RPAMS CCV (Ultraviolet-C) UVC Light Systems

A force multiplier in the fight to protect against COVID

EPA EST. NO. 97050-OR-1. RESTRICTED USE PESTICIDE/GERMICIDAL UVC

RP CCV UVC LIGHT DOSAGE

When deploying the RPAMS CCV UVC supplemental disinfection systems, a critical requirement is selecting the targeted reduction level of a specific microbe or, more specifically, reduction of colony forming units (CFU) of the targeted microbe(s).

From a sanitation/disinfection perspective, the complexities of using a microscope to count every individual cell of a target microbe would be impractical. Instead, existing data derived by diluting a sample and spreading it across a petri plate, microbiologists have already counted groups of microbes, called colonies, and each colony is assumed to have grown from a single Colony Forming Unit (CFU).

Similarly, when calculating the changes in CFUs after disinfection, microbiologists express the performance as a percentage reduction in terms of a reduction factor and typically in factors of 10 using a logarithmic (log) reduction scale – a log reduction factor (LRV).

Log reduction is a mathematical term that is used to express the relative number of living microbes that are eliminated by disinfection.

Log reduction = log10 (N0 /N)
Where:
N0 = Colony forming units of the microorganisms before exposure to UV light
N = Colony forming units of the microorganisms after exposure to UV light

For example, a 1 log reduction corresponds to inactivating 90 percent of a target microbe with the microbe count being reduced by a factor of 10. Thus, a 2 log reduction will see a 99 percent reduction, or microbe reduction by a factor of 100, and so on. Table 1 (below) shows the chart of log reduction:

LOG REDUCTION	REDUCTION FACTOR	PERCENT REDUCED
1	10	90%
2	100	99%
3	1,000	99.9%
4	10,000	99.99%
5	100,000	99.999%
6	1,000,000	99.9999%

The RPAMS CCV UVC germicidal systems achieve the desired log reduction factor by ensuring that the process delivers a microbe-specific UVC dose based on peer reviewed efficacy studies.

Every pathogen has a unique spectral sensitivity "fingerprint." By using 254nm UVC wavelengths and selected doses of energy, the amount of supplemental disinfection (i.e. LRV of the pathogen) can be established. Dosage is determined based on the intensity of the UVC energy and the exposure time at a specific wavelength.

BW CCV-002 UV DOSAGE CHART

Germicidal lamps provide effective augmented disinfection against various microorganisms. A small cross-section is shown below.

ORGANISM	ALTERNATE NAME	TYPE	DISEASE	DOSE*	µWSec/cm² Distance		
					4-5 inches	6-8 inches	12 inches
Corynebacterium diptheriae	C. diphtheriae	Bacteria	Diptheria	6,500	2 sec	3 sec	6 sec
Legionella pneumophila	L. pneumophila	Bacteria	Legionnaire's Disease	12,300	4 sec	6 sec	12 sec
Mycobacterium tuberculosis	M. tuberculosis	Bacteria	Tuberculosis (TB)	10,000	3 sec	5 sec	10 sec
Pseudomonas aeruginosa	P. aeruginosa	Bacteria		3,900	2 sec	2 sec	5 sec
Serratia Marcescens	S. marcescens	Bacteria		6,160	2 sec	3 sec	6 sec
Staphylococcus aureus	S. aureus	Bacteria		6,600	2 sec	3 sec	6 sec
Staphylococcus epidermidis	S. epidermidis	Bacteria		5,800	2 sec	3 sec	5 sec
Adeno Virus Type III		Virus		4,500	2 sec	2 sec	5 sec
Coxsackie A2		Virus		6,300	2 sec	3 sec	6 sec
Influenza		Virus	Flu	6,300	2 sec	3 sec	6 sec

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REV-01072021

UV Dose Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa and Viruses[1]

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BRIEF DESCRIPTION AND SELECTION CRITERIA FOR CONTENT OF THE TABLES

Tables 1-4 present a summary of published data on the Ultraviolet (UV) dose-response of various organisms that are pathogens, indicators, or organisms encountered in the application, testing of performance, and validation of UV disinfection technologies. The tables reflect the state of knowledge, but include the variation in technique and biological response that currently exists in the absence of standardized protocols. Users of the data for their own purposes are advised to exercise critical judgment in how they use the data.

In most cases, the data are generated from low pressure (LP) monochromatic mercury arc lamp sources for which the lamp fluence rate (intensity) can be measured empirically and multiplied by exposure time to obtain a dose. Earlier data do not always contain the correction factors that are now considered standard practice (Bolton and Linden 2003). Some data are from polychromatic medium pressure (MP) mercury arc lamps, and in some cases both lamp types are used. In a few cases, filtered polychromatic UV light is used to achieve a narrow band of irradiation around 254 nm. These studies are also designated as LP.

