Fluence (UV Dose) Required to Achieve Incremental Log Inactivation of Bacteria, Protozoa, Viruses and Algae

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Introduction

Revision history

This paper represents the second revision of a compilation that goes back to 1999. The original compilation (Wright and Sakamoto 1999) was an internal document of Trojan Technologies. The first revision was published in 2006 (Chevrefils et al. 2006). Data from the previous reviews have been included here. In addition, data from the past 10 years have been added and a new table for algae has been added. Two other reviews of the UV sensitivity of microorganisms have been published (Hijnen et al. 2006; Coohill and Sagripanti 2008).

Brief description and selection criteria for content of the tables

Tables 1-5 (only available in the downloaded magazine version) present a summary of published data on the ultraviolet (UV) fluence-response data for various microorganisms 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 (irradiance) can be measured empirically and multiplied by exposure time (in seconds) to obtain an incident fluence onto the sample being irradiated; however, earlier data do not always contain the correction factors that are now considered standard practice (Bolton and Linden 2003; Bolton et al. 2015a) in order to determine the average fluence delivered to the microorganisms within the irradiated sample. Such uncorrected data are marked and should be considered as upper limits, since the necessary corrections have not been made. 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 fluence is documented. The references from which the data are abstracted must be carefully read to understand how the reported fluences are calculated and what the assumptions and procedures are in the calculations.

It is the intention of the authors and sponsors to keep this table dynamic, with periodic updates. Recommendations for inclusion in the tables, along with the reference source, should be sent to:

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The selection criteria for inclusion are recommended as follows:

1. Data must already be published in a peer-reviewed journal or other peer-reviewed publication media; some exceptions have been allowed where data are only available in non-peer-reviewed papers;
2. For the publications where an LP or MP UV lamp was used as the UV source, the calculated fluence should usually be determined by using a collimated beam apparatus; however, for other UV sources, this criterion was not strictly followed and such cases are noted;
3. Ideally, the fluence rate (irradiance) should be measured with a recently calibrated radiometer, and when this has not been done, a well-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 are abstracted should describe the experimental procedures including collimated beam procedures, fluence calculation procedures along with any assumptions made, organism culturing procedures, enumeration and preparation for experiments;
5. Ideally, as noted above, the protocol published by Bolton and Linden (2003) or the recently published IUVA Protocol (Bolton et al. 2015a) should be followed. In cases where this protocol has not been followed, notes to that effect have been provided. Such data should be considered as an upper limit for the fluence since the normal correction factors have not been applied. In some cases only the water factor has been applied; these are deemed to have met the protocol criterion, since the water factor is the most important correction.
6. Responses should be determined over a range of fluences; that is, a complete fluence-response curve is preferred to a single fluence-response measurement.

These criteria will be applied strictly for future editions of these tables.

For the users of these tables, the following points can be helpful in understanding the information provided:

- In some papers, the authors used different methods for enumeration of their selected microorganism and based on that, they reported different fluence-responses in their work compared with the work of others. Where this has happened for a specific paper, a brief description of the implemented method is provided within the box containing the name of the tested microorganism.
- For the studies with UV sources other than an LP lamp (e.g., filtered MP lamps, UV-LEDs, excimer lamps, etc.) the full width at half maximum (FWHM) of wavelength distribution around the peak wavelength is usually about 10-12 nm, except for the tunable laser where the bandwidth is < 1 nm.
- Where the authors have reported kinetic models based on their experimental data, these models were used in fluence calculations for these tables. Where model fits were not provided, the fluence reported for each specific log reduction number was extracted by graphic linearization (Web Plot Digitizer software) between two adjacent experimental data points in the fluence range.
- In some cases, fluence-response curves have been determined at several wavelengths, so that an action spectrum can be determined. These cases are noted as "action spectrum;" however, only data for wavelengths near 254 nm are included in the tables. Data for other wavelengths can be obtained from the cited reference.
- The reader should be aware that for a given microorganism there is a data spread even after the selection criteria have been applied. Some studies have applied a Bayesian statistical analysis (e.g., see Qian et al. 2004, 2005) to obtain an average fluence-response curve and 95 percentile limits. Some of the factors that could affect the reported data are: the medium (e.g., drinking water or wastewater), differences in the nutritional state of the cells being assayed, the presence of particles because of a failure to fully disperse cells following pre-concentration for the collimated beam assay, etc.
- For a given microorganism, the fluence-response curve can depend markedly on the strain examined. This is why studies of a given strain have been grouped together.
- Note that the data in the tables below originate from highly controlled protocols usually using defined media and culture methods, irradiation methods, etc. These data are useful when validating UV technologies and envisioning regulations; however, as water quality, nutritional state, particle content and a number of other factors can impact on microbe responses to disinfection in real environmental samples or processed water, such real waters should be used for site specific assessments of UV, and design specification should benefit from the results of assays using these site-specific waters.
- In some cases, the quality of the data was questionable and did not meet some of the selection criteria listed above. In these cases, the data entries are in italics.

These tables can be used as a helpful document for understanding the fluence-responses for different organisms at different wavelengths, with different UV sources; however, if more details are important for the users of these data, they must read the reference provided for each study.

Units and nomenclature

Throughout this review, fluence rate and irradiance (units mW/cm^2) are used interchangeably since they are virtually identical in a collimated beam apparatus. The term fluence (units mJ/cm^2) is used, which is the proper term [see Bolton et al. (2015b) for a recommended set of terms and definitions] rather than UV dose, which was used in earlier revisions of this document; however, it should be noted that the term UV dose is still widely used. Finally, it is noted that in Europe and other parts of the world, the units W/m^2 for irradiance or fluence rate and J/m^2 for fluence (UV dose) are more commonly used. One $mW/cm^2 = 10\ W/m^2$ and $1\ mJ/cm^2 = 10\ J/m^2$.

The tables

Five tables have been prepared covering spores, bacteria, viruses, algae and other microorganisms. These tables – as well as a reference list – are too large for print, but the full review can be downloaded from the Member Zone on the IUVA website at www.iuva.org. ■

Table 1. Fluences for multiple log reductions for various spores

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation							
Spore	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**Proto-col?**	**Notes**	**Reference**
Aspergillus brasiliensis (previously known as ***Aspergillus niger***) ATCC 16404 (dark culture)	LP	122	226	293			yes		Taylor-Edmonds et al. 2015
Aspergillus niger									
ATCC 32625	LP	116	245	370	560		yes		Clauß 2006
ATCC 32625	Excimer 222 nm	90	220	325	430		yes		Clauß 2006
Bacillus anthracis									
Sterne	LP	28	37	52			yes		Nicholson & Galeano 2003
Sterne	LP	23	30				yes		Blatchley III et al. 2005
Ames	LP	25	~40	>120 with tailing			yes		Rose & O'Connell 2009
34F2 (Sterne) method: soil extract-peptone-beef extract agar	LP	23	~40	>120 with tailing			yes		Rose & O'Connell 2009
34F2 (Sterne) method: Schaeffer's sporulation medium	LP	23	36	80			yes		Rose & O'Connell 2009
Bacillus atrophaeus									
ATCC 9372	LP	22	38	55	71		yes		Zhang et al. 2014
	LP	10	16	26	39		yes		Sholtes et al. 2016
	UV-LED 260 nm	6	10	14	19	31	yes		Sholtes et al. 2016
Bacillus cereus									
ATCC 11778	Excimer 222 nm	25	43	69			yes		Clauß 2006
ATCC 11778	LP	52	93	140			yes		Clauß 2006
T	LP	23	30	35	40		yes		Blatchley III et al. 2005
Bacillus megaterium (spores) QMB 1551	265 nm	*28*	*42*	*55*			no		Donnellan & Stafford 1968
Bacillus pumilus									
ASFUVRC	Filtered MP 258 nm	87	130	184			yes		Beck et al. 2015
ASFUVRC	LP	173	348				yes		Boczek et al. 2016
ATCC 27142	LP	68	138	204	272		yes		Boczek et al. 2016
Bacillus subtilis									
ATCC 6633	LP	12	18	24	30	36	yes		Quails & Johnson 1983
ATCC 6633	LP	36	48	59	77		yes		Chang et al. 1985
ATCC 6633	LP	28	40	50			yes		Sommer et al. 1998
ATCC 6633	LP	19	40	60	81		yes		Sommer et al. 1999

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation							
Spore	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**Proto-col?**	**Notes**	**Reference**
***Bacillus subtilis* (cont.)**									
ATCC 6633	LP	31	47	64	80		yes	Action spectrum	Cabaj et al. 2002
ATCC 6633	LP	25	39	50	60		yes		Nicholson & Galeano 2003
ATCC 6633	LP	24	35	47	79		yes		Mamane-Gravetz & Linden 2004
ATCC 6633 (surface cultured)	LP	11	18	24	31		yes	Action spectrum	Mamane-Gravetz et al. 2005
ATCC 6633 (liquid cultured)	LP	13	23	33			yes		Bohrerova et al. 2006
ATCC 6633 (surface cultured)	LP	9	15				yes		Bohrerova et al. 2006
ATCC 6633 (surface cultured)	Excimer 222 nm	7	12	18	23		yes		Pennell et al. 2008
ATCC 6633 (surface cultured)	LP	19	24	30	35		yes		Pennell et al. 2008
ATCC 6633 (surface cultured)	282 nm	19	29	39	49		yes		Pennell et al. 2008
ATCC 6633	LP	9	17	26	34		yes		Bichae et al. 2009
ATCC 6633	LP	21	32	43	55		yes	Action spectrum	Chen et al. 2009
ATCC 6633 (surface cultured)	LP	18	39	61	82		yes		Sun & Liu 2009
ATCC 6633	LP	24	37	51	80 + tailing		yes		Mamane et al. 2009
ATCC 6633	LP	26	40	55	69		yes		Wang et al. 2010
ATCC 6633	Excimer 222 nm	13	21	30	38		yes		Wang et al. 2010
ATCC 6633	Excimer 172 nm	435	869				yes		Wang et al. 2010
ATCC 6633	UV-LED 269 nm	*2*	*10*	*17*	*25*		yes		Würtele et al. 2010
ATCC 6633	UV-LED 282 nm	*3*	*11*	*18*	*26*		yes		Würtele et al. 2010
ATCC 6051	LP	8	13	17	20 + tailing		yes		Jin et al. 2006
TKJ 6312	LP	0.7	1.5	2.3	3.7		yes		Sommer et al. 1999
WN624	LP	25	36	49	60		yes		Nicholson & Galeano 2003
***Cylindrospermum* spores**	LP	*14*	*26*	*43*			no		Singh 1975
Clostridium pasteurianum									
ATCC 6013	LP	3.4	5.3	6.7	8.4		yes		Clauß 2006
ATCC 6013	Excimer 222 nm	4.3	6.1	7.9	9.6		yes		Clauß 2006
Encephalitozoon intestinalis									
	LP	2.8	5.6	8.4			yes		John et al. 2003
(microsporidia)	LP & MP	*<3*	*3*	*<6*			yes		Huffman et al. 2002

