Pathogen Inactivation Dose Reference List[1] - 222nm, 254nm & Pulsed Xenon UV Light Sources

	Pathogen	Reported Dose Required to Inactivate 99.9% of Tested Pathogen Strain Under Laboratory Conditions[1] (D99.9, mJ/cm^2)[2,3,4]			Medium Used for Testing[2,3,4]	Reference[1]	Tested Pathogen Strain
		222nm[5]	254nm[6]	Pulsed Xenon[7]			
Viruses	SARS-CoV-2	3.6[9]	-	-	Dry surface in Petri dish	[1][8]	SARS-CoV-2 (2019-nCoV/Japan/AI/I-004/2020) [1] [25] SARS-CoV-2 (USA/WA1-2020) [2]
		-	3.4	-	Dry surface in Petri dish	[2]	
		-	4.0	-	Dry surface in Petri dish	[2]	
		-		17.2[10]	Dry surface in Petri dish	[25]	
	Human Coronavirus	1.2-1.7	-		Aerosol	[3][8]	Alpha HCoV-229E and beta HCoV-OC43 [3] Strain 229E, ATCC VR-740 [31]
		-	-	19.4[10]	Dry surface in Petri dish	[31]	
	Influenza A (H1N1)	<6.0	<6.0	-	Liquid in culture dish	[4][8]	Influenza A (H1N1/pdm09 strain A/Michigan/45/2015) [4] Influenza A (H1N1 /A/PR/8/34 H1N1) [5] [6] Influenza A (H1N1 /A/PR/8/34, ATCC 1469) [26]
		3.8	-	-	Aerosol	[5][8]	
		-	2.4-3.1	-	Aerosol	[6]	
		-	-	27.5[10]	Dry surface in Petri dish	[26]	
	Feline calicivirus (FCV)	24	24	-	Liquid in culture dish	[4][8]	Feline calicivirus (F4) [4] Feline calicivirus (VR-782) [7] [27] [28] [38]
		-	43.0	-	Liquid in Petri dish	[7]	
		-	-	74.4[10]	Dry surface in Petri dish	[27][28]	
		15.3[11]	-	-	Wet surface on stainless steel disk	[38]	
	Escherichia coli bacteriophage MS2 (MS2)	22	58	-	Liquid in Petri dish	[8][8]	*E. coli* bacteriophage MS2 (15597-B1) [8] *E. coli* bacteriophage MS2 (TIB-71) [7] *E. coli* bacteriophage MS2 (700891) [9]
		-	121	-	Liquid in Petri dish	[7]	
		-	44	-	Liquid in Petri dish	[9]	

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	Pathogen	Reported Dose Required to Inactivate 99.9% of Tested Pathogen Strain Under Laboratory Conditions[1] (D99.9, mJ/cm^2)[2,3,4]			Medium Used for Testing[2,3,4]	Reference[1]	Tested Pathogen Strain
		222nm[5]	254nm[6]	Pulsed Xenon[7]			
Bacteria	*Staphylococcus aureus* (MRSA)	<6.0	<6.0	-	Liquid in Petri dish	[4][8]	*S. aureus* (MRSA clinical isolates) [4] *S. aureus* (non-MRSA 25923) [10] *S. aureus* (MRSA clinical isolates) [11] *S. aureus* (MRSA BAA-1556) [12] *S. aureus* (MRSA ATCC 33592) [29] [30] *S. aureus* (MRSA ATCC 33591) [34]
		14	7.3	-	Liquid in Petri dish	[10]	
		15	-	-	Liquid in Petri dish	[11]	
		-	8.7	-	Liquid (PBS or wastewater) in Petri dish	[12]	
		-	-	6.8[10]	Dry surface in Petri dish	[29][30]	
		24.2[11]	-	-	Wet surface on stainless steel disk	[34]	
	Salmonella enterica (Salmonella)	12	8.5	-	Liquid in culture dish	[4][8]	*S. enterica* (serogroup *S. typhimurium*, clinical isolates) [4] *S. enterica* (serogroup *S. enteritidis* 1049-1-99 & 61-358-1) [13] *S. enterica* (serogroup *S. typhimurium* ATCC 19585, ATCC 43971, & ATCC DT104) [14] *S. enterica* (ATCC 10708) [29] *S. enterica* (ATCC 33592) [30] *S. enterica* (ATCC 14028) (Typhi *Salmonella*) [35] *S. enterica* (ATCC 10708) (Non-Typhi *Salmonella*) [36]
		-	100-300	-	Dry surface on egg	[13]	
		3.8~5.9	-	-	Liquid in Petri dish	[14]	
		-	-	9.0[10]	Dry surface in Petri dish	[29][30]	
		25.2[11]	-	-	Wet surface on stainless steel disk	[35]	
		6.9[11]	-	-	Wet surface on stainless steel disk	[36]	
	Mycobacterium tuberculosis (TB)	-	5.7	-	Liquid in Petri dish	[15]	*M. tuberculosis* (H37Rv) [15] *M. tuberculosis* (Erdman TMCC 107 & 199RB TMCC 109) [16] *M. tuberculosis* (Erdman TMCC 107) [17]
		-	2.3-5.5	-	Aerosol	[16]	
		-	9.6	-	Agar surface	[17]	
	Listeria monocytogenes (Listeria)	2.4	3.36	-	Liquid in Petri dish	[33]	Listeria monocytogenes (ATCC 19111, ATCC 19115, & ATCC 15313 [33]