None of the data incorporate any impact of photorepair processes. Only the response to the inactivating UV dose is documented. The references from which the data are abstracted must be carefully read to understand how the reported doses are calculated and what the assumptions and procedures are in the calculation.

At the time this table was being prepared, a parallel initiative (Hijnen et al. 2006) was ongoing and is recommended to the reader.

It is the intention of Trojan Technologies, Ecole Polytechnique de Montreal and INRS- Institut Armand-Frappier to keep this table dynamic, with periodic updates. Recommendations for inclusion in the tables, along with the reference source, can be sent to:

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The selection criteria for inclusion are recommended as follows:

1. *Data must be already published in a peer-reviewed journal or other peer-reviewed publication media;*
2. *The dose-response should be empirically determined in the laboratory with the assistance of a collimated beam apparatus;*
3. *Ideally, the fluence rate (intensity) should be measured with a recently calibrated radiometer and when this has not been done, a we/I-characterized organism should be run as a reference to provide a comparison with the literature values to substantiate that the radiometer is within calibration.*
4. *The publication from which the data is abstracted should describe the experimental procedures including collimated beam procedures, dose calculation procedures along with any assumptions made, organism culturing procedures, enumeration and preparation for experiments.*
5. *Responses should be determined over a range of doses; that is, a complete dose-response cuNe is preferred to a single dose-response measurement.*

Table 1. *UV Doses for Multiple Log Reductions for Various Spores*

Spore	Lamp Type	UV Dose (Fluence) (mJ/cm²) for a given Log Reduction without photo-reactivation							Reference
		1	2	3	4	5	6	7	
Bacillus subtilis ATCC6633	*NIA*	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

Table 2. *UV Doses for Multiple Log Reductions for Various Bacteria*

Bacterium	Lamp Type	UV Dose (Fluence) (mJ/cm²) for a given Log Reduction without photo-reactivation							Reference
		1	2	3	4	5	6	7	
Aeromonas hydrophila ATCC7966	LP	1.1	2.6	3.9	5	6.7	8.6		Wilson et al. 1992
Aeromonas salmonicida	LP	1.5	2.7	3.1	5.9				Liltved and Landfald 1996
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
Escherichia coli ATCC 11229	*NIA*	2.5	3	3.5	5	10	15		Harris et al. 1987
Escherichia coli ATCC 11229	*NIA*	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
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	6	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 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 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 O25:K98:NM	LP	5	7.5	9	10	11.5			Sommer et al. 2000
Escherichia coli 026	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:Hl 1	LP	4	5	5.5	6	7			Sommer et al. 2000
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 Wild type	LP	4.4	6.2	7.3	8.1	9.2			Sommer et al. 1998

Table 2. *(continued)*

Bacterium	Lamp Type	UV Dose (Fluence) (mJ/cm²) for a given Log Reduction without photo-reactivation							Reference
		1	2	3	4	S	6	7	
Halobacterium elongata 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 ATCC 43 60	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
Legionella pneumophila ATCC331 2	MP	1.9	3.8	5.8	7.7	9.6			Oguma et al. 2004
Pseudomonas stutzeri	UVB	100	150	195	230				Joux et al. 1999
RB2256	UVB	175	>300						Joux et al. 1999
Salmonella spp.	LP	<2	2	3.5	7	14	29		Yaun et al. 2003
Salmonella anatum (from human feces)	NIA	7.5	12	15					Tosa and Hirata 1998
Salmonella derby (from human feces)	NIA	3.5	7.5						Tosa and Hirata 1998
Salmonella enteritidis (from human feces)	NIA	5	7	9	10				Tosa and Hirata 1998
Salmonella infantis (from human feces)	NIA	2	4	6					Tosa and Hirata 1998
Salmonella typhi ATCC 19430	LP	1.8	4.8	6.4	8.2				Wilson et al. 1992
Salmonella typhi ATCC 6539	NIA	2.7	4.1	5.5	7.1	8.5			Chang et al. 1985
Salmonella typhimurium (from human feces)	NIA	2	3.5	5	9				Tosa and Hirata 1998
Salmonella typhimurium (from human feces)	NIA	2	3.5	5	9				Tosa and Hirata 1998
Salmonella typhimurium (in act. sludge)	LP	3	11.5	22	SO				Maya et al. 2003
Salmonella typhimurium	UVB	SO	100	175	210	250			Joux et al. 1999
Shigella dysenteriae ATCC29027	LP	0.5	1.2	2	3	4	5.1		Wilson et al. 1992
Shigella sonnei ATCC9290	NIA	3.2	4.9	6.5	8.2				Chang et al. 1985
Staphylococcus aureus ATCC25923	NIA	3.9	5.4	6.5	10.4				Chang et al. 1985
Streptococcus faecalis ATCC29212	NIA	6.6	8.8	9.9	11.2				Chang et al. 1985
Streptococcus faecalis (secondary effluent)	NIA	5.5	6.5	8	9	12			Harris et al. 1987
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 natriegens	UVB	37.5	75	100	130	150			Joux et al. 1999
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