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation							
Spore	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**Proto-col?**	**Notes**	**Reference**
Fischeralla muscicola spores	LP	*189*					no		Singh 1975
Penicillium expansum									
ATCC 36200	LP	11	38	49	65		yes		Clauß 2006
ATCC 36200	Excimer 222 nm	22	33	42			yes		Clauß 2006
Streptomyces griseus									
ATCC 10137	LP	8.5	13	15	18		yes		Clauß 2006
ATCC 10137	Excimer 222 nm	13	17	20	26		yes		Clauß 2006
Thermoactinomyces vulgaris									
ATCC 43649	LP	55	90	115	140		yes		Clauß 2006
ATCC 43649	Excimer 222 nm	25	38	46	55		yes		Clauß 2006

Table 2. Fluences for multiple log reductions for various bacteria

		Fluence (UV dose) (mJ/cm²) for a given log reduction without photoreactivation								
Bacterium	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Aeromonas hydrophila ATCC7966	LP	1.1	2.5	4.0	5.5	6.9	8.4	yes		Wilson et al. 1992
Aeromonas salmonicida AL 2017	LP	1.5	2.7	3.1	5.9			yes		Liltved & Landfald 1996
Arthrobacter nicotinovorans										
ATCC 49919	LP	8	10	12	14			yes		Clauß 2006
ATCC 49919	Excimer 222 nm	10	15	18	20			yes		Clauß 2006
***Bacillus cereus* (veg. bacteria)**										
ATCC 11778	LP	6	7	9	12			yes		Clauß 2006
ATCC 11778	Excimer 222 nm	9	11	14	18			yes		Clauß 2006
Bacillus megaterium (veg. cells) QMB 1551	265 nm	*4.6*						no		Donnellan & Stafford 1968
Burkholderia mallei										
M9	LP	1.0	2.4	3.8	5.2			yes		Rose & O'Connell 2009
M13	LP	1.2	2.7	4.1	5.5			yes		Rose & O'Connell 2009
Brucella melitensis										
ATCC 23456	LP	2.8	5.3	7.8	10.3			yes		Rose & O'Connell 2009
IL195	LP	3.7	5.8	7.8	9.9			yes		Rose & O'Connell 2009
Burkholderia pseudomallei										
ATCC 11688	LP	1.7	3.5	5.5	7.4			yes		Rose & O'Connell 2009
CA650	LP	1.4	2.8	4.3	5.7			yes		Rose & O'Connell 2009
Brucella suis										
KS528	LP	2.7	5.3	7.9	10.5			yes		Rose & O'Connell 2009
MO 562	LP	1.7	3.6	5.6	7.5			yes		Rose & O'Connell 2009
Campylobacter jejuni										
ATCC 43429	LP	1.0	2.1	3.4	4.6	5.8		yes		Wilson et al. 1992
biotype 1 strain 709/84	LP	0.8	1.3	1.7	2.1			yes		Butler et al. 1987
Citrobacter diversus	LP	5	7	9	11.5	13		yes		Giese & Darby 2000
Citrobacter freundii	LP	5	9	13				yes		Giese & Darby 2000
Corynebacterium diphtheriae	LP	*3.4*						no		Sharp 1939
Deinococcus radiodurans										
ATCC 13939	LP	113	142	170	205			yes		Clauß 2006
ATCC 13939	Excimer 222 nm	44	57	91				yes		Clauß 2006
Eberthella typhosa	LP	*2.1*						no		Sharp 1939
Enterococcus faecium Vancomycin-resistant	LP	7	9	11	13	15		yes		McKinney & Pruden 2012

		Fluence (UV dose) (mJ/cm²) for a given log reduction without photoreactivation								
Bacterium	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Enterococcus faecalis										
ATCC27285	LP	3.7	8.0	14 + tailing				yes		Moreno-Andrés et al. 2016
DSM 20478	LP	7.1	8.7	13 + tailing				yes		Chen et al. 2015
DSM 20478	MP	5.5	7.6	12 + tailing				yes		Chen et al. 2015
Escherichia coli										
ATCC 11229	LP	3.0	4.8	6.7	8.4	10.5		yes		Chang et al. 1985
ATCC 11229	LP	2.5	3.0	3.5	5	10	15	yes		Harris et al. 1987
ATCC 11229	LP	*7*	*8*	*9*	*11*	*12*		no		Hoyer 1998
ATCC 11229	LP	3.4	5.0	6.7	8.3	10		yes		Sommer et al. 1998
ATCC 11229	LP	3.5	4.7	5.5	6.5	7.5	9.6	yes		Sommer et al. 2000
ATCC 11229	LP	2.5	3.0	3.5	4.5	5.0	6.0	yes		Sommer et al. 2001
ATCC 11229	LP	3.9	5.4	6.8	8.2	9.7		yes		Zimmer & Slawson 2002
ATCC 11229	LP	3.3	4.9	5.7	6.6			yes		Clauß et al. 2005
ATCC 11229	Excimer 222 nm	4.9	7.7	9.1	10.3			yes		Clauß et al. 2005
ATCC 11229	LP or MP	1.6	3.0	5.0	6.5			yes		Bohrerova et al. 2008
ATCC 11229	LP	4.7	6.2	7.2	8.3	9.3		yes		Quek & Hu 2008
ATCC 11229	MP	2.5	4.0	4.7	5.3	6.0	7.3	yes		Quek & Hu 2008
ATCC 11229	LP	4.1	5.1	6.2				yes		Bowker et al. 2011
ATCC 11229	UV-LED 255 nm	*5.9*	*7.9*					yes		Bowker et al. 2011
ATCC 11229	UV-LED 275 nm	4.3	6.2	7.7				yes		Bowker et al. 2011
ATCC 11303	LP	4	6	9	10	13	15	yes		Wu et al. 2005
ATCC 11775	LP	1.1	2.0	3.0	3.4	4.0		yes		Quek & Hu 2008
ATCC 11775	MP	0.9	1.6	2.4	3.0	3.4		yes		Quek & Hu 2008
ATCC 15597	LP	6.4	8.9	11	12	13		yes		Quek & Hu 2008
ATCC 15597	MP	5.0	6.8	8.3	9.4	11	12	yes		Quek & Hu 2008
ATCC 25922	LP	6.0	6.5	7.0	8.0	9	10	yes		Sommer et al. 1998
ATCC 29425	LP	5.4	8.5	20				yes		Chatterley & Linden 2010
ATCC 29425	UV-LED 265 nm	3.6	5.9	17	20			yes		Chatterley & Linden 2010
ATCC 700891	LP	7.3	10	12	13	15		yes		Quek & Hu 2008
ATCC 700891	MP	4.8	6.8	8.2	9.0	9.8		yes		Quek & Hu 2008
B	LP	1.0	2.4	4.4	6			yes		Shin et al. 2008
B	MP	0.9	2.1	4.2	6			yes		Shin et al. 2008
B ATCC 13033	LP	1.2	3.0	4.7	6.5	8.2	10	yes		Sholtes et al. 2016
B ATCC 13033	UV-LED 260 nm	1.2	3.0	4.7	6.5	8.2	10	yes		Sholtes et al. 2016
C	LP	2	3	4	5.6	6.5	8	yes		Otaki et al. 2003

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Bacterium	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
***Escherichia coli* (cont.)**										
C3000	LP or MP	3.0	4.3	5.5	7.0			yes		Eischeid & Linden 2007
CGMCC 1.3373	LP	3.1	5.9	8.0	13			yes		Guo et al. 2009
CGMCC 1.3373	MP	3.1	5.9	9.6	13			yes		Guo et al. 2009
CN13	XeBr Exci-lamp 282 nm	5.5	7.5	9.6	12					Matafonova et al. 2012
K12	LP	*1.1*	*1.9*	*2.6*	*3.4*			no		Qiu et al. 2004
K12 IFO 3301	LP & MP	2	4	6	7	9		yes		Oguma et al. 2002
K12 IFO 3301	LP	1.5	2.0	3.5	4.2	5.5	6.2	yes		Otaki et al. 2003
K12 IFO 3301	LP & MP	2.2	4.4	6.7	8.9	11		yes		Oguma et al. 2004
K12 IFO 3301	UV-LED 265 nm	2.6	4.7	6.6	9.0	12		yes		Oguma et al. 2013
K12 IFO 3301	UV-LED 280nm	3.4	6.9	10	14			yes		Oguma et al. 2013
K12 IFO 3301	LP	1.9	4	6	8			yes		Rattanakul et al. 2014
K12 IFO 3301	UV-LED 285 nm	7.8	13	16	23	34		yes		Oguma et al. 2015
K12 IFO 3301	LP	2	4	6				yes		Oguma et al. 2001
NBIMB 9481	LP	5.9	8.0	9.3	10.5	12		yes		Quek & Hu 2008
NBIMB 9481	MP	4.3	6.2	7.3	8.6			yes		Quek & Hu 2008
NBIMB 10083	LP	2.8	4.4	5.6	6.6	7.6		yes		Quek & Hu 2008
NBIMB 10083	MP	2.5	4.3	5.1	6.0	6.8	7.6	yes		Quek & Hu 2008
OP50	LP	2.0	4.4	6.7	9.1			yes		Bichai et al. 2009
O157: H7	LP	*1.5*	*3.0*	*4.5*	*6.0*			no		Tosa & Hirata 1999
O157: H7	LP	*<2*	*<2*	*2.5*	*4*	*8*	*17*	??		Yaun et al. 2003
O157: H7 ATCC 43894	LP	1.4	2.8	4.2	5.5	6.9		yes		Wilson et al. 1992
O157: H7 CCUG 29193	LP	3.5	4.7	5.5	7			yes		Sommer et al. 2000
O157: H7 CCUG 29197	LP	2.5	3.0	4.6	5.0	5.5		yes		Sommer et al. 2000
O157: H7 CCUG 29199	LP	0.4	0.7	1.0	1.1	1.3	1.4	yes		Sommer et al. 2000
O25: K98: NM	LP	5.0	7.5	9	10	12		yes		Sommer et al. 2000
O26	LP	*5.4*	*8.0*	*10.5*	*12.8*			no		Tosa & Hirata 1999
O50: H7	LP	2.5	3.0	3.5	4.5	5	6	yes		Sommer et al. 2000
O78: H11	LP	4	5	5.5	6	7		yes		Sommer et al. 2000
145 Ampicillin resistant	LP	0.8	1.9	3.0	4.7			yes		Templeton et al. 2009
018 Trimethoprim resistant	LP	1.5	3.0	4.0	4.9			yes		Templeton et al. 2009
SMS-3-5	LP	3	5.1	6.5	7.6			yes		McKinney & Pruden 2012
wild type	LP	2.7	4.0	5.3	6.6			yes		Butler et al. 1987
wild type	LP	4.4	6.2	7.3	8.1	9.2		yes		Sommer et al. 2000
	LP	2.0	3.6	5.2	6.8			yes		Hu et al. 2012