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	Pathogen	Reported Dose Required to Inactivate 99.9% of Tested Pathogen Strain Under Laboratory Conditions[1] (D99.9, mJ/cm^2)[2,3,4]			Medium Used for Testing[2,3,4]	Reference[1]	Tested Pathogen Strain
		222nm[5]	254nm[6]	Pulsed Xenon[7]			
Bacteria	*Pseudomonas aeruginosa* (PAE)	<6.0	<<6.0	-	Liquid in Petri dish	[4][8]	*P. aeruginosa* (clinical isolates) [4] *P. aeruginosa* (PA01, 47085) [12] *P. aeruginosa* (10145) [18] *P. aeruginosa* (27853) [10]
		-	3.8-4.3	-	Liquid (PBS or wastewater) in Petri dish	[12]	
		-	7.4	-	Liquid in Petri dish	[18]	
		5.9	2.3	-	Liquid in Petri dish	[10]	
	Campylobacter jejuni	<<6	<<6	-	Liquid in Petri dish	[4][8]	*C. jejuni* (clinical isolate) [4] *C. jejuni* (biotype 1 strain 709/84) [19]
		-	1.8	-	Liquid in Petri dish	[19]	
	Clostridium difficile (endospores) *(C. diff)*	20<D99.9<30	>50	-	Liquid in Petri dish	[4][8]	*C. difficile* (clinical isolate & JCM1296) [4] *C. difficile* (43593) [11]
		68	-	-	Liquid in Petri dish	[11]	
	Bacillus subtilis (vegetative cells)	325	370	-	Liquid in Petri dish	[10]	*B. subtilis* (6051) [10]
	Bacillus subtilis (endospores)	325	370	-	Liquid in Petri dish	[10]	*B. subtilis* (6051) [10] *B. subtilis* (6633) [18] *B. subtilis* (6633) [21]
		-	44	-	Liquid in Petri dish	[18]	
		30	55	-	Liquid in Petri dish	[21]	
	Bacillus cereus (vegetative cells)	14	8.5	-	Liquid in Petri dish	[10]	*B. cereus* (11778) [10]
	Bacillus cereus (endospores)	36<D99.9<72	>96	-	Liquid in Petri dish	[4][8]	*B. cereus* (clinical isolate) [4] *B. cereus* (water isolates) [20] *B. cereus* (11778) [10]
		-	179	-	Liquid in Petri dish	[20]	
		69	140	-	Liquid in Petri dish	[10]	

Pathogen Inactivation Dose Reference List[1] - 222nm, 254nm & Pulsed Xenon UV Light Sources

	Pathogen	Reported Dose Required to Inactivate 99.9% of Tested Pathogen Strain Under Laboratory Conditions[1] (D99.9, mJ/cm^2)[2,3,4]			Medium Used for Testing[2,3,4]	Reference[1]	Tested Pathogen Strain
		222nm[5]	254nm[6]	Pulsed Xenon[7]			
Bacteria	*Escherichia coli* (*E. coli*)	6-9	<<6	-	Liquid in Petri dish	[4][8]	*E. coli* (enterohaemorrhagic, clinical isolate) [4] *E. coli* (SMS-3-5 BAA-1743) [12] *E. coli* (water isolates) [20] *E. coli* (O157:H7 35150, 43889, & ATCC 43890) [14] *E. coli* (K-12) [22] *E. coli* (ATCC 8739) [29] [37] *E. coli* (ATCC 11229) [30]
		-	6.5-7.4	-	Liquid (PBS or wastewater) in Petri dish	[12]	
		-	19	-	Liquid in Petri dish	[20]	
		1.5	-	-	Liquid in Petri dish	[14]	
		3.3-9.7	-	-	Liquid in Petri dish	[22]	
		-	-	10.3[10]	Dry surface in Petri dish	[29][30]	
		18.1[11]	-	-	Wet surface on stainless steel disk	[37]	

	Pathogen Inactivation Dose Reference List[1] - 222nm, 254nm & Pulsed Xenon UV Light Sources						
	Pathogen	Reported Dose Required to Inactivate 99.9% of Tested Pathogen Strain Under Laboratory Conditions[1] (D99.9, mJ/cm^2)[2,3,4]			Medium Used for Testing[2,3,4]	Reference[1]	Tested Pathogen Strain
		222nm[5]	254nm[6]	Pulsed Xenon[7]			
Fungi	*Candida albicans*	24<<D99.9<72	24<<D99.9<72	-	Liquid in Petri dish	[4][8]	*C. albicans* (NBRC1385) [4] *C. albicans* (CEC 749) [23]
		-	19	-	Liquid in Petri dish	[23]	
	Penicillium expansum	42	49	-	Liquid in Petri dish	[10]	*P. expansum* (36200) [10]
	Aspergillus niger (spores)	-	929	-	Liquid in cellophane pouch	[24]	*A. niger* (FRR 5664) [24] *A. niger* (32625) [10]
		-	729	-	Dry spores on membrane filter	[24]	
		325	370	-	Liquid in Petri dish	[10]	
	Candia auris	-	-	174.3[10]	Dry surface in Petri dish	[32]	*C. auris* (AR Bank #0381) [32]

Reference#	Publication Title	Link to Publication	Primary Author
[01]	Effectiveness of 222-nm ultraviolet light on disinfecting SARS-CoV-2 surface contamination	DOI: 10.1016/j.ajic.2020.08.022	Kitagawa
[02]	Rapid and complete inactivation of SARS-CoV-2 by ultraviolet-C irradiation	DOI: 10.1038/s41598-020-79600-8	Storm
[03]	Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses	DOI: 10.1038/s41598-020-67211-2	Buonanno
[04]	Ultraviolet-C light with wavelength of 222 nm inactivates a wide spectrum ofmicrobial pathogens	DOI: 10.1016/j.jhin.2020.03.030	Narita
[05]	Far-UVC light: A new tool to control the spread of airborne-mediated microbial diseases	DOI: 10.1038/s41598-018-21058-w	Welch
[06]	Aerosol Susceptibility of Influenza Virus to UV-C Light	DOI:10.1128/AEM.06960-11	McDevitt
[07]	Inactivation of murine norovirus, feline calicivirus and echovirus 12 as surrogates for human norovirus (NoV) and coliphage (F+) MS2 by ultraviolet light (254 nm) and the effect of cell association on UV inactivation	DOI: 10.1111/j.1472-765x.2010.02982.x	Park
[08]	Synergy of MS2 disinfection by sequential exposure to tailored UV wavelengths	DOI: 10.1016/j.watres.2018.06.017	Hull
[09]	Comparison of ultraviolet light-emitting diodes and low-pressure mercury-arc lamps for disinfection of water	DOI: 10.1080/09593330.2016.1144798	Sholtes
[10]	Higher effectiveness of photoinactivation of bacterial spores, UV resistant vegetative bacteria and mold spores with 222 nm compared to 254 nm wavelength	DOI: 10.1002/aheh.200600650	Clauß

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Reference#	Publication Title	Link to Publication	Primary Author
[11]	Evaluation of a hand-held far-ultraviolet radiation device for decontamination of Clostridium difficile and other healthcare-associated pathogens	DOI: 10.1186/1471-2334-12-120	Nerandzic
[12]	Ultraviolet Disinfection of Antibiotic Resistant Bacteria and Their Antibiotic Resistance Genes in Water and Wastewater	DOI: 10.1021/es303652q	McKinney
[13]	Comparison of UV-C and Pulsed UV Light Treatments for Reduction of Salmonella, Listeria monocytogenes, and Enterohemorrhagic Escherichia coli on Eggs	DOI: 10.4315/0362-028X.JFP-17-128	Holck
[14]	Increased Resistance of Salmonella enterica Serovar Typhimurium and Escherichia coli O157:H7 to 222-Nanometer Krypton-Chlorine Excilamp Treatment by Acid Adaptation	DOI: 10.1128/AEM.02221-18	Kang
[15]	Ultraviolet light inactivation and photoreactivation in the mycobacteria	DOI: 10.1128/IAI.4.3.318-319.1971	David
[16]	Ultraviolet susceptibility of BCG and virulent tubercle bacilli	https://pubmed.ncbi.nlm.nih.gov/817628/	Riley
[17]	Relative susceptibility of acid-fast and non-acid-fast bacteria to ultraviolet light	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC377194/	Collins
[18]	Inactivation kinetics and efficiencies of UV-LEDs against Pseudomonas aeruginosa, Legionella pneumophila, and surrogate microorganisms	DOI: 10.1016/j.watres.2017.11.047	Rattanakul
[19]	Susceptibility of Campylobacter jejuni and Yersinia enterocolitica to UV radiation	DOI: 10.1128/AEM.53.2.375-378.198	Butler
[20]	Inactivation of chlorine-resistant bacterial spores in drinking water using UV irradiation, UV/Hydrogen peroxide and UV/Peroxymonosulfate: Efficiency and mechanism	DOI: 10.1016/j.jclepro.2019.118666	Zeng

Reference#	Publication Title	Link to Publication	Primary Author
[21]	Comparison of the Disinfection Effects of Vacuum UV (VUV) and UV Light on Bacillus subtilis Spores in Aqueous Suspensions at 172, 222 and 254nm	DOI: 10.1111/j.1751-1097.2009.00640.x	Wang
[22]	Simultaneous atrazine degradation and E. coli inactivation by UV/S2O82-/Fe2+ process under KrCl excilamp (222 nm) irradiation	DOI: 10.1016/j.ecoenv.2018.11.014	Popova
[23]	Ultraviolet-C Light for Treatment of Candida albicans Burn Infection in Mice	DOI: 10.1111/j.1751-1097.2011.00886.x	Dai
[24]	Inactivation of food spoilage fungi by ultra violet (UVC) irradiation	DOI: 10.1016/j.ijfoodmicro.2008.11.020	Begum
[25]	Pulsed broad-spectrum UV light effectively inactivates SARS-CoV-2 on multiple surfaces	DOI: 10.1101/2021.02.12.431032	Jureka
[26]	NG15861 August 2020, “Virucidal Efficacy of a Test Device For Use on Inanimate, Nonporous Surfaces”	Contact PURO Lighting	Independent accredited third-party testing lab: Microchem Laboratory, Round Rock, TX
[27]	NG9047-A3 July 2017, "Determination of the Antiviral Effectiveness of Test Device Against Feline Calicivirus"	Contact PURO Lighting	Independent accredited third-party testing lab: Microchem Laboratory, Round Rock, TX
[28]	NG9046 July 2017, "Determination of the Antiviral Effectiveness of Test Device Against Feline Calicivirus"	Contact PURO Lighting	Independent accredited third-party testing lab: Microchem Laboratory, Round Rock, TX

Reference#	Publication Title	Link to Publication	Primary Author
[29]	NG9204-A1 August 2017, "Antibacterial Activity and Sanitizing Efficacy using Violet Defense® technology"	Contact PURO Lighting	Independent accredited third-party testing lab: Microchem Laboratory, Round Rock, TX
[30]	NG15214 Tested May 2020, "Antibacterial Activity and Sanitizing Efficacy using Violet Defense® technology"	Contact PURO Lighting	Independent accredited third-party testing lab: Microchem Laboratory, Round Rock, TX
[31]	NG15862 Tested August 2020, "Virucidal Efficacy of a Test Device For Use on Inanimate, Nonporous Surfaces"	Contact PURO Lighting	Independent accredited third-party testing lab: Microchem Laboratory, Round Rock, TX
[32]	NG13050 June 2019, "Antibacterial Activity and Sanitizing Efficacy of Violet Defense's Device"	Contact PURO Lighting	Independent accredited third-party testing lab: Microchem Laboratory, Round Rock, TX
[33]	Inactivation dynamics of 222 nm krypton-chlorine excilamp irradiation on Gram-positive and Gram-negative foodborne pathogenic bacteria	DOI: 10.1016/j.foodres.2018.04.018	Kang
[34]	Confidential Test Report No. AC-12b, 16 July 2021, Methicillin-Resistant Staphylococcus aureus – MRSA (ATCC 33591)	Contact PURO Lighting	Independent accredited third-party testing lab: Resinnova Laboratories, Silver Spring, MD
[35]	Confidential Test Report No. AC-13b, 26 July 2021, Salmonella enterica (formerly typhimurium) (ATCC 14028) (Typhi Salmonella)	Contact PURO Lighting	Independent accredited third-party testing lab: Resinnova Laboratories, Silver Spring, MD

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Reference#	Publication Title	Link to Publication	Primary Author
[36]	Confidential Test Report No. AC-14b, 09 August 2021, Salmonella enterica (formerly choleraesuis) (ATCC 10708) (Non-Typhi Salmonella)	Contact PURO Lighting	Independent accredited third-party testing lab: Resinnova Laboratories, Silver Spring, MD
[37]	Confidential Test Report No. AC-15b, 10 August 2021, Escherichia coli (ATCC 8739)	Contact PURO Lighting	Independent accredited third-party testing lab: Resinnova Laboratories, Silver Spring, MD
[38]	Confidential Test Report No. AC-16a, 17 August 2021, Feline Calicivirus (ATCC VR-782)	Contact PURO Lighting	Independent accredited third-party testing lab: Resinnova Laboratories, Silver Spring, MD

NOTES:

1: The data presented in this reference list are obtained from peer-reviewed research publications or independent laboratory testing reports. Refer to identified reference for experimental setup and design. Experimental setups and design that differ from those used in the referenced research or laboratory testing may produce different dose values than listed here to inactivate 99.9% of any given pathogen.

2: The dose required to achieve a 99.9% inactivation (also known as a 3-Log10 reduction) of pathogens can be referred to as a D99.9 value. D99.9 values reported in this reference list are as tested under laboratory conditions and are either obtained directly from the reference or interpolated or extrapolated using data from the reference. Note that the D99.9 values in actual application may differ from the reported values as a result of differences between the application and the experimental setup or other environmental conditions. The D99.9 values reported in this reference list are provided for informational purposes only.

3: D99.9 values (the dose required to achieve a 99.9% inactivation) can be used to determine a k-factor, also known as the UV rate constant. The k-factor/UV rate constant serves to scale the natural logarithmic function that depicts pathogen survival as a function of dose, enabling modeling of predicted levels of inactivation of a particular pathogen. Note that both k and D99.9 are specific to a given pathogen, UV spectrum, and environmental condition (water, surface, air) as represented by the medium used for testing. Kowalski, W. (2009), Ultraviolet Germicidal Radiation Handbook, Chapter 3, Springer-Verlag.

4: For applications where inactivation of pathogens in the air is desired, airborne UV rate constants should be used to model predicted pathogen inactivation, if they exist. Use of airborne UV rate constants will result in the most accurate modeling. Where no airborne UV rate constants are available, however, either water or surface UV rate constants may be utilized as a conservative substitute. The susceptibility of microbes is greater in air than when suspended in liquid, films or on the surface of agar plates. While exact ratios can vary considerably, bacteria are roughly five times more susceptible to germicidal irradiation in air than on surfaces, whereas viruses tend to be closer to three times more susceptible. In virtually all cases, however, with only one or two anomalous exceptions, UV rate constants for water and surface are lower than those for air, even at 100% relative humidity. Consequently, modeling that uses water or surface UV rate constants as substitutes for airborne UV rate constants is appropriate because it can be expected to underestimate the predicted level of pathogen inactivation. Furthermore, UV susceptibility of microbes on surfaces may be higher or lower than it is in water, for any given species. However, these differences are small enough to validate the use of water UV rate constants to predict surface disinfection rates. That is, water UV rate constants are a reasonable substitute for surface UV rate constants when surface UV rate constants are not available. Kowalski, W. (2009), Ultraviolet Germicidal Handbook, Chapter 4. Springer-Verlag.

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