

Ultraviolet Light Exposure Dosage

(紫外線暴露劑量參考經驗值)

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: $DOSE = I \times T$ 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 (mJ/cm^2) Needed For a Given Log Reduction							
Log Reduction(指數減少率)	1	2	3	4	5	6	Reference
Spore							
Bacillus anthracis spores - Anthrax spores	24.32	46.2					Light Sources Inc. 2014
Bacillus magaterium sp. (spores)	2.73	5.2					Light Sources Inc. 2014
Bacillus subtilis ATCC6633	24	35	47	79			Mamane-Gravetz and Linden 2004
Bacillus subtilis WN626	0.4	0.9	1.3	2			Marshall et al., 2003
Bacillus subtilis spores	11.6	22					Light Sources Inc. 2014
Bacterium							
Aeromonas salmonicida	1.5	2.7	3.1	5.9			Liltved and Landfald 1996
Aeromonas hydrophila ATCC7966	1.1	2.6	3.9	5	6.7	8.6	Wilson et al. 1992
Bacillus anthracis - Anthrax	4.52	8.7					Light Sources Inc. 2014
Bacillus magaterium sp. (veg.)	1.3	2.5					Light Sources Inc. 2014
Bacillus paratyphus	3.2	6.1					Light Sources Inc. 2014
Bacillus subtilis	5.8	11					Light Sources Inc. 2014
Campylobacter jejuni ATCC 43429	1.6	3.4	4	4.6	5.9		Wilson et al. 1992
Citrobacter diversus	5	7	9	11.5	13		Giese and Darby 2000
Citrobacter freundii	5	9	13				Giese and Darby 2000
Clostridium tetani	13	22					Light Sources Inc. 2014

Log Reduction	1	2	3	4	5	6	Reference
<i>Corynebacterium diphtheriae</i>	3.37	6.51					Light Sources Inc. 2014
<i>Ebertelia typhosa</i>	2.14	4.1					Light Sources Inc. 2014V
<i>Escherichia coli</i> O157:H7 CCUG 29193	3.5	4.7	5.5	7			Sommer et al. 2000
<i>Escherichia coli</i> O157:H7 CCUG 29197	2.5	3	4.6	5	5.5		Sommer et al. 2000
<i>Escherichia coli</i> O157:H7 CCUG 29199	0.4	0.7	1	1.1	1.3	1.4	Sommer et al. 2000
<i>Escherichia coli</i> O157:H7 ATCC 43894	1.5	2.8	4.1	5.6	6.8		Wilson et al. 1992
<i>Escherichia coli</i>	3	6.6					Light Sources Inc. 2014
<i>Escherichia coli</i> ATCC 11229	7	8	9	11	12		Hoyer 1998
<i>Escherichia coli</i> ATCC 11303	4	6	9	10	13	15	Wu et al. 2005
<i>Escherichia coli</i> ATCC 25922	6	6.5	7	8	9	10	Sommer et al. 1998
<i>Escherichia coli</i> K-12 IFO3301	2.2	4.4	6.7	8.9	11		Oguma et al. 2004
<i>Escherichia coli</i> O157:H7	<2	<2	2.5	4	8	17	Yaun et al. 2003
<i>Halobacterium elongate</i> ATCC33173	0.4	0.7	1				Martin et al. 2000
<i>Halobacterium salinarum</i> ATCC43214	12	15	17.5	20			Martin et al. 2000
<i>Klebsiella pneumoniae</i>	12	15	17.5	20			Giese and Darby 2000
<i>Klebsiella terrigena</i> ATCC33257	4.6	6.7	8.9	11			Wilson et al. 1992
<i>Legionella pneumophila</i> ATCC33152	1.9	3.8	5.8	7.7	9.6		Oguma et al. 2004
<i>Legionella pneumophila</i> ATCC 43660	3.1	5	6.9	9.4			Wilson et al. 1992
<i>Legionella pneumophila</i> ATCC33152	1.6	3.2	4.8	6.4	8		Oguma et al. 2004
<i>Leptospira canicola</i> - Infectious Jaundice	3.15	6					Light Sources Inc. 2014
<i>Micrococcus candidus</i>	6.05	12.3					Light Sources Inc. 2014
<i>Micrococcus sphaeroides</i>	1	15.4					Light Sources Inc. 2014
<i>Mycobacterium tuberculosis</i>	6.2	10					Light Sources Inc. 2014
<i>Neisseria catarrhalis</i>	4.4	8.5					Light Sources Inc. 2014
<i>Phytomonas tumefaciens</i>	4.4	8					Light Sources Inc. 2014
<i>Proteus vulgaris</i>	3	6.6					Light Sources Inc. 2014
<i>Pseudomonas stutzeri</i>	100	150	195	230			Joux et al. 1999