		Fluence (UV dose) (mJ/cm²) for a given log reduction without photoreactivation								
Bacterium	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Faecal coliforms	LP	6	9	13	22			yes		Maya et al. 2003
Francisella tularensis										
LVS	LP	1.3	3.1	4.8	6.6			yes		Rose & O'Connell 2009
NY98	LP	1.4	3.8	6.3	8.7			yes		Rose & O'Connell 2009
Faecal streptococci	LP	9	14	22	30			yes		Maya et al. 2003
Halobacterium elongata ATCC 33173	LP	*0.4*	*0.7*	*1.0*				no		Martin et al. 2000
Halobacterium salibarum ATCC 43214	LP	*12*	*15*	*18*	*20*			no		Martin et al. 2000
Helicobacter pylori										
Texas isolate	LP	2.2	3.0	3.8	4.6	5.7	6.6	yes		Hayes et al. 2006
ATCC 43504	LP	4.5	5.7	6.7	7.5	8.0		yes		Hayes et al. 2006
ATCC 49503	LP	1.7	3.1	4.0	5.3	7		yes		Hayes et al. 2006
Klebsiella pneumoniae	LP	5	7	10	12			yes		Giese & Darby 2000
Klebsiella terrigena ATCC 33257	LP	3.6	6.4	9.3	12	15		yes		Wilson et al. 1992
Legionella longbeachae ATCC 33462	LP	1.4	3.0	4.7	6.3			yes		Cervero-Arago et al. 2014
Legionella pneumophila										
Philadelphia 2	LP	*0.9*	*1.8*	*2.8*	*3.7*			no		Antopol & Ellner 1979
ATCC 33152	LP	1.6	3.2	4.8	6.4	8.0		yes		Oguma et al. 2004
ATCC 33152	MP	1.9	3.8	5.8	7.7	9.6		yes		Oguma et al. 2004
ATCC 33152	LP	1.7	3.0	4.3	5.7			yes		Cervero-Arago et al. 2014
ATCC 33823	LP	1.7	3.1	4.5	5.8			yes		Cervero-Aragó et al. 2014
ATCC 43660	LP	3.0	5.0	7.2	9.3			yes		Wilson et al. 1992
Sero group 1	LP	1.7	2.9	4.2	5.4			yes		Cervero-Aragó et al. 2014
Sero group 8	LP	1.8	3.3	4.7	6.1			yes		Cervero-Aragó et al. 2014
Leptospira										
biflexa serovar patoc Patoc I	LP	2.3	3.8	5.1	6.7			no		Stamm and Charon 1988
illini 3055	LP	2.8	3.8	4.8				no		Stamm and Charon 1988
interrogans serovar Pomona Pomona	LP	0.8	1.2	1.7				no		Stamm and Charon 1988
Listeria monocytogenes	LP	*2.2*	*3.0*	*3.2*	*4.1*	*4.6*		no		Collins 1971
Mycobacterium avium										
33B	LP	5.8	8.1	10	13			yes		Hayes et al. 2008
W41	LP	5.7	7.9	10	12	15		yes		Hayes et al. 2008

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Bacterium	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
***Mycobacterium avium* (cont.)**										
D55A01	LP	6.4	9.4	12	15			yes		Hayes et al. 2008
Mycobacterium avium hominissuis										
HMC02 (white transparent) (WT)	LP	7.7	12	17	22			yes		Shin et al. 2008
HMC02 (white transparent) (WT)	MP	8.1	12	16				yes		Shin et al. 2008
HMC02 (white opaque) (WO)	LP	7.1	11	17				yes		Shin et al. 2008
HMC02 (white opaque) (WO)	MP	6.6	11	15	19			yes		Shin et al. 2008
Mycobacterium bovis BCG	LP	*2.2*	*4.4*					no		Collins 1971
Mycobacterium intracellulare										
B12CC2	LP	7.8	11	13	16			yes		Hayes et al. 2008
ATCC 13950	LP	7.4	11	15	19			yes		Hayes et al. 2008
Mycobacterium phlei	LP	*3.6*						no		Collins 1971
Mycobacterium terrae										
ATCC 15755	LP	3.9	9.3	16 + tailing				yes	**(1)**	Bohrerova & Linden 2006a
ATCC 15755	LP	3.7	9.3	16				yes		Bohrerova & Linden 2006b
ATCC 15755	MP	3.2	11	39				yes		Bohrerova & Linden 2006b
Mycobacterium tuberculosis	LP	*2.2*	*4.3*					no		Collins 1971
Pseudomonas aeruginosa										
ATCC 9027	LP	*3.8*	*6.5*	*10*	*17*			no		Abshire & Dunton 1981
ATCC 10145	LP	*4.6*						no		Abshire & Dunton 1981
ATCC 14207	LP	*3.7*						no		Abshire & Dunton 1981
ATCC 15442	LP	*3.8*						no		Abshire & Dunton 1981
ATCC 27853	LP	*4.9*						no		Abshire & Dunton 1981
ATCC 27853	LP	0.8	1.6	2.3	3.1			yes		Clauß 2006
ATCC 27853	Excimer 222 nm	3.1	4.8	5.9	7.5	10		yes		Clauß 2006
01	LP	1.3	2.7	4.3	6.3	10		yes		McKinney & Pruden 2012
B2	LP	*5.6*						no		Abshire & Dunton 1981
G2	LP	*3.0*						no		Abshire & Dunton 1981
BS4	LP	*3.5*						no		Abshire & Dunton 1981
WB1	LP	*5.8*						no		Abshire & Dunton 1981
SH-2918	LP	*3.5*						no		Abshire & Dunton 1981
NCTC 10662	LP	1.5	2.6	3.8	5.0	6.2		yes		Blatchley et al. 2016
Salmonella spp.	LP	*<2*	*2*	*3.5*	*7*	*14*	*29*	??		Yaun et al. 2003

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Bacterium	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Salmonella typhimurium										
ATCC 6539	LP	2.6	4.5	5.8	7	8		yes		Chang et al. 1985
ATCC 19430	LP	2.0	4.1	6.2	8.3			yes		Wilson et al. 1992
(in act. sluge)	LP	3	12	22	50			yes		Maya et al. 2003
LT2 SL3770	LP	4	5.7	7.8				yes	Action spect-rum	Chen et al. 2009
	LP	3.9	5.3	6.7	7.7	13		yes		Hu et al. 2012
Serratia marcescens	LP	*2.2*						no		Sharp 1939
Shewanella algae	LP	*0.9*	*1.7*	*2.4*	*3.2*			no		Qiu et al. 2004
Shewanella oneidensis										
DLM7	LP	*0.3*	*0.5*	*0.8*	*1.1*			no		Qiu et al. 2004
MR4	LP	*0.7*	*1.4*	*2.1*	*2.8*			no		Qiu et al. 2004
MR1	LP	*0.2*	*0.4*	*0.6*	*0.9*			no		Qiu et al. 2004
Shewanella putrefaciens 200	LP	*0.5*	*0.8*	*1.1*	*1.4*			no		Qiu et al. 2004
Shigella dysenteriae										
ATCC 29027	LP	0.1	1.0	1.9	2.8	3.8	4.7	yes		Wilson et al. 1992
	LP	0.5	1.1	1.9	2.5	3.1		yes		Hu et al. 2012
Shigella paradysenteriae	LP	*1.7*						no		Sharp 1939
Shigella sonnei										
ATCC 9290	LP	3.2	4.9	6.5	8.2			yes		Chang et al. 1985
Staphylococcus albus										
	LP	*1.8*						no		Sharp 1939
	LP	*1.1*	*3.2*	*4.0*	*4.8*			no		Collins 1971
Staphylococcus aureus										
	LP	2.1	3.2					no	Action spect-rum	Gates 1929
(hem)	LP	*2.6*						no		Sharp 1939
ATCC 25923	LP	3.9	5.4	6.5	10			yes		Chang et al. 1985
ATCC 25923	LP	4.4	5.8	6.4	7.3	9		yes		Clauß 2006
ATCC 25923	Excimer 222 nm	9.3	12	14	18			yes		Clauß 2006
ATCC BAA-1556 (Methicillin resistant)	LP	4.5	7.2	8.8	10			yes		McKinney & Pruden 2012
Streptococcus faecalis ATCC 29212	LP	6.6	8.6	9.8	11.1			yes		Chang et al. 1985
Streptococcus hemolyticus	LP	*2.2*						no		Sharp 1939
Vibrio anguillarum	LP	0.5	1.2	1.5	2.0			yes		Liltved & Landfald 1996
Vibrio cholerae										
Classical OGAWA 154	LP	*0.8*	1.4	2.3	3.9	6.8		no		Banerjee & Chatterjee 1977

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Bacterium	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
***Vibrio cholerae* (cont.)**										
el tor MAK 154	LP	*1.7*	4.1	7.1				no		Banerjee & Chatterjee 1977
NAG 1976	LP	*2.5*	8.9					no		Banerjee & Chatterjee 1977
ATCC 25872	LP	0.7	1.4	2.1	2.8	3.6		yes		Wilson et al. 1992
Vibrio parahaemolyticus 2977	LP	*4.4*						no		Banerjee & Chatterjee 1977
Yersinia enterocolitica										
Sero-group 0:3 strain 304/84	LP	1.2	2.2	3.0	3.6			yes		Butler et al. 1987
ATCC 4780	LP	2.1	4.1	5.0	5.8			yes		Clauß et al. 2005
ATCC 4780	Excimer 222 nm	3.1	6.1	7.6	8.8	10	12	yes		Clauß et al. 2005
ATCC 27729	LP	1.6	2.7	4.0	5.1			yes		Wilson et al. 1992
Yersinia pestis										
A1122	LP	1.4	2.6	3.7	4.9			yes		Rose & O'Connell 2009
Harbin	LP	1.3	2.2	3.2	4.1			yes		Rose & O'Connell 2009
Yersinia ruckeri	LP	1	2	3	4			yes		Liltved & Landfald 1996