Table 3. *UV Doses for Multiple Log Reductions for Various Protozoa*

Protozoan	Lamp Type	UV Dose (Fluence) (mJ/cm²) for a given Log Reduction without photo-reactivation							Reference
		1	2	3	4	5	6	7	
Cryptosporidium hominis	LP&MP	3	5.8						Johnson et al. 2005
Cryptosporidium parvum, oocysts, tissue culture assay	*NIA*	1.3	2.3	3.2					Shin et al. 2000
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
Cryptosporidium parvum	MP	<1	<1	<1					Zimmer et al. 2003
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
Giardia lamblia, gerbil infectivity assay	LP	<0.5	<0.5	<0.5	<1				Linden et al. 2002b
Giardia lamblia	LP	<10	-10	<20					Campbell et al. 2002
Giardia lamblia	LP	<2	<2	<4					Mofidi et al. 2002
Giardia lamblia,excystation assay	*NIA*	> 63							Rice and Hoff 1981
Giardia lamblia, excystation assay	*NIA*	40	180						Karanis et al. 1992
Giardia muris, excystation assay	*NIA*	77	110						Carlson et al. 1985
G. *muris*, cysts, mouse infectivity assay	*NIA*	<2	<6	10 + tailing					Craik et al. 2000
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
G. *muris*, cysts	MP	<5	<5	5					Amoah et al. 2005

Table 4. *UV Doses for Multiple Log Reductions for Various Viruses*

Virus	Host	Lamp Type	UV Dose (Fluence) (mJ/cm²) per Log Reduction						Reference
			1	2	3	4	5	6	
PRD-1 (Phage)	*S. typhimurium* Lt2	*NIA*	9.9	17.2	23.5	30.1			Meng and Gerba 1996
B40-8 (Phage)	*B. Fragilis*	LP	11	17	23	29	35	41	Sommer et al. 2001
B40-8 (Phage)	*B. fragilis* HSP-40	LP	12	18	23	28			Sommer et al 1998
MS2 (Phage)	*Salmonella typhimurium* WG49	*NIA*	16.3	35	57	83	114	152	Nieuwstad and Havelaar 1994

Table 4. *(continued)*

Virus	Host	Lamp Type	UV Dose (Fluence) (mJ/cm²) per Log Reduction						Reference
			1	2	3	4	5	6	
MS2 DSM 5694 (Phage)	*E. coli* NCIB 9481	NIA	4	16	38	68	110		Wiedenmann et al. 1993
MS2ATCC 15977-Bl (Phage)	*E.coli* ATCC 15977-Bl	LP	15.9	34	52	71	90	109	Wilson et al. 1992
MS2 NCIMB 10108 (Phage)	*Salmonella typhimurium* WG49	NIA	12.1	30.1					Tree et al. 1997
MS2 (Phage)	*E. coli* K-12 Hfr	LP	21	36					Sommer et al. 1998
MS2 (Phage)	*E.coli* CR63	NIA	16.9	33.8					Rauth 1965
MS2 (Phage)	*E. coli* 15977	NIA	13.4	28.6	44.8	61.9	80.1		Meng and Gerba 1996
MS2 (Phage)	*E. coli* C3000	NIA	35						Battigelli et al. 1993
MS2 (Phage)	*E. coli* ATCC 15597	NIA	19	40	61				Oppenheimer et al. 1993
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 Savoye 2004
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. 2003
MS2 (Phage)	*E. coli* C3000	LP	20	42	68	90			Linden et al. 2002a
MS2 (Phage)	*E.coli* K-12	LP	18.5	36	55				Sommer et al. 2001
MS2 (Phage)	*E.coli* NCIMB 9481	NIA	14						Tree et al. 2005
PHI X 174 (Phage)	*E.coli* WG5	LP	2.2	5.3	7.3	10.5			Sommer et al. 1998
PHI X 174 (Phage)	*E. coli* C3000	NIA	2.1	4.2	6.4	8.5	10.6	12.7	Battigelli et al. 1993
PHI X 174 (Phage)	*E. coli* ATCC15597	NIA	4	8	12				Oppenheimer et al. 1993
PHI X 174 (Phage)	*E.coli* WG 5	LP	3	5	7.5	10	12.5	15	Sommer et al. 2001
PHI X 174 (Phage)	*E.coli* ATCC 13706	LP	2	3.5	5	7			Giese and Darby 2000
Staphylococcus aureus phage A 994 (Phage)	*Staphylococcus aureus* 994	LP	8	17	25	36	47		Sommer et al. 1989
Calicivirus canine	MOCK cell line	LP	7	15	22	30	36		Husman et al. 2004
Calicivirus feline	CRFK cell line	LP	7	16	25				Husman et al. 2004
Calicivirus feline	CRFK cell line	NIA	4	9	14				Tree et al. 2005
Calicivirus feline	CRFK cell line	LP	5	15	23	30	39		Thurston-Enriquez 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 *I*PRF *I*5 cell line	LP	40	78	119	160	195	235	Gerba et al. 2002
Adenovirus type 15	A549 cell line (ATCC CCL-185)	LP	40	80	122	165	210		Thompson et al. 2003
Adenovirus type 40	PLC *I*PRF *I*5 cell line	LP	55	105	155				Thurston-Enriquez et al. 2003
Adenovirus type 40	PLC *I*PRF *I*5 cell line	LP	30	ND	ND	124			Meng and Gerba 1996
Adenovirus type 41	PLC *I*PRF *I*5 cell line	LP	23.6	ND	ND	111.8			Meng and Gerba 1996
Poliovirus Type 1 ATCC Mahoney	NIA	NIA	6	14	23	30			Harris et al. 1987
Poliovirus Type 1 LSc2ab ()	MA104 cell	NIA	5.6	11	16.5	21.5			Chang et al. 1985

Table 4. *(continued)*

Virus	Host	Lamp Type	UV Dose (Fluence) (mJ/cm^2) per Log Reduction						Reference
			1	2	3	4	5	6	
Poliovirus Type 1 LSc2ab	BGM cell	LP	5.7	11	17.6	23.3	32	41	Wilson et al. 1992
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. 2002
Poliovirus Type Mahoney	Monkey kidney cell line Vero	LP	3	7	14	40			Sommer et al. 1989
Coxsackievirus B5	Buffalo Green Monkey cell line	N/A	6.9	13.7	20.6				Battigelli et al. 1993
Coxsackievirus B3	BGM cell line	LP	8	16	24.5	32.5			Gerba et al. 2002
Coxsackievirus B5	BGM cell line	LP	9.5	18	27	36			Gerba et al. 2002
Reovirus-3	Mouse L-60	N/A	11.2	22.4					Rauth 1965
Reovirus Type 1 Lang strain	N/A	N/A	16	36					Harris et al. 1987
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. 1993
Rotavirus SA-11	MA-104 cell line	N/A	7.1	14.8	25				Chang et al. 1985
Rotavirus SA-11	MA-104 cell line	LP	9.1	19	26	36	48		Wilson et al. 1992
Rotavirus	MA104 cells	LP	20	80	140	200			Caballero et al. 2004
Hepatitis A HM175	FRhK-4 cell	LP	5.1	13.7	22	29.6			Wilson et al. 1992
Hepatitis A	HAV/HFS/GBM	N/A	5.5	9.8	15	21			Wiedenmann et al. 1993
Hepatitis A HM175	FRhK-4 cell	N/A	4.1	8.2	12.3	16.4			Battigelli et al. 1993
Echovirus I	BGM cell line	LP	8	16.5	25	33			Gerba et al. 2002
Echovirus II	BGM cell line	LP	7	14	20.5	28			Gerba et al. 2002

The SARS-CoV-2 strain used was USA-WA1/2020 NR-52281. Viral stocks of SARS- COV-2 were obtained from the Biodefense and Emerging Infections Research Resources Repository and were propagated in Vero-E6 cells grown in Dulbecco's Modified Eagle Medium (DMEM) without phenol red, with 2% Fetal Bovine Serum (FBS), L-glutamine, penicillin/streptomycin, non-essential amino acids, and hydroxyethyl piperazineethanesulfonic acid (HEPES). The virus stock was purposely produced in a phenol red-free medium to avoid photodegradation or photooxidation that may affect the results. For stock virus titration, aliquots of viral stock were applied on confluent Vero-E6 cells in 96-well plates for a 50% tissue culture infectious dose (TCID50) assay. Viral stocks were determined to be 8 x 107 TCID50/mL. The infected articles were placed under a UVGI device and were individually treated with a dose of 1.5 J/cm2 (254 nm). Then, they were rotated and the opposite side of the article was again irradiated with 1.5 J/cm2. The irradiation time for each side was approximately 60-70 seconds (or 90-105 J/cm2).