Light Sources Inc. 2014
Poliovirus – Poliomyelitis			3.15	6.3	9.45	126.0			UV-Light.co.UK
Poliovirus 1	BGM cell line	N/A	5	11	18	27			Tree et al. 2005
Poliovirus 1	CaCo2 cell-line (ATCC HTB37)	LP	7	17	28	37			Thompson et al. 2003
Poliovirus 1	BGM cell line	LP	8	15.5	23	31			Gerba et al.
Poliovirus Type Mahoney	Monkey kidney cell line Vero	LP	3	7	14	40			Sommer et al. 1989
Poliovirus Type 1 ATCC Mahoney	N/A	N/A	6	14	23	30			Harris et al. 1987
Poliovirus Type 1 LSc2ab ()	MA104 cell	N/A	5.6	11	16.5	21.5			Chang et al. 1985
Poliovirus Type 1 LSc2ab	BGM cell	LP	5.7	11	17.6	23.3	32	41	Wilson et al. 1992
PRD-1 (Phage)	S. typhimurium Lt2	N/A	9.9	17.2	23.5	30.1			Meng and Gerba
Reovirus Type 1 Lang strain	N/A	N/A	16	36					Harris et al. 1987
Reovirus-3	Mouse L-60	N/A	11.2	22.4					Rauth 1965
Rotavirus	MA104 cells	LP	20	80	140	200			Caballero et al.
Rotavirus SA-11	Monkey kidney cell line MA 104	LP	8	15	27	38			Sommer et al. 1989
Rotavirus SA-11	MA-104 cell line	N/A	7.6	15.3	23				Battigelli et al.
Rotavirus SA-11	MA-104 cell line	N/A	7.1	14.8	25				Chang et al.
Rotavirus SA-11	MA-104 cell line	LP	9.1	19	26	36	48		Wilson et al.
Staphylococcus aureus phage A 994	*aphylococcus aureus* 994	LP	8	17	25	36	47		Sommer et al. 1989
Tobacco mosaic	N/A	N/A	240.0	440.0					Light Sources Inc. 2014

Appendix 3 – Persistence of Bacteria (As compiled via a Google Search)

Persistence of Clinically Relevant Bacteria on Dry Inanimate Surfaces[1]	
Organism	**Persistence**
Acinetobacter spp.	3 days to 5 months
Bordetella pertussis	3-5 days
Campylobacter jejuni	Up to 6 days
Clostridium difficile (spores)	5 months
Chlamydia pneumoniae	Up to 30 hours
Chlamydia psittaci	15 days
Corynebacterium diphtheria	7 days – 6 months
Corynebacterium pseudotuberculosis	1-8 days
Escherichia coli	1.5 hours – 16 months
Enterococcus spp. including VRE and VSE	5 days – 4 months
Haemophilus influenza	12 days
Helicobacter pylori	Up to 90 minutes
Klebsiella spp.	2 hours – 30 months
Listeria spp.	1 day – 4 months
Mycobacterium bovis	Up to 2 months
Mycobacterium tuberculosis	1 day – 4 months
Neisseria gonorrhoeae	1-3 days
Proteus vulgaris	1-2 days
Pseudomonas aeruginosa	6 hours – 16 months; 5 weeks on dry floor
Salmonella typhi	6 hours – 4 weeks
Salmonella typhimurium	10 days – 4.2 years
Salmonella spp.	1 day
Serratia marcescens	3 days – 2 months; 5 weeks on dry floor
Shigella spp.	2 days – 5 months
Staphylococcus aureus, including MRSA	7 days – 7 months
Streptococcus pneumoniae	1-20 days
Streptococcus pyogenes	3 days – 6.5 months
Vibrio cholera	1-7 days

References:

Amoah, K., Craik, S., Smith, D.W. and Belosevic, M. 2005. Inactivation of Cryptosporidium oocysts and Giardia cysts by ultraviolet light in the presence of natural particulate matter, AQUA, J. Wat. Supply 54(3): 165-178.

Ballester, N.A. and Malley, J.P. 2004. Sequencial disinfection of adenovirus type 2 with UV-chlorinechloramine, J. Amer. Wat. Works Assoc., 96(10): 97-102.

Batch, L.F., Schulz, C.R. and Linden, K.G. 2004. Evaluating water quality effects on UV disinfection of MS2 coliphage, J. Amer. Wat. Works Assoc., 96(7): 75-87.