Table 3. Fluences for multiple log reductions for various protozoa

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation							
Protozoan	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**Proto-col?**	**Notes**	**Reference**
Acanthamoeba castellanii									
ATCC 30234 (life stage: trophozoites; plaque assay)	LP	40					yes		Chang et al. 1985
CCAP 15342 (life stage: trophozoites; method: MPN)	LP	32	52	72			yes		Cervero-Arago et al. 2014
CCAP 15342 (life stage: cysts; method: MPN)	LP	45	75	91	125		yes		Cervero-Arago et al. 2014
Acanthamoeba culbertsoni ATCC 30171 (mouse infectivity assay; *Mus musculus* species, strain CD-1)	LP	38	58	125	148		yes		Maya et al. 2003
Acanthamoeba spp.									
isolated strain (life stage: trophozoites; mouse infectivity assay; *Mus musculus* species, strain CD-1)	LP	39	75	132	160		yes		Maya et al. 2003
155 (life stage: trophozoites; method: MPN)	LP	28	31	66	71		yes		Cervero-Arago et al. 2014
155 (life stage: cysts; method: MPN)	LP	34	67	99			yes		Cervero-Arago et al. 2014
Cryptosporidium Hominis [cell culture infectivity assay using HCT-8 cells (CCL-244) & MDBK cells]	LP & MP	3.0	5.8				yes		Johnson et al. 2005
Cryptosporidium parvum									
[mouse infectivity assay (neonatal CD-1 mice)]	MP	<3	<3	<3	19		yes		Bolton et al. 1998; Bukhari et al. 1999
[mouse infectivity assay (neonatal CD-1 mice)]	LP	<3	<3	3-6	>16		yes		Clancy et al. 2000
[mouse infectivity assay (neonatal CD-1 mice)]	MP	<3	<3	3-9	>11		yes		Clancy et al. 2000
[mouse infectivity assay (neonatal CD-1 mice)]	LP & MP	2.4	<5	5.2	9.5		yes		Craik et al. 2001

		Fluence (UV dose) (mJ/cm²) for a given log reduction without photoreactivation							
Protozoan	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**Proto-col?**	**Notes**	**Reference**
***Cryptosporidium parvum* (cont.)**									
[mouse infectivity assay & cell culture infectivity assay using MDCK cells (CCL-34)]	LP	1	2	>5			yes		Shin et al. 2001
[mouse infectivity assay (neonatal CD-1 mice)]	MP	<10	<10	>10			yes		Belosevic et al. 2001
[mouse infectivity assay (SCID mice)]	LP	0.5	1.0	1.4	2.2		no		Morita et al. 2002
[cell culture infectivity assay using HCT-8 cells (CCL-244)]	LP	2	<3	<3			yes		Zimmer et al. 2003
[cell culture infectivity assay using HCT-8 cells (CCL-244)]	MP	<1	<1	<1			yes		Zimmer et al. 2003
[culture-immunofluorescence (CC–IFA) based infectivity assay]	MP	1	2	2.9	4		yes		Bukhari et al. 2004
[mouse infectivity assay (neonatal CD-1 mice)]	LP	<2	<2	<2	<4	<10	yes		Clancy et al. 2004
[mouse infectivity assay (neonatal CD-1 mice)]	MP	<5	<5	<5	~6		yes		Amoah et al. 2005
[cell culture infectivity assay using HCT-8 cells (CCL-244)]	LP	1.8	5.6	25			yes		Ryu et al. 2008
HNJ-1 [mouse infectivity assay (SCID mice)]	LP	<0.7	<1.4	2.2			yes		Oguma et al. 2001
[cell culture infectivity assay using HCT-8 cells (CCL-244)]	Laser 254 nm	1.3	1.9	2.3	2.8		yes	Action spect-rum	Beck et al. 2015
Cryptosporidium spp.	LP & MP	0.8	1.5	3.0	6.0		yes	(2)	Qian et al. 2004
Giardia lamblia									
(excystation assay)	LP?	*40*	*180*				no?		Karanis et al. 1992
(gerbil infectivity assay)	LP	<10	~10	20			yes		Campbell & Wallace 2002
(gerbil infectivity assay)	LP	<0.5	<0.5	<0.5	<1		yes		Linden et al. 2002
(gerbil infectivity assay)	LP	<2	<2	<4			yes		Mofidi et al. 2002
Giardia muris									
(mouse infectivity assay)	MP	1	4.5	28 + tailing			yes		Craik et al. 2000
(mouse infectivity assay)	MP	<10	<10	<25	~60		yes		Belosevic et al. 2001
(mouse infectivity assay)	LP	<2	<2	<4			yes		Mofidi et al. 2002
(mouse infectivity assay)	LP	*<2*	*<2*	*~2*	*~2.3*		no		Hayes et al. 2003
(mouse infectivity assay)	LP	<5	<5	5			yes		Amoah et al. 2005

		Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation							
Protozoan	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**Proto-col?**	**Notes**	**Reference**
Giardia spp.	LP & MP	0.6	1.1	1.9	3.4		yes	(2)	Qian et al. 2004
Naegleria fowleri									
Cysts (method: MPN)	LP	32	63	104	121		yes		Sarkar and Gerba 2012
Trophozoites (method: MPN)	LP	8	13	18	24		yes		Sarkar and Gerba 2012
Toxoplasma gondii									
oocysts [immunofluorescence assay (IFA)]	LP	7.2	13	17	19		yes		Dumètre et al. 2008
[mouse infectivity assay (SCID mice)]	LP	3.4	6.8	10			yes		Ware et al. 2010
Vermamoeba vermiformis									
CCAP 15434 /7A (life stage: trophozoites; method: MPN)	LP	11	19	26	34		yes		Cervero-Arago et al. 2014
CCAP 15434/7A (life stage: cysts; method: MPN)	LP	17	38	54	78		yes		Cervero-Arago et al. 2014
195 (life stage: trophozoites; method: MPN)	LP	10	17	24	32		yes		Cervero-Arago et al. 2014
195 (life stage: cysts; method: MPN)	LP	32	60	76	110		yes		Cervero-Arago et al. 2014

Table 4. Fluences for multiple log reductions for various viruses

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Adenovirus											
Type 1 method: MPN	PLC/ PRF/5 and HeLa cell line	LP	35	69	103	138			yes		Nwachuku et al. 2005
Type 2	PLC/ PRF/5	LP	40	78	119	160	195	235	yes		Gerba et al. 2002
Type 2	Human lung cell line	LP	35	55	75	100			yes		Ballester & Malley 2004
Type 2	A549 cell line	LP	20	45	80	110			yes		Shin et al. 2005
Type 2	A549 cell line	LP	~30	~60					yes		Linden et al. 2007
Type 2	A549 cell line	MP	~10	~20	~30	~40	~50		yes		Linden et al. 2007
Type 2	A549 cell line	MP <240 nm blocked	~15	~30	~45	~60			yes		Linden et al. 2007
Type 2	A549 cell line	LP	8	31	50	80	117		yes		Eischeid et al. 2009
Type 2 method: TCID50	A549 cell line	LP	35	78	126	168			yes		Linden et al. 2009
Type 2 method: TCID50	A549 cell line	MP	14	29	44	80	120		yes	(3)	Linden et al. 2009
Type 2 method: cell culture	HEK293 cells human embryonic kidney	LP	37	88	120				yes		Baxter et al. 2007
Type 2 adenoid 6 (VR-846)	A-549 cell line (CCL-185)	LP	42	83	124	166			yes		Sirikanchana et al. 2008
Type 2	A549 cell line	MP	4	7	14	22	40 + tailing		yes		Eischeid et al. 2009
Type 2 method: TCID50	A549 cell line (CCL-185)	LP	36	82					yes		Shin et al. 2009
Type 2 method: TCID50	A549 cell line (CCL-185)	MP	15	29	45	59	80		yes		Shin et al. 2009
Type 2 ATCC VR-846; method: TCID50	A549 cell line (CCL-185)	LP	56	108	159	206			yes		Bounty et al. 2012
Type 2 method: plaque assay	A549 cell line (CCL-185)	LP	39	71	98	125			yes		Rodriguez et al. 2013

Virus	Host	Lamp Type	Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation 1	2	3	4	5	6	Proto-col?	Notes	Reference
Adenovirus (cont.)											
Type 2 method: plaque assay	A549 cell line (CCL-185)	MP	7	18	28	47			yes		Rodriguez et al. 2013
Type 2 method: LR-qPCR 6 kb fragment	A549 cell line (CCL-185)	LP	5	20-50	100				yes		Rodriguez et al. 2013
Type 2 method: LR-qPCR 6 kb fragment	A549 cell line (CCL-185)	MP	4	15-50	100				yes		Rodriguez et al. 2013
Type 2 method: LR-qPCR 1 kb fragment	A549 cell line (CCL-185)	LP	18	50	100				yes		Rodriguez et al. 2013
Type 2 method: LR-qPCR 1 kb fragment	A549 cell line (CCL-185)	MP	*5 + tailing*						yes		Rodriguez et al. 2013
Type 2 method: LR-qPCR 10 kb fragment	A549 cell line (CCL-185)	LP	*15*						yes		Rodriguez et al. 2013
Type 2 method: LR-qPCR 10 kb fragment	A549 cell line (CCL-185)	MP	39	94					yes		Rodriguez et al. 2013
Type 2 ATCC VR-846 method: MPN	A549 cell line (CCL-185)	LP	43	86	130	174			yes	Action spect-rum	Beck et al. 2014
Type 2 ATCC VR-846; method: LR-PCR 1.1 kbp fragment	A549 cell line (CCL-185)	LP	45	68					yes		Beck et al. 2014
Type 2 ATCC VR-846; method: LR-PCR 1.1 kbp fragment	A549 cell line (CCL-185)	Laser 254 nm	32	80-90 + tailing					yes		Beck et al. 2014
Type 2 ATCC VR-846 method: MPN	A549 cell line (CCL-185)	LP	40	76	120				yes		Beck et al. 2014