Log Reduction	1	2	3	4	5	6	Reference
<i>Pseudomonas aeruginosa</i>	5.5	10.5					Light Sources Inc. 2014
<i>Pseudomonas fluorescens</i>	3.5	6.6					Light Sources Inc. 2014
<i>Salmonella paratyphi</i> - Enteric fever	3.2	6.1					Light Sources Inc. 2014
<i>Salmonella anatum</i> (from human feces)	7.5	12	15				Tosa and Hirata 1998
<i>Salmonella derby</i> (from human feces)	3.5	7.5					Tosa and Hirata 1998
<i>Salmonella enteritidis</i> (from human feces)	5	7	9	10			Tosa and Hirata 1998
<i>Salmonella infantis</i> (from human feces)	2	4	6				Tosa and Hirata 1998
<i>Salmonella</i> spp.	<2	2	3.5	7	14	29	Yaun et al. 2003
<i>Salmonella typhi</i> ATCC 19430	1.8	4.8	6.4	8.2			Wilson et al. 1992
<i>Salmonella typhi</i> ATCC 6539	2.7	4.1	5.5	7.1	8.5		Chang et al. 1985
<i>Salmonella typhimurium</i> (from human feces)	2	3.5	5	9			Tosa and Hirata 1998
<i>Salmonella typhimurium</i>	50	100	175	210	250		Joux et al. 1999
<i>Salmonella enteritidis</i>	4	7.6					Light Sources Inc. 2014
<i>Salmonella typhimurium</i>	8	15.2					Light Sources Inc. 2014
<i>Salmonella typhosa</i> - Typhoid fever	2.15	4.1					Light Sources Inc. 2014
<i>Sarcina lutea</i>	19.7	26.4					Light Sources Inc. 2014
<i>Serratia marcescens</i>	2.42	6.16					Light Sources Inc. 2014
<i>Shigella dysenteriae</i> ATCC29027	0.5	1.2	2	3	4	5.1	Wilson et al. 1992
<i>Shigella dysenteriae</i> - Dysentery	2.2	4.2					Light Sources Inc. 2014
<i>Shigella flexneri</i> - Dysentery	1.7	3.4					Light Sources Inc. 2014
<i>Shigella paradysenteriae</i>	1.68	3.4					Light Sources Inc. 2014
<i>Shigella sonnei</i> ATCC9290	3.2	4.9	6.5	8.2			Chang et al. 1985
<i>Spirillum rubrum</i>	4.4	6.16					Light Sources Inc. 2014
<i>Staphylococcus aureus</i> ATCC25923	3.9	5.4	6.5	10.4			Chang et al. 1985
<i>Staphylococcus albus</i>	1.84	5.72					Light Sources Inc. 2014
<i>Staphylococcus aureus</i>	2.6	6.6					Light Sources Inc. 2014
<i>Staphylococcus hemolyticus</i>	2.16	5.5					Light Sources Inc. 2014
<i>Staphylococcus lactis</i>	6.15	8.8					Light Sources Inc. 2014

Log Reduction(指數減少率)	1	2	3	4	5	6	Reference
<i>Streptococcus faecalis</i> (secondary effluent)	5.5	6.5	8	9	12		Harris et al. 1987
<i>Streptococcus faecalis</i> ATCC29212	6.6	8.8	9.9	11.2			Chang et al. 1985
<i>Streptococcus viridans</i>	2	3.8					Light Sources Inc. 2014
<i>Vibrio anguillarum</i>	0.5	1.2	1.5	2			Liltved and Landfald 1996
<i>Vibrio cholerae</i> ATCC25872	0.8	1.4	2.2	2.9	3.6	4.3	Wilson et al. 1992
<i>Vibrio comma</i> - Cholera	3.375	6.5					Light Sources Inc. 2014
<i>Vibrio natriegens</i>	37.5	75	100	130	150		Joux et al. 1999
<i>Yersinia enterocolitica</i> ATCC27729	1.7	2.8	3.7	4.6			Wilson et al. 1992
<i>Yersinia ruckeri</i>	1	2	3	5			Liltved and Landfald 1996
Yeasts							
Brewers yeast	3.3	6.6					Light Sources Inc. 2014
Common yeast cake	6	13.2					Light Sources Inc. 2014
<i>Saccharomyces cerevisiae</i>	6	13.2					Light Sources Inc. 2014
<i>Saccharomyces ellipsoideus</i>	6	13.2					Light Sources Inc. 2014
<i>Saccharomyces</i> spores	8	17.6					Light Sources Inc. 2014
Molds							
<i>Aspergillus flavus</i>	60	99					Light Sources Inc. 2014
<i>Aspergillus glaucus</i>	44	88					Light Sources Inc. 2014
<i>Aspergillus niger</i>	132	330					Light Sources Inc. 2014
<i>Mucor racemosus</i> A	17	35.2					Light Sources Inc. 2014
<i>Mucor racemosus</i> B	17	35.2					Light Sources Inc. 2014
<i>Oospora lactis</i>	5	11					Light Sources Inc. 2014
<i>Penicillium digitatum</i>	44	88					Light Sources Inc. 2014
<i>Penicillium expansum</i>	13	22					Light Sources Inc. 2014
<i>Penicillium roqueforti</i>	13	26.4					Light Sources Inc. 2014
<i>Rhizopus nigricans</i>	111	220					Light Sources Inc. 2014
Protozoan							
<i>Chlorella Vulgaris</i>	13	22					Light Sources Inc. 2014
<i>Cryptosporidium hominis</i>	3	5.8					Johnson et al. 2005
<i>Cryptosporidium parvum</i>	2.4	<5	5.2	9.5			Craik et al. 2001

Log Reduction(指數減少率)	1	2	3	4	5	6	Reference
Cryptosporidium parvum, oocysts, tissue culture assay	1.3	2.3	3.2				Shin et al. 2000
Encephalitozoon cuniculi, microsporidia	4	9	13				Marshall et al. 2003
Encephalitozoon hellem, microsporidia	8	12	18				Marshall et al. 2003
Encephalitozoon intestinalis, microsporidia	3	5	6				Marshall et al. 2003
G. muris, cysts	<5	<5	5				Amoah et al. 2005
G. muris, cysts, mouse infectivity assay	<2	<6	10 + tailing				Craik et al. 2000
Giardia lamblia	<10	~10	<20				Campbell et al. 2002
Giardia muris	<1.9	<1.9	~2	~2.3			Hayes et al. 2003
Nematode Eggs	45	92					Light Sources Inc. 2014
Paramecium	11	20					Light Sources Inc. 2014

UV Dose (mJ/cm²) Needed For a Given Log Reduction

<i>Virus</i>	<i>Host</i>	Log Reduction						Reference
		1	2	3	4	5	6	
Adenovirus type 15	A549 cell line (ATCC CCL-185)	40	80	122	165	210		Thompson et al. 2003
Adenovirus type 2	A549 cell line	20	45	80	110			Shin et al. 2005
Adenovirus type 2	Human lung cell line	35	55	75	100			Ballester and Malley 2004
Adenovirus type 2	PLC / PRF / 5 cell line	40	78	119	160	195	235	Gerba et al. 2002
Adenovirus type 40	PLC / PRF / 5 cell line	55	105	155				ston-Enriquez et al. 2003
Adenovirus type 41	PLC / PRF / 5 cell line	23.6	ND	ND	112			Meng and Gerba 1996

<i>Virus</i>	<i>Host</i>	1	2	3	4	5	6	Reference
<i>B40-8 (Phage)</i>	B. Fragilis	11	17	23	29	35	41	Sommer et al. 2001
Bacteriophage - E. Coli	N/A	2.6	6.6					Light Sources Inc. 2014
Calicivirus canine	MDCK cell line	7	15	22	30	36		Husman et al. 2004
Calicivirus feline	CRFK cell line	5	15	23	30	39		ston-Enriquez et al. 2003
Coxsackievirus B3	BGM cell line	8	16	24.5	32.5			Gerba et al. 2002
Coxsackievirus B5	Buffalo Green Monkey cell line	6.9	13.7	20.6				Battigelli et al. 1993
Coxsackievirus B5	BGM cell line	9.5	18	27	36			Gerba et al. 2002
Echovirus I	BGM cell line	8	16.5	25	33			Gerba et al. 2002
Echovirus II	BGM cell line	7	14	20.5	28			Gerba et al. 2002
Hepatitis A	HAV/HFS/GBM	5.5	9.8	15	21			Wiedenmann et al.
Hepatitis A HM175	FRhK-4 cell	5.1	13.7	22	29.6			1993 n et al. 1992
								Wilso
Hepatitis A HM175	FRhK-4 cell	4.1	8.2	12.3	16.4			Battigelli et al. 1993
Infectious Hepatitis	N/A	5.8	8					Light Sources Inc. 2014
Influenza	N/A	3.4	6.6					Light Sources Inc. 2014
<i>MS2 (Phage)</i>	Salmonella typhimurium WG49	16.3	35	57	83	114	152	Nieuwstad and Havelaar
MS2 (Phage)	<i>E. coli</i> ATCC 15597	20	42	70	98	133		Lazarova and Savoye 2004
MS2 (Phage)	<i>E. coli</i> HS(pFamp)R		45	75	100	125	155	Thompson et al. 2003
MS2 ATCC	<i>E. coli</i> ATCC 15977 – B1	15.9	34	52	71	90	109	Wilson et al. 1992
15977-B1 (Phage)								

<i>Virus</i>	<i>Host</i>	1	2	3	4	5	6	Reference
MS2 DSM 5694 (Phage)	<i>E. coli</i> NCIB 9481	4	16	38	68	110		Wiedenmann et al. 1993
MS2 NCIMB 10108 (Phage)	<i>Salmonella</i> <i>typhimurium</i> WG49	12.1	30.1					Tree et al. 1997
PHI X 174 (Phage)	<i>E. coli</i> C3000	2.1	4.2	6.4	8.5	10.6	12.7	Battigelli et al. 1993
PHI X 174 (Phage)	<i>E. coli</i> WG 5	3	5	7.5	10	12.5	15	Sommer et al. 2001
Poliovirus - Poliomyelitis	N/A	3.15	6.6					Light Sources Inc. 2014
Poliovirus 1	BGM cell line	5	11	18	27			Tree et al. 2005
Poliovirus 1	CaCo2 cell-line (ATCC HTB37)	7	17	28	37			Thompson et al. 2003
Poliovirus Type Mahoney	Monkey kidney cell line Vero	3	7	14	40			Sommer et al. 1989
Poliovirus Type 1 LSc2ab ()	MA104 cell	5.6	11	16.5	21.5			Chang et al. 1985
Poliovirus Type 1 LSc2ab	BGM cell	5.7	11	17.6	23.3	32	41	Wilson et al. 1992
<i>PRD-1 (Phage)</i>	<i>S. typhimurium</i> Lt2	9.9	17.2	23.5	30.1			Meng and Gerba 1996
Reovirus Type 1 Lang strain	N/A	16	36					Harris et al. 1987
Reovirus-3	Mouse L-60	11.2	22.4					Rauth 1965
Rotavirus	MA104 cells	20	80	140	200			Caballero et al. 2004
Rotavirus SA-11	MA-104 cell line	9.1	19	26	36	48		Wilson et al. 1992

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