Battigelli, D.A., Sobsey, M.D. and Lobe, D.C. 1993. The inactivation of Hepatitis A virus and other model viruses by UV irradiation, Wat. Sci. Tech., 27(3-4): 339-342.

Belosevic, M., Craik, S.A., Stafford, J.L. Neumann, N.E., Kruithof, J. and Smith, D.W. 2001. Studies on the resistance/reaction of Giardia muris cysts and C. parvum oocysts exposed to medium-pressure ultraviolet radiation, FEMS Microbiol. Lett., 204(1): 197-204.

Bolton J.R. and Linden, K.G. 2003. Standardization of methods for fluence (UV Dose) determination in benchscale UV experiments. J. Environ. Eng. 129(3): 209-216.

Bukhari, Z., Abrams, F. and LeChevallier, M. 2004. Using ultraviolet light for disinfection of finished water, Water Sci. Tech., 50(1): 173-178.

Caballero, S., Abad, F.X., Loisy, F., Le Guyader, F.S., Cohen, J., Pinto, R.M. and Bosch, A. 2004. Rotavirus virus-like particles as surrogates in environmental persistence and inactivation studies, Appl. Env. Microbiol. 70(7): 3904-3909.

Campbell, A.T. and Wallis, P. 2002. The effect of UV irradiation on human-derived *Giardia lamblia* cysts, Wat. Res., 36(4): 963- 969.

Carlson, D.A., Seabloom, R.W., DeWalle, F.B., Wetzler, T.F., Engeset, J., Butler, R., Wangsuphachart, S. and Wang, S. 1985. Ultraviolet disinfection of water for small water supplies. US EPA Report No. EPA/600/S2-85/092.

Cass AL, Kelly JW, Probst JC, Addy CL, McKeown RE. Identification of device-associated infections utilizing administrative data. American Journal of Infection Control. 2013; Published online 17 June 2013.

Chang, J.C.H., Osoff, S.F., Lobe, D.C., Dorfman, M.H., Dumais, C.M., Qualls, R.G. and Johnson, J.D. 1985. UV inactivation of pathogenic and indicator microorganisms, Appl. Environ. Microbiol., 49(6): 1361-1365.

Clancy, J.L., Bukhari, Z., Hargy, T.M., Bolton, J.R., Dussert, B.W. and Marshall, M.M. 2000. Using UV to inactivate *Cryptosporidium* – Even extremely low dosages of ultraviolet light can be highly effective for inactivating *Cryptosporidium* oocysts, J. Amer. Wat. Works Assoc., 92(9): 97-104.

Clancy, J.L., Marshall, M.M., Hargy, T.M. and Korich, D.G. 2004. Susceptibility of five strains of *Cryptosporidium parvum* oocysts to UV light, J. Amer. Wat. Works Assoc., 96(3), 84-93.

Craik, S.A., Finch, G.R., Bolton, J.R. and Belosevic, M. 2000. Inactivation of *Giardia muris* cysts using medium- pressure ultraviolet radiation in filtered water, Wat. Res.,34(18): 4325-4332.

Craik, S.A., Weldon, D., Finch, G.R., Bolton, J.R. and Belosevic, M. 2001. Inactivation of *Cryptosporidium parvum* oocysts using medium- and low-pressure ultraviolet radiation, Wat. Res., 35(6): 1387-1398.

Faires MC, Pearl DL, Berke O, Reid-Smith RJ, Weese JS. The identification and epidemiology of methicillin-resistant Staphylococcus aureus and Clostridium difficile in patient rooms and the ward environment. BMC Infectious Diseases 2013, 13:342

Gerba, C.P., Gramos, D.M. and Nwachuku, N. 2002. Comparative inactivation of enteroviruses and adenovirus 2 by UV light, Appl. Environ. Microbiol.,68(10): 5167-5169.

Giese, N. and Darby, J. 2000. Sensitivity of microorganisms to different wavelengths of UV light: implications on modeling of medium pressure UV systems, Wat. Res., 34(16): 4007-4013.

Grohskopf LA, Sinkowitz-Cochran RL, Garrett Dom et al. A national point-prevalence survey of pediatric intensive care unit-acquired infections in the United States. Journal of Pediatrics. 2002; 140, 432-438.

Harris, G.D., Adams, V.D., Sorensen, D.L. and Curtis, M.S. 1987. Ultraviolet inactivation of selected bacteria and viruses with photoreactivation of the bacteria, Wat. Res.,21(6): 687-692.

Hayes, S.L., Rice, E.W., Ware, M.W. and Schaefer III, F.W.2003. Low pressure ultraviolet studies for inactivation of *Giardia muris* cysts, J. Appl. Microbiol., 94(1): 54-59.

Hijnen, W.A.M., Beerendonk, E.F. and Medema, G.J. 2006. Inactivation credit of UV radiation for viruses, bacteria and protozoan (oo)cysts in water; a review, Wat. Res.,40(1): 3-22.

Hoyer, O. 1998. Testing performance and monitoring of UV systems for drinking water disinfection, Wat. Supply,16(1-2): 424-429.

Huffman, D.E., Gennaccaro, A., Rose, J.B. and Dussert, B.W. 2002. Low- and medium-pressure UV inactivation of microsporidia *Encephalitozoon intestinalis*, Wat. Res.,36(12): 3161-3164.

Husman, A.M.D., Bijkerk, P., Lodder, W., Van den Berg, H., Pribil, W., Cabaj, A., Gehringer, P., Sommer, R. and Duizer, E. 2004. Calicivirus inactivation by nonionizing 253.7-nanometer-wavelength (UV) and ionizing (Gamma) radiation, Appl. Environ. Microbiol., 70(9):5089-5093.

Infection Control Breaches in the Operating Room. Infection Control Today. 2013.

Johnson, A.M., Linden, K., Ciociola, K.M., De Leon, R., Widmer, G. and Rochelle, P.A. 2005. UV inactivation of *Cryptosporidium hominis* as measured in cell culture, Appl. Environ. Microbiol., 71(5): 2800-2802.

Joux, F., Jeffrey, W.H., Lebaron, P. and Mitchell, D. L. 1999. Marine bacterial isolates display diverse responses to UV-B radiation, Appl. Environ. Microbiol., 65(9):3820-3827.

Karanis, P., Maier, W.A., Seitz, H.M. and Schoenen, D. 1992. UV sensitivity of protozoan parasites, Aqua, 41:95-100.

Lazarova,V. and Savoye, P. 2004. Technical and sanitary aspect of wastewater disinfection by ultraviolet irradiation for landscape irrigation, Wat. Sci. Technol., 50(2): 203-209.

Light Sources Inc and American Ultraviolet Company. UV Irradiation Dosage Table. Accessed from http://www.americanairandwater.com/uv-facts/uv-dosage.htm. Accessed on 3-26-2014

Liltved, H. and Landfald, B. 1996. Influence of liquid holding recovery and photoreactivation on survival of ultraviolet-irradiated fish pathogenic bacteria, Wat. Res.,30(5): 1109-1114.

Linden, K.G., Batch, L. and Schulz, C. 2002a. UV disinfection of filtered water supplies: water quality impacts on MS2 dose-response curves, Proceedings Amer. Wat. Works Assoc. Annu. Conf., Amer. Wat. Works Assoc., Denver, CO.

Linden, K.G., Shin, G.-A., Faubert, G., Cairns, W. and Sobsey, M.D. 2002b. UV disinfection of *Giardia lamblia* cysts in water, Environ. Sci. Techol., 36(11): 2519-2522.

Lucado, J., Paez, K., Andrews, R., Steiner, C..Adult Hospital Stays with Infections Due to Medical Care, 2007.HCUP Statistical Brief #94. August 2010. Agency for Healthcare Research and Quality, Rockville, MD.

Mamane-Gravetz, H. and Linden, K.G. 2004. UV disinfection of indigenous aerobic spores: Implications for UV reactor validation in unfiltered waters, Wat. Res.,38(12): 2898-2906.

Marshall, M.M., Hayes, S., Moffett, J., Sterling, C.R. and Nicholson, W.L. 2003. Comparison of UV inactivation of three *Encephalitozoon* species with that of spores of two DNA repair-deficient *Bacillus subtilis* biodosimetry strains, Appl. Environ. Microbiol., 69(1): 683-685.

Martin, E.L., Reinhardt, R.L., Baum, L.L., Becker, M.R., Shaffer, J.J. and Kokjohn, T.A. 2000. The effects of ultraviolet radiation on the moderate halophile *Halomonas elongata* and the extreme halophile *Halobacterium salinarum*, Can. J. Microbiol., 46(2): 180-187.

Maya, C., Beltran, N., Jimenez, B. and Bonilla, P. 2003. Evaluation of the UV disinfection process in bacteria and amphizoic amoebae inactivation, Wat. Sci. Technol.: Wat. Supply, 3(4): 285-291.

Meng, Q.S. and Gerba, C.P. 1996. Comparative inactivation of enteric adenoviruses, poliovirus and coliphages by ultraviolet irradiation, Wat. Res., 30(11):2665-2668.

Mofidi, A.A., Meyer, E.A., Wallis, P.M., Chou, C.I., Meyer, B.P., Ramalingam, S. and Coffey, B.M. 2002. The effect of UV light on the inactivation of *Giardia lamblia* and *Giardia muris* cysts as determined by animal infectivity assay, Wat. Res., 36(8): 2098-2108.

Morita, S., Namikoshi, A., Hirata, T., Oguma, K., Katayama, H., Ohgaki, S., Motoyama, N. and Fujiwara, M. 2002. Efficacity of UV irradiation in inactivating *C. parvum* oocysts, Appl. Environ. Microbiol., 68(11):5387-5393.

Nieuwstad, T.J. and Havelaar, A.H. 1994. The kinetics of batch ultraviolet inactivation of bacteriophage MS2 and microbiological calibration of an ultraviolet pilot plant, J. Environ. Sci. Health, A29(9): 1993-2007.

Oguma, K., Katayama, H. and Ohgaki, S. 2002. Photoreactivation of *E. coli* after low- or medium- pressure UV disinfection determined by an endonuclease sensitive site assay, Appl. Environ. Microbiol., 68(12), 6029-6035.

Oguma, K., Katayama, H. and Ohgaki, S. 2004. Photoreactivation of *Legionella pneumophila* after inactivation by low- or medium-pressure ultraviolet lamp, Wat. Res., 38(11): 2757-2763.

Oppenheimer, J.A., Hoagland, J.E., Laine, J.-M., Jacangelo, J.G. and Bhamrah, A. 1993. Microbial inactivation and charcaterization of toxicity and by-products occurring in reclaimed wastewater disinfected with UV radiation, Conf. on Planning, Design and Operation of Effluent Disinfection Systems, Whippany, NJ, May 23-25, 1993,

Pyrek, K. Pathogen Persistence, Transmission and Cross-Contamination Prevention. VIRGO Publishing. Aug 2012.

Wat. Environ. Fed., Alexandria, VA Otaki, M., Okuda, A., Tajima, K., Iwasaki, T., Kinoshita, S. and Ohgaki, S. 2003. Inactivation differences of microorganisms by low pressure UV and pulsed xenon lamps, Wat. Sci. Technol., 47(3): 185-190.

Rauth, A.M. 1965. The physical state of viral nucleic acid and the sensitivity of viruses to ultraviolet light, Biophys. J., 5: 257-273.

Rice, E.W. and Hoff, J.C. 1981. Inactivation of *Giardia lamblia* cysts by ultraviolet irradiation, Appl. Environ. Microbiol., 42(3): 546-547.

Shin, G.-A., Linden, K.G. and Sobsey, M.D. 2000. Comparative inactivation of *Cryptosporidium parvum* oocysts and colliphage MS2 by monochromatic UV radiation, Proceedings of Disinfection 2000: Disinfection of Wastes in the New Millennium, New Orleans, Water Environment Federation, Alexandria, VA.

Shin, G.-A., Linden, K.G., Arrowood, M.J. and Sobsey, M.D. 2001. Low-pressure UV inactivation and DNA repair potential of *C. parvum* oocysts, Appl. Environ. Microbiol., 67(7): 3029-3032.

Shin, G.A., Linden, K.G. and Sobsey, M.D. 2005. Low pressure ultraviolet inactivation of pathogenic enteric viruses and bacteriophages, J. Environ. Engr. Sci., 4: S7-S11.

Sommer, R., Weber, G., Cabaj, A., Wekerle, J., Keck, G., and Schauberger, G. 1989. UV inactivation of micro- organisms in water. Zbl. Hyg. 189: 214-224.

Sommer, R., Haider, T., Cabaj, A., Pribil, W. and Lhotsky, M. 1998. Time dose reciprocity in UV disinfection of water, Water Sci. Technol., 38(12): 145-150.

Sommer, R., Cabaj, A., Sandu, T. and Lhotsky, M. 1999. Measurement of UV radiation using suspensions of microorganisms, J. Photochem. Photobiol., 53(1-3): 1-5.

Sommer, R., Lhotsky, M., Haider, T. and Cabaj, A. 2000. UV inactivation, liquid-holding recovery, and photoreactivation of *E. coli* O157 and other pathogenic *E. coli* strains in water, J. Food Protection, 63(8): 1015-1020.

Sommer, R., Pribil, W., Appelt, S., Gehringer, P., Eschweiler, H., Leth, H., Cabaj, A. and Haider, T. 2001. Inactivation of bacteriophages in water by means of non-ionizing (UV-253.7 nm) and ionizing (gamma) radiation: A comparative approach, Wat. Res., 35(13): 3109- 3116.

Srinivasan MD, Arjun, American Recovery and Reinvestment Act Epidemiology and Laboratory Capacity (ELC) for Infectious Disease Program Healthcare-Associated Infections (HAIs) Grantee Meeting CDR Oct 19-20 2009.

Thurston-Enriquez, J.A. , Haas, C.N. , Jacangelo, J. , Riley, K. and Gerba, C.P. 2003. Inactivation of feline calcivirus and adenovirus type 40 by UV radiation, Appl. Environ. Microbiol., 69(1): 577-582.

Thompson, S.S., Jackson, J.L., Suva-Castillo, M., Yanko, W.A., Jack, Z.E., Kuo, J., Chen, C.L., Williams, F.P. and Schnurr, D.P. 2003. Detection of infectious human adenoviruses in tertiary-treated and ultraviolet-disinfected wastewater, Wat. Environ. Res., 75(2): 163-170.

Tosa, K. and Hirata, T. 1998. HRWM-39: Photoreactivation of Salmonella following UV disinfection, IAWQ 19th Biennial International Conference, Vol. 10, Health- Related Water Microbiology.

Tosa, K. and Hirata, T. 1999. Photoreactivation of enterohemorrhagic *E. coli* following UV disinfection, Wat. Res., 33(2): 361-366.

Tree, J.A., Adams, M.R. and Lees, D.N. 1997. Virus inactivation during disinfection of wastewater by chlorination and UV irradiation and the efficacy of F+ bacteriophage as a 'viral indicator', Wat. Sci. Technol., 35(11-12): 227-232.

Tree, J.A., Adams, M.R. and Lees, D.N. 2005. Disinfection of feline calicivirus (a surrogate for Norovirus) in wastewaters, J. Appl. Microbiol., 98: 155-162.

UV-Light.co.UK, UV Light Technology Limited, https://www.uv-light.co.uk/uv-dose-required-for-inactivation-of-viruses-bacteria-moulds-etc/ accessed on 2-20-2018.

Wiedenmann, A. , Fischer, B., Straub, U., Wang, C.-H., Flehmig, B. and Schoenen, D. 1993. Disinfection of Hepatitis A virus and MS-2 coliphage in water by ultraviolet irradiation: Comparison of UV-susceptibility, Wat. Sci. Tech., 27(3-4): 335-338.

Wiener-Well Y, Galuty M, Rudensky B, Schlesinger Y, Attias D, Yinnon AM. Nursing and physician attire as possible source of nosocomial infections. American Journal of Infection Control. 2011 Sep;39(7):555-9.

Wilson, B.R., Roessler, P.F., Van Dellen, E., Abbaszadegan, M. and Gerba, C.P. 1992. Coliphage MS-2 as a UV water disinfection efficacy test surrogate for bacterial and viral pathogens, Proceedings, Water Quality Technology Conference, Nov 15-19, 1992, Toronto, Canada, pp. 219-235, Amer. Wat. Works Assoc., Denver, CO.

Wu, Y., Clevenger, T. and Deng, B. 2005. Impacts of goethite particles on UV disinfection of drinking water, Appl. Environ. Microbiol., 71(7): 4140-4143.

Yaun, B.R., Sumner, S.S., Eifert, J.D. and Marcy, J.E. 2003. Response of *Salmonella* and *E. coli* O157:H7 to UV energy, J. Food Protection, 66(6): 1071-1073.

Zimmer, J.L. and Slawson, R.M. 2002. Potential repair of *E. coli* DNA following exposure to UV radiation from both medium- and low-pressure UV sources used in drinking water treatment, Appl. Environ. Microbiol., 68(7): 3293-3299.

Zimmer, J.L., Slawson, R.M. and Huck, P.M. 2003. Inactivation and potential repair of *C. parvum* following low- and medium-pressure ultraviolet irradiation, Wat. Res., 37(14): 3517-3523.