Virus	Host	Lamp Type	Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation 1	2	3	4	5	6	Proto-col?	Notes	Reference
Adenovirus (cont.)											
Type 2 ATCC VR-846 method: MPN	A549 cell line (CCL-185)	MP	8	18	34				yes	(3)	Beck et al. 2014
Type 2 ATCC VR-846 method: MPN	A549 cell line (CCL-185)	MP	32	71	135				yes	(4)	Beck et al. 2014
Type 2; method: cell culture	A549 cell line (CCL-185)	Laser 254 nm	40	70	101				yes		Beck et al. 2014
Type 2; method: infectivity	A549 cell line	LP	33	118					no		Calgua et al. 2014
Type 2; method: qPCR	A549 cell line	LP	*140*						no		Calgua et al. 2014
Type 2; method: MPN	A549 cell line (CCL-185)	LP	47	86	129	172			yes		Ryu et al. 2015
Type 2; ATCC VR-846; method: ICC-qPCR	A549 cell line (CCL-185)	LP	40	81	121	161			yes		Ryu et al. 2015
Type 2; method: total culturable virus assay	A549 cell line (CCL-185)	LP	26	100	135	168	203	234	yes		Boczek et al. 2016
Type 4; ATCC VR-1572; method: ICC qPCR	PLC/ PRF/5 ATCC CRL-8024	LP	10	34	69	116			yes		Gerrity et al. 2008
Type 5; method: cell culture	HEK 293 cells human embryonic kidney	LP	45	76	120				yes		Baxter et al. 2007
Type 5	HEK293	LP	38	76	114	152			yes		Guo et al. 2010
Type 5	HEK293	MP	23	45	68	90			yes		Guo et al. 2010
Type 5	PLC/PRF/5	LP	31	62	93	123			yes		Guo et al. 2010
Type 5	PLC/PRF/5	MP	22	43	65	87			yes		Guo et al. 2010
Type 5	XP17BE	LP	13	26	39	52			yes		Guo et al. 2010
Type 5	XP17BE	MP	9	18	27	36			yes		Guo et al. 2010
Type 5	A549 cell line (CCL-185)	LP	51	101	151				yes		Rattanakul et al. 2014

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Adenovirus (cont.)											
Type 5	A549 cell line (CCL-185)	LP	63	100	151				yes		Rattanakul et al. 2015
Type 5 ATCC VR5	A549 cell line (CCL-185)	UV-LED 285 nm	50	82	126				yes		Oguma et al. 2015
Type 6; method: MPN	PLC/ PRF/5 and HeLa cell line	LP	39	77	115	154			yes		Nwachuku et al. 2005
Type 40; strain: Dugan	PLC/PRF5 cell line	LP	50	109	167				yes		Thurston-Enriquez et al. 2003
Type 40; method: MPN	PLC/PRF5 cell line	MP	16	23	~30	~40			yes		Linden et al. 2007
Type 40; method: MPN	PLC/PRF5 cell line	LP	63	88	109	>120			yes		Blatchley et al. 2008
Type 40	HEK293	LP	35	70	105	139			yes		Guo et al. 2010
Type 40	HEK293	MP	17	33	50	66			yes		Guo et al. 2010
Type 40	PLC/PRF/5	LP	34	67	101	134			yes		Guo et al. 2010
Type 40	PLC/PRF/5	MP	16	33	49	65			yes		Guo et al. 2010
Type 41; ATCC VR-930; method: ICC-RT-PCR	HEK 293 cells ATCC CRL-1573	LP	56	111	167	222			yes		Ko et al. 2005
Type 41; method: cell culture	HEK 293 cells human embryonic kidney & PLC/PRF/5 (heaptoma) cells	LP	62	120					yes		Baxter et al. 2007
Type 41	HEK293	LP	45	91	136	182			yes		Guo et al. 2010
Type 41	HEK293	MP	20	39	59	78			yes		Guo et al. 2010
Type 41	PLC/PRF/5	LP	34	68	103	137			yes		Guo et al. 2010
Type 41	PLC/PRF/5	MP	18	36	53	71			yes		Guo et al. 2010
Type 41	XP17BE	LP	14	29	43	57			yes		Guo et al. 2010
Type 41	XP17BE	MP	11	21	32	42			yes		Guo et al. 2010
Atlantic halibut nodavirus (AHNV)	SSN-1 cell line	LP	35	70	104	140	176	211	yes		Liltved et al. 2006
B40-8 (phage)											
	B. fragilis HSP-40	LP	12	18	23	28			yes		Sommer et al. 1998
	B. fragilis	LP	11	17	23	29	35	41	yes		Sommer et al. 2001

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	Host	Lamp Type	1	2	3	4	5	6	Proto-col?	Notes	Reference
Calicivirus feline											
	CRFK cell line	LP	5	15	23	30	39		yes		Thurston-Enriquez et al. 2003
	MDCK cell line	LP	7	15	22	30	36		yes		de Roda Husman et al. 2004
	CRFK cell line	LP	7	16	25				yes		de Roda Husman et al. 2004
FCV ATCC VR-782	Crandell Reese feline kidney cell CRfk, ATCC CCL-94	LP	5	12	18	26			yes		Park et al. 2011
Coxsackievirus											
B3	BGM cell line	LP	8	16	25	33			yes		Gerba et al. 2002
B4	BGM cell line	LP	7	13	18	24	29		yes		Shin et al. 2005
B5	BGM cell line	LP	9.5	18	27	36			yes		Gerba et al. 2002
B5	BGM cell line	LP	7	14	21				yes		Battigelli et al. 1993
Echovirus											
I	BGM cell line	LP	8	17	25	33			yes		Gerba et al. 2002
II	BGM cell line	LP	7	14	21	28			yes		Gerba et al. 2002
12	foetal rhesus monkey kidney cell FRhK-4, ATCC CRL-1688	LP	8	13	18	28	40		yes		Park et al. 2011
GA phage	*E. coli* Hfr K12 ATCC 23631	LP	18	38	58	87	121		yes		Simonet & Gantzer 2006
Hepatitis											
A HM175	FRhK-4 cell	LP	5.4	15	25	35			yes		Wilson et al. 1992
A HM175	FRhK-4 cell	LP	4	8	12	16			yes		Battigelli et al. 1993
A	HAV/HFS/ GBM	LP	*6*	*10*	*15*	*21*			no		Wiedenmann et al. 1993
Infectious pancreatic necrosis virus (IPNV)	BF-2 cell line	LP	82	165	246	325			yes		Liltved et al. 2006
Infectious salmon anaemia virus (ISAV)	SHK-1 cell line	LP	2.5	5.0	7.5				yes		Liltved et al. 2006

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
JC polyomavirus											
Mad-4 method: cell culture	SVG-A cells	LP	*60*	*124*	*171*				no		Calgua et al. 2014
Mad-4 method: qPCR	SVG-A cells	LP	*>180*						no		Calgua et al. 2014
MS2 coliphage											
	N/A	UV-LED 255 nm	14	26	38				yes		Aoyagi et al. 2011
	E. coli Famp	LP	13	25	44	64			yes		Rodriguez et al. 2014
	E. coli Famp	MP	9	17	31	46	56		yes		Rodriguez et al. 2014
	E. coli Cr63	LP	17	34					yes		Rauth 1965
	E. coli C3000	LP	35						yes		Battigelli et al. 1993
	E. coli ATCC15597	LP?	19	40	61				no		Oppenheimer et al. 1993
	Salmonella typhimurium WG49	LP	16	35	57	83	114	152	no		Nieuwstad & Havelaar 1994
	E. coli ATCC15597	LP	13	29	45	62	80		yes		Meng & Gerba 1996
	E. coli C3000	LP	13	28					yes		Shin et al. 2001
	E. coli K-12 Hfr	LP	21	36					yes		Sommer et al. 1998
	E. coli K-12	LP	19	36	55				yes		Sommer et al. 2001
	E. coli C3000	LP	20	42	68	90			yes		Linden et al. 2002
	E. coli ATCC 15977	LP	20	50	85	120			yes		Thurston-Enriquez et al. 2003
	E. coli ATCC 15977	LP	20	42	70	98	133		no		Lazarova & Savoye 2004
	E. coli C3000	LP	20	42	69	92			yes		Batch et al. 2004
	E. coli ATCC 15977	LP	29	58	87	116			yes		Nwachuku et al. 2005
	E. coli ATCC 15977	LP	14	33	50	66			yes		Hu et al. 2012
	E. coli K12 A/λ(F+)	LP	22	48					yes		Rattanakul et al. 2014

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	Host	Lamp Type	1	2	3	4	5	6	Proto-col?	Notes	Reference
MS2 coliphage (cont.)											
	E. coli Famp ATCC 700891	LP	14	30	45	60			yes		Sholtes et al. 2016
	E. coli Famp ATCC 700891	UV-LED 260 nm	13	36	40	53			yes		Sholtes et al. 2016
method: cell culture	*Salmonella typhimurium* WG49	LP	20	40	61	91	119	146	no		Calgua et al. 2014
method: qPCR	*Salmonella typhimurium* WG49	LP	*<180*						no		Calgua et al. 2014
ATCC15977-B1	*E. coli* ATCC 15977	LP	17	38	59	81	103	123	yes		Wilson et al. 1992
ATCC15977-B1	*E. coli* HS(pFamp)R	LP	16	45	72	100	128	154	yes		Thompson et al. 2003
ATCC15977-B1	*E. coli* ATCC 15977	LP	15	32	51	72	98		yes		Lazarova & Savoye 2004
ATCC15977-B1	*E. coli* ATCC 15977	LP	25	42	66	97			yes		Butkus et al. 2004
ATCC15977-B1	*E. coli* ATCC 15977	LP	20	40	62	92	141	173	yes		Ko et al. 2005
ATCC15977-B1	*E. coli* ATCC 15977	LP	20	40	62	92	141	173	yes		Ko et al. 2005
ATCC15977-B1	*E. coli* ATCC 15977	LP	18	38	59	80			yes		Sun & Liu 2009
ATCC15977-B1	*E. coli* NCTC12486	LP	20	40	60				yes	Action spect-rum	Mamane-Gravetz et al. 2005
ATCC15977-B1	*E. coli* Hfr K12 ATCC 23631	LP	20	40	68	95	125		yes		Simonet & Gantzer 2006
ATCC15977-B1	*E. coli* ATCC 15597	LP	18	40					yes		Templeton et al. 2006
ATCC15977-B1	*E. coli* ATCC 15597 C3000	LP	14	29	45				yes		Bohrerova et al. 2006
ATCC15977-B1	*E. coli* Famp	LP	*16*	*>30*					yes		Lee et al. 2008
ATCC15977-B1	*E. coli* ATCC 15597	LP	20	39	61	83			yes		Blatchley III et al. 2008
ATCC15977-B1	*E. coli* ATCC 15597	LP	18	41					yes		Bowker et al. 2011
ATCC15977-B1	*E. coli* ATCC 15597	UV-LED 255 nm	25	50					yes		Bowker et al. 2011

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
MS2 coliphage (cont.)											
ATCC15977-B1	*E. coli* ATCC 15597	UV-LED 275 nm	25	55					yes		Bowker et al. 2011
ATCC15977-B1	*E. coli* Famp ATCC 700891	LP	14	32	51				yes		Park et al. 2011
ATCC15977-B1	N/A	LP	13	30	53	70			yes		Timchak & Gitis 2012
ATCC15977-B1	*E. coli* ATCC 15597 Migula	LP	18	52	75	92	106	116	yes		Guo & Hu 2012
ATCC15977-B1	*E. coli* ATCC 15597	LP	20	40	70	95	120	138	no		Sherchan et al. 2014
ATCC15977-B1	*E. coli* ATCC 15597 C3000	LP	20	45					yes		Jenny et al. 2014
ATCC15977-B1	*E. coli* ATCC 15597 C3000	UV-LED 260 nm	15	32	48				yes		Jenny et al. 2014
ATCC15977-B1	*E. coli* ER2738	UV-LED 255 nm	19	42	72				no		Simons et al. 2014
ATCC15977-B1	*E. coli* Hfr K12 ATCC23631	LP	6	13	21	29	37	46	yes		Song et al. 2015
ATCC15977-B1	*E. coli* HS(pFamp)R ATCC 700891	LP	18	33	63				yes	Action spect-rum	Beck et al. 2015
ATCC15977-B1 (Action spect-rum weighted fluence)	*E. coli* HS(pFamp)R ATCC 700891	MP	15	32	52				yes	Action spect-rum	Beck et al. 2015
ATCC15977-B1	*E. coli* HS(pFamp)R ATCC 700891	LP	20	40	60				yes	Action spect-rum	Beck et al. 2016
ATCC15977-B1	*E. coli* K12 A/λ(F+)	UV-LED 285 nm	32	70	106				yes		Oguma et al. 2015
ATCC15977-B1	*E. coli* Famp ATCC 700891	LP	17	35	60	88	116		yes		Boczek et al. 2016

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
MS2 coliphage (cont.)											
F-specific	*E. coli* WG21	LP	8	17	25	33			yes		Havelaar et al. 1990
F-specific	*E. coli* WG21	MP	9	19	28	38			yes		Havelaar et al. 1990
ATCC15977-B1 F-specific	*E. coli* C3000	LP	14	29	49				yes		Shin et al. 2005
ATCC15977-B1 F-specific	*E. coli* ATCC 15597 C3000	LP	19	42	69				yes		Shin et al. 2009
ATCC15977-B1 F-specific	*E. coli* ATCC 15597 C3000	MP	16	33	53	90			yes		Shin et al. 2009
DSM5694	*E. coli* NCIB 9481	LP?	4	16	38	68	110		no		Wiedenmann et al. 1993
Myoviridae	*E. coli* C	LP	1.8	3.6	5.1	6.7	8.5		yes		Shin et al. 2005
Murine norovirus											
NCIMB10108	RAW 264.7 cells	LP	10	15	22	27	30		yes		Lee et al. 2008
CW3	RAW 264.7 macropags ATCC TIB-71	LP	10	15	22	27	30		yes		Park et al. 2011
Phage B124-54	*B. fragilis* strain GB-124	LP	14	21	28				yes		Diston et al. 2012
PHI X 174											
(phage)	*E. coli* C3000	LP?	2.1	4.2	6.4	8.5	11	13	yes		Battigelli et al. 1993
(phage)	*E. coli* ATCC 15597	LP?	*4*	*8*	*12*				no		Oppenheimer et al. 1993
(phage)	*E. coli* WG5	LP	2.2	5.3	7.3	10.5			yes		Sommer et al. 1998
(phage)	*E. coli* ATCC 13706	LP	2.0	3.5	5	7			yes		Giese & Darby 2000
(phage)	*E. coli* WG5	LP	3	5	7.5	10	13	15	yes		Sommer et al. 2001
	N/A	UV-LED 255 nm	1.6	3.3	5.1				yes		Aoyagi et al. 2011
	N/A	UV-LED 280 nm	2.3	5.1	8.6				yes		Aoyagi et al. 2011
ATCC 13706	N/A	LP	7.1	14	21	28	37	47	yes		Timchak & Gitis 2012
	E. coli CN13	LP	N/A	N/A	N/A	8.9			yes		Rodriguez et al. 2014
	E. coli CN13	MP	N/A	N/A	N/A	6.7			yes		Rodriguez et al. 2014

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Picornaviridae aphthovirus (foot and mouth disease virus)											
O189	baby hamster kidney (BHK-21) cell line	LP	25	50	75	100			no	(5)	Nuanualsuwan et al. 2008
A132	baby hamster kidney (BHK-21) cell line	LP	20	39	59	78			no	(5)	Nuanualsuwan et al. 2008
A Sakol	baby hamster kidney (BHK-21) cell line	LP	22	44	67	89			no	(5)	Nuanualsuwan et al. 2008
AS 1	baby hamster kidney (BHK-21) cell line	LP	31	63	94	125			no	(5)	Nuanualsuwan et al. 2008
Poliovirus											
Type 1 LSc2ab	MA104 cells	LP	N/A	5.6	11	17	22		yes		Chang et al. 1985
Type 1 ATCC Mahoney	N/A	LP	6	14	23	30			yes		Harris et al. 1987
Type 1 LSc2ab	BGM cell line	LP	2.8	11	20	28	37	46	yes		Wilson et al. 1992
Type 1	BGM cell line	LP	8.0	16	23	31			yes		Gerba et al. 2002
Type 1 LSc2ab	BGM cell line	LP	7	17	28	37			yes		Thompson et al. 2003
Vaccine strain method: plaque assay	N/A	LP	6.4	14	22	33			no		Lazarova & Savoye 2004
Vaccine strain method: TCID50	N/A	LP	6.4	14	21	31			no		Lazarova & Savoye 2004
Type 1	BGM cell line	LP	8.7	17	25				yes		Shin et al. 2005
Type 1	BGM cell line	LP	7	14	21	29	39	50 + tail-ing	yes		Simonet & Gantzer 2006
PRD-1 (Tectiviridae)											
phage	*Salmonella typhimurium* Lt2	LP	10	17	24	30			yes		Meng & Gerba 1996
ATCC BAA-769-B1	*Salmonella typhimurium* Lt2	LP	18	50	81	108	138		yes		Shin et al. 2005

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
PRD-1 (Tectiviridae) (cont.)											
	Salmonella typhimurium Lt2	LP	N/A	N/A	N/A	36			yes		Rodriguez et al. 2014
	Salmonella typhimurium Lt2	MP	N/A	N/A	N/A	32			yes		Rodriguez et al. 2014
Qβ											
	N/A	UV-LED 255 nm	11	23					yes		Aoyagi et al. 2011
	N/A	UV-LED 280 nm	*27*						yes		Aoyagi et al. 2011
	E. coli ATCC 15597 C3000	LP	12	25	40				yes		Jenny et al. 2014
	E. coli ATCC 15597 C3000	UV-LED 260 nm	9	19	29	41			yes		Jenny et al. 2014
ATCC 23631-B1	*E. coli* ATCC 23631	LP	8	18	28	40			yes		Blatchley III et al. 2008
ATCC 23631-B1	*E. coli* ATCC 23631	LP	*N/A*	*20*					yes	Action spect-rum	Beck et al. 2015
ATCC 23631-B1	*E. coli* ATCC 23631	laser 254 nm	11	22	34	46			yes	Action spect-rum	Beck et al. 2015
phage	*E. coli* Hfr K12 ATCC 23631	LP	12	23	36	50	66	83	yes		Simonet & Gantzer 2006
phage	*E. coli* K12 A/λ(F+)	LP	10	23	35				yes		Rattanakul et al. 2014
ATCC 23631 B1	*E. coli* K12 A/λ(F+)	UV-LED 285 nm	27	54	81				yes		Oguma et al. 2015
phage	*E. coli* K12 A/λ(F+)	LP	11	26	40	55			yes		Oguma et al. 2013
Reovirus											
3	Mouse L-60	LP?	11	22					yes		Rauth 1965
Type 1 Lang strain	N/A	LP	16	36					yes		Harris et al. 1987

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
Rotavirus											
SA-11	Monkey kidney Cell line MA 104	LP	8	15	27	38			yes		Sommer et al. 1989
	MA 104 cell line	LP	*20*	*80*	*140*	*200*			no		Caballero et al. 2004
SA-11	MA 104 cell line	LP	7	15	25				yes		Chang et al. 1985
SA-11	MA 104 cell line	LP	9	19	26	36	48		yes		Wilson et al. 1992
SA-11	MA 104 cell line	LP	7	15	23				yes		Battigelli et al. 1993
SA-11 ATCC VR-1565 method: cell culture; assay based on CPE	MA 104 cells ATCC CRL-2378.1	LP	7	15	31 + tailing				yes		Li et al. 2009
SA-11 ATCC VR-1565 method: RT-qPCR assay	MA 104 cells ATCC CRL-2378.1	LP	29	58	88	117 + tailing			yes		Li et al. 2009
Human (HRV-Wa)	N/A	LP	16	24	32	40			yes		Hu et al. 2012
SA-11	MA-104 cell line	LP	10	21	32	43	53		yes		Wilson et al. 1992
Siphoviridae	*E. coli* C	LP	1.8	3.6	5.7	7.5	9.3		yes		Shin et al. 2005
T1											
	E. coli CN13	LP	*N/A*	*N/A*	*N/A*	*13*			yes		Rodriguez et al. 2014
	E. coli CN13	MP	*N/A*	*N/A*	*N/A*	*19*			yes		Rodriguez et al. 2014
T1UV											
HER 468	*E. coli* CN13 ATCC 700609	LP	N/A	8.3					yes	Action spect-rum	Beck et al. 2015
HER 468	*E. coli* CN13 ATCC 700609	Laser 254 nm	4.3	8.5	13	17			yes	Action spect-rum	Beck et al. 2015
T4											
	E. coli	LP	1.1	2.0	3.0	4.0	6.7		yes		Bohrerova et al. 2008
	E. coli	MP	1.1	1.7	2.6	4.0	7		yes		Bohrerova et al. 2008
	E. coli	LP	3.6	8.0	13				yes		Hu et al. 2012
ATCC 11303	N/A	LP	3.7	7.4	11	17	23	29	yes		Timchak & Gitis 2012

			Fluence (UV dose) (mJ/cm^2) for a given log reduction without photoreactivation								
Virus	**Host**	**Lamp Type**	**1**	**2**	**3**	**4**	**5**	**6**	**Proto-col?**	**Notes**	**Reference**
T7											
	E. coli	LP	1.7	5.8	11	16	20		yes		Bohrerova et al. 2008
	E. coli	MP	1.3	3.7	8	13	18		yes		Bohrerova et al. 2008
coliphage	*E. coli* ATCC 11303	LP	2.7	6.0	11				yes		Bowker et al. 2011
coliphage	*E. coli* ATCC 11303	LP	2.7	6.0	11				yes		Bowker et al. 2011
coliphage	*E. coli* ATCC 11303	UV-LED 255 nm	2.9	6.9	14				yes		Bowker et al. 2011
coliphage	*E. coli* ATCC 11303	UV-LED 275 nm	2.7	6.0	12	17			yes		Bowker et al. 2011
ATCC BAA-1025-B2	*E. coli* CN13 ATCC 700609	LP	N/A	3.8					yes	Action spect-rum	Beck et al. 2015
ATCC BAA-1025-B2	*E. coli* CN13 ATCC 700609	Laser 254 m	1.6	3.6	6.6				yes	Action spect-rum	Beck et al. 2015
T7m											
ATCC 11303-B38	*E. coli* B ATCC 11303	LP	N/A	3.4					yes	Action spect-rum	Beck et al. 2015
ATCC 11303-B38	*E. coli* B ATCC 11303	Laser 254 m	1.7	3.8	6.3	11			yes	Action spect-rum	Beck et al. 2015
V_1 (Podoviridae)	*E. coli* WG5	LP	3.1	5.9	8.8				yes		Shin et al. 2005

Table 5. Fluences for multiple log reductions for various algae and other microorganisms

Microorganism	Lamp Type	Fluence (UV dose) (mJ/cm²) for a given log reduction without photoreactivation 1	2	3	4	5	Proto-col?	Notes	Reference
Ascaris suum									
(intact eggs) from worms	LP	100	328 + tailing				yes		Brownell & Nelson 2006
(decorticated eggs) from worms	LP	30					yes		Brownell & Nelson 2006
Cryptococcus carnescens yeast PYCC 5988	LP	18	32				yes		Pereira et al. 2013
Candida sp. New species similar to *C. pomicola* yeast PYCC 5991	LP	<10	25				yes		Pereira et al. 2013
Metschnikowia viticola/Candida kofuensis yeast									
PYCC 5993	LP	10	20				yes		Pereira et al. 2013
PYCC 5994	LP	8	17				yes		Pereira et al. 2013
Metschnikowia viticola/ Candida kofuensis yeast PYCC 5992	LP	10	23				yes		Pereira et al. 2013
Microcystis aeruginosa									
PCC7806	LP	*10*	*28*	*>60*			no		Sakai et al. 2011
PCC7806	MP	*15*	*130*	*>200*			no		Sakai et al. 2011
Rhodosporidium babjevae yeast PYCC 5996	LP	40	90				yes		Pereira et al. 2013
Rhodotorula minuta (Saito) yeast PYCC 5990	LP	43	90				yes		Pereira et al. 2013
Rhodotorula mucilaginosa yeast									
PYCC 5989	LP	44	81				yes		Pereira et al. 2013
PYCC 5995	LP	57	113				yes		Pereira et al. 2013
Saccharomyces cerevisiae XS800	LP	42	70	100			no		Kim et al. 2004
Tetraselmis suecica algae K0297	LP	370	540	720			no		Olsen et al. 2015

Table Notes

1. Spiked into wastewater.
2. These data are medians derived from a Bayesian analysis of many studies.
3. DNA weighted fluence.
4. Action spectrum weighted fluence.
5. The water depth was only 2 mm, so the water factor would have been very close to 1.0. Thus although the Protocol corrections were not made, the corrections would have been small.

References

Abshire, R.L.; and Dunton, H. 1981. Resistance of selected strains of *Pseudomonas aeruginosa* to low-intensity ultraviolet radiation, Appl. Environ. Microbiol., 41(6): 1419–1423.

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, J. Water Supply: Res. Technol. – Aqua, 54(3): 165-178.

Antopol, S.C.; and Ellner, P.D. 1979. Susceptibility of *Legionella pneumophila* to ultraviolet radiation, Appl. Environ. Microbiol., 38(2): 347–348.

Aoyagi, Y.; Takeuchi, M.; Yoshida, K.; Kurouchi, M.; Yasui, N.; Kamiko, N.; Araki, T.; and Nanishi, Y. 2011. Inactivation of bacterial viruses in water using deep ultraviolet semiconductor light-emitting diode. J. Environ. Eng., 137(12): 1215–1218.

Ballester, N.A.; and Malley, J.P., Jr. 2004. Sequential disinfection of adenovirus type 2 with UV-chlorine-chloramine, J. AWWA, 96(10): 97–103.

Banerjee, S.K.; and Chatterjee, S.N. 1977. Sensitivity of the vibrios to ultraviolet-radiation, Int. J. Rad. Biol., 32(2): 127–133.

Batch, L.F.; Schulz, C.R.; and Linden, K.G. 2004. Evaluating water quality effects on UV disinfection of MS2 coliphage, J. AWWA, 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, Water Sci. Technol., 27(3-4): 339–342.

Baxter, C.S.; Hofmann, R.; Templeton, M.R.; Brown, M; and Andrews, R.C. 2007. Inactivation of adenovirus types 2, 5 and 41 in drinking water by UV light, free chlorine, and monochloramine, J. Environ. Eng., 133(1): 95–103.

Beck, S.E.; Rodriguez, R.A.; Linden, K.G.; Hargy, T.M.; Larason, T.C.; and Wright, H.B. 2014. Wavelength dependent UV inactivation and DNA damage of adenovirus as measured by cell culture infectivity and long range quantitative PCR, Environ. Sci. Technol., 48: 591–598.

Beck, S.E.; Wright, H.R.; Hargy, T.M.; Larason, T.C.; and Linden, K.G. 2015. Action spectra for validation of pathogen disinfection in medium-pressure ultraviolet (UV) systems, Water Res., 70: 27–37.

Beck, S.E.; Rodriguez, R.A.; Hawkins, M.A.; Hargy, T.M.; Larason, T.C.; and Linden, K.G. 2016. Comparison of UV-induced inactivation and RNA damage in MS2 phage across the germicidal spectrum, Appl. Environ. Microbiol., 82(5): 1468–1474.

Belosevic, M.; Craik, S.A.; Stafford, J.L.; Neumann, N.F.; Kruithof, J.; and Smith, D.W. 2001. Studies on the resistance/reactivation of *Giardia muris* cysts and *Cryptosporidium parvum* oocysts exposed to medium-pressure ultraviolet radiation, FEMS Microbiol. Lett., 204(1): 197–203.

Bichai, F.; Barbeau, B.; and Payment, P. 2009. Protection against UV disinfection of *E. coli* bacteria and *B. subtilis* spores ingested by *C. elegans* nematodes, Water Res., 43(14): 3397–3406.

Blatchley, E.R. III; Meeusen, A.; Aronson, A.I.; and Brewster, L. 2005. Inactivation of *Bacillus* spores by ultraviolet or gamma radiation, J. Environ. Eng., 131(9): 1245–1252.

Blatchley, E.R. III; Shen, C.; Scheible, O.K.; Robinson, J.P.; Ragheb, K.; Bergstrom, D.E.; Rokjer, D. 2008. Validation of large-scale, monochromatic UV disinfection systems for drinking water using dyed microspheres, Water Res., 42(3): 677–688.

Blatchley E.R. III; Oguma, K.; and Sommer, R. 2016. Comment on the 'UV disinfection induces a VBNC state in *Escherichia coli* and *Pseudomonas aeruginosa*,' *IUVA News*, 18(3): 12–16.

Boczek, L.A.; Rhodes, E.R.; Cashdollar, J.L.; Ryu, J.; Popovici, J.; Hoelle, J.M.; Sivaganesan, M.; Hayes, S.L.; Rodgers, M.R.; and Ryu, H. 2016. Applicability of UV resistant *Bacillus pumilus* endospores as a human adenovirus surrogate for evaluating the effectiveness of virus inactivation in low-pressure UV treatment systems, J. Microbiol. Meth., 122: 43–49.

Bohrerova, Z.; and Linden, K.G. 2006a. Ultraviolet and chlorine disinfection of *Mycobacterium* in wastewater: effect of aggregation, Water Environ. Res., 78(6): 565–571.

Bohrerova, Z.; and Linden, K.G. 2006b. Assessment of DNA damage and repair in *Mycobacterium terrae* after exposure to UV irradiation, J. Appl. Microbiol, 101: 995–1001.

Bohrerova, Z.; Mamane, H.; Ducoste, J.; and Linden, K.G. 2006. Comparative inactivation of *Bacillus subtilis* spores and MS-2 coliphage in a UV reactor: implications for validation, J. Environ. Eng., 132(12): 1554–1561.

Bohrerova, Z.; Shemer, H.; Lantis, R.; Impellitteri, C.A.; and Linden, K.G. 2008. Comparative disinfection efficiency of pulsed and continuous-wave UV irradiation technologies, Water Res., 42(12): 2975–2982.

Bolton, J.R.; and Linden, K.G. 2003. Standardization of methods for fluence (UV dose) determination in bench-scale UV experiments, J. Environ. Eng., 129(3): 209–215.

Bolton, J.R.; Dussert, B.; Bukhari, Z.; Hargy, T.; and Clancy, J.L. 1998. Inactivation of *Cryptosporidium parvum* by medium pressure ultraviolet light in finished drinking water, in Proceedings of the AWWA Annual Conference, June, 1998, Dallas, TX, Vol. A, pp 389-403; American Water Works Association, Denver, CO.

Bolton, J.R.; Beck, S.E.; and Linden, K.G. 2015a. Protocol for the determination of fluence (UV dose) using a low-pressure or low-pressure high-output UV lamp in bench-scale collimated beam ultraviolet experiments, IUVA News, 17(1): 11–16.

Bolton, J.R.; Mayor-Smith, I.; and Linden, K.G. 2015b. Rethinking the concepts of fluence (UV dose) and fluence rate: The Importance of photon-based units – A systemic review, Photochem. Photobiol., 91: 1252–1262.

Bounty, S.; Rodriguez, R.A.; and Linden, K.G. 2012. Inactivation of adenovirus using low-dose UV/H_2O_2 advanced oxidation, Water Res., 46(19): 6273–6278.

Bowker, C.; Sain, A.; Shatalov, M.; and Ducoste, J. 2011. Microbial UV fluence-response assessment using a novel UV-LED collimated beam system, Water Res., 45(5): 2011–2019.

Brownell, S.A.; and Nelson, K.L. 2006. Inactivation of single-celled *Ascaris suum* eggs by low-pressure UV radiation, Appl. Environ. Microbiol., 72(3): 2178–2184.

Bukhari, Z.; Hargy, T.M.; Bolton, J.R.; Dussert, B.; and Clancy, J.L. 1999. Medium-pressure UV for oocyst inactivation, J. AWWA, 91(3): 86–94.

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

Butkus, M.A.; Labare, M.P.; Starke, J.A.; Moon, K; and Talbot, M. 2004. Use of aqueous silver to enhance inactivation of coliphage MS-2 by UV disinfection, Appl. Environ. Microbiol., 70(5): 2848–2853.

Butler, R.C.; Lund, V.; and Carlson, D.A. 1987. Susceptibility of *Campylobacter jejuni* and *Yersinia enterocolitica* to UV radiation, Appl. Environ. Microbiol., 53(2): 375–378.

Cabaj, A.; Sommer, R.; Pribil, W.; and Haider, T. 2002. The spectral UV sensitivity of microorganisms used in biodosimetry, Water Sci. Technol. – Water Supply, 2(3): 175–181.

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

Calgua, B.; Carratalà, A.; Guerrero-Latorre, L.; de Abreu Corrêa, A.; Kohn, T.; Sommer, R.; and Girones, R. 2014. UVC inactivation of dsDNA and ssRNA viruses in water: UV fluences and a qPCR-based approach to evaluate decay on viral infectivity, Food Environ. Virol., 6: 260–268.

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

Cervero-Aragó, S.; Sommer, R.; and Araujo, R.M. 2014. Effect of UV irradiation (253.7 nm) on free *Legionella* and *Legionella* associated with its amoebae hosts, Water Res., 67: 299–309.

Chang, J.C.H.; Ossoff, 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.

Chatterley, C.; and Linden, K. 2010. Demonstration and evaluation of germicidal UV-LEDs for point-of-use water disinfection, J. Water Health, 8(3): 479–486.

Chen, P.-Y.; Chu, X.-N.; Liu, L.; and Hu, J.-Y. 2015. Effects of salinity and temperature on inactivation and repair potential of *Enterococcus faecalis* following medium- and low-pressure ultraviolet irradiation, J. Appl. Microbiol., 120: 816–825.

Chen, R.-Z.; Craik, S.A.; and Bolton, J.R. 2009. Comparison of the action spectra and relative DNA absorbance spectra of microorganisms: information important for the determination of germicidal fluence (UV dose) in an ultraviolet disinfection of water, Water Res., 43: 5087–5096.

Chevrefils, G.; Caron, É.; Wright, H.; Sakamoto, G.; Payment, P.; Barbeau, B.; and Cairns, B. 2006. IUVA News, 8(1): 38–45.

Clancy, J.L.; Bukhari, Z.; Hargy, T.M.; Bolton, J.R.; Dussert, B.W.; and Marshall, M.M. 2000. Using UV to inactive *Cryptosporidium*, J. AWWA, 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. AWWA, 96(3): 84–93.

Clauß, M. 2006. Higher effectiveness of photoinactivation of bacterial spores, UV resistant vegetative bacteria and mold spores with 222 nm compared to 254 nm wavelength, Acta Hydrochim. Hydrobiol, 34(6): 525–532.

Clauß, M.; Mannesmann, R.; and Kolch, A. 2005. Photoreactivation of *Escherichia coli* and *Yersinia enterolytica* after irradiation with a 222 nm excimer lamp compared to a 254 nm low-pressure mercury lamp, Acta Hydrochim. Hydrobiol., 33(6): 579–584.

Collins, F.M. 1971. Relative susceptibility of acid-fast and non-acid-fast bacteria to ultraviolet light, Appl. Microbiol, 21(3): 411–413.

Coohill, T.P.; and Sagripanti, J.-L. 2008. Overview of the inactivation by 254 nm ultraviolet radiation of bacteria with particular relevance to biodefense, Photochem. Photobiol., 84(5): 1084–1090.

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 drinking water, Water 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, Water Res., 35(6): 1387–1398.

de Roda Husman, A.M.; 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.

Diston, D.; Ebdon, J.E.; and Taylor, H.D. 2012. The effect of UV-C radiation (254 nm) on candidate microbial source tracking phages infecting a human-specific strain of *Bacteroides fragilis* (GB-24), J. Water Health, 10(2): 262–270.

Donnellan, Jr., J.E.; and Stafford, R.S. 1968. The ultraviolet photochemistry and photobiology of vegetative cells and spores of *Bacillus megaterium*, Biophys. J., 8:17–28.

Dumètre, A.; Le Bras, C.; Baffet, M.; Meneceur, P.; Dubey, J.P.; Derouin, F.; Duguet, J.-P.; Joyeux, M.; and Moulin, L. 2008. Effects of ozone and ultraviolet radiation treatments on the infectivity of *Toxoplasma gondii* oocysts, Vetin. Parasitol., 153: 209–213.

Eischeid, A.C.; and Linden, K.G. 2007. Efficiency of pyrimidine dimer formation in *Escherichia coli* across UV wavelengths, J. Appl. Microbiol., 103: 1650–1656.

Eischeid, A.C.; Meyer, J.N.; and Linden, K.G. 2009. UV disinfection of adenoviruses: molecular indications of DNA damage efficiency, Appl. Environ. Microbiol., 75(1): 23–28.

Gates, F.L. 1929. A study of the bacterial action of ultraviolet light I. The reaction to monochromatic radiations, J. Gen. Physiol., 13: 231–248.

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.

Gerrity, D.; Ryu, H.; Crittenden, J.; and Abbaszadegan, M. 2008. UV inactivation of adenovirus type 4 measured by integrated cell culture qPCR, J. Environ. Sci. Health, Part A, 43(14): 1628–1638.

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

Guo, H.; and Hu, J. 2012. Effect of hybrid coagulation–membrane filtration on downstream UV disinfection, Desalin., 290: 115–124.

Guo, H.; Chu, X.; and Hu, J. 2010. Effect of host cells on low- and medium-pressure UV inactivation of adenoviruses, Appl. Environ. Microbiol., 76(21): 7068–7075.

Guo, M.; Hu, H.; Bolton, J.R.; and Gamal El-Din, M. 2009. Comparison of low- and medium-pressure ultraviolet lamps: Photoreactivation of *Escherichia coli* and total coliforms in secondary effluents of municipal wastewater treatment plants, Water Res., 43(3): 815–821.

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, Water Res., 21(6): 687–692.

Havelaar, A.H.; Meulemans, C.C.E.; Pot-Hogeboom, W.M.; and Koster, J. 1990. Inactivation of bacteriophage MS2 in wastewater effluent with monochromatic and polychromatic ultraviolet light, Water Res., 24(11): 1387–1393.

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.

Hayes, S.L.; White, K.M.; and Rodgers, M.R. 2006. Assessment of the effectiveness of low-pressure UV light for inactivation of *Helicobacter pylori*, Appl. Environ. Microbiol., 72(5): 3763–3765.

Hayes, S.L.; Sivaganesan, M.; White, K.M.; and Pfaller, S.L. 2008. Assessing the effectiveness of low-pressure ultraviolet light for inactivating *Mycobacterium avium* complex (MAC) micro-organisms, Lett. Appl. Microbiol., 47(5): 386–392.

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, Water Res., 40(1): 3–22.

Hoyer, O. 1998. Testing performance and monitoring of UV systems for drinking water disinfection, Water Supply, 16(1/2): 419–424.

Hu, X.; Geng, S.; Wang, X.; and Hu, C. 2012. Inactivation and photorepair of enteric pathogenic microorganisms with ultraviolet irradiation, Environ. Eng. Sci., 29(6): 549–553.

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

Jenny, R.M.; Simmons III, O.D.; Shatalov, M.; and Ducoste, J.J. 2014. Modeling a continuous flow ultraviolet Light Emitting Diode reactor using computational fluid dynamics, Chem. Eng. Sci., 116: 524–535.

Jin, S.; Mofidi, A.A.; and Linden, K.G. 2006. Polychromatic UV fluence measurement using chemical actinometry, biodosimetry, and mathematical techniques, J. Environ. Eng., 132(8): 831–841.

John, D.E.; Nwachuku, N.; Pepper, I.L.; and Gerba, C.P. 2003. Development and optimization of a quantitative cell culture infectivity assay for the microsporidium *Encephalitozoon intestinalis* and application to ultraviolet light inactivation, J. Microbiol. Meth., 52: 183–196.

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.

Karanis, P.: Maier, W.A.; Seitz, H.M.; and Schoenen, D. 1992. UV sensitivity of protozoan parasites, J. Water SRT – Aqua, 41(2): 95–100.

Kim, J.K.; Petin, V.G.; and Tkhabisimova, M.D. 2004. Survival and recovery of yeast cells after simultaneous treatment of UV light radiation and heat, Photochem. Photobiol., 79(4): 349–355.

Ko, G.; Cromeans, T.L.; and Sobsey, M.D. 2005. UV inactivation of adenovirus type 41 measured by cell culture mRNA RT-PCR, Water Res., 39(15): 3643–3649.

Lazarova, V.; and Savoye, Ph. 2004. Technical and sanitary aspect of wastewater disinfection by UV irradiation for landscape irrigation, Water Sci. Technol., 50(2): 203–209.

Lee, J.; Zoh, K.; and Ko, G. 2008. Inactivation and UV disinfection of murine norovirus with TiO_2 under various environmental conditions, Appl. Environ. Microbiol., 74(7): 2111–2117.

Li, D.; Gu, A.Z.; He, M.; Shi, H.-C.; and Yang, W. 2009. UV inactivation and resistance of rotavirus evaluated by integrated cell culture and real-time RT-PCR assay, Water Res., 43(13): 3261–3269.

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

Liltved, H.; Vogelsang, C.; Modahl, I.; and Dannevig, B.H. 2006. High resistance of fish pathogenic viruses to UV irradiation and ozonated seawater, Aquacult. Eng., 34(2): 72–82.

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

Linden, K.G.; Thurston, J.; Schaefer, R.; and Malley, Jr., J.P. 2007. Enhanced UV inactivation of adenoviruses under polychromatic UV lamps, Appl. Environ. Microbiol., 73(23): 7571–7574.

Linden, K.G.; Lee, J.-K.; Scheible, K.; Shen, C.; and Posy, P. 2009. Demonstrating 4-log adenovirus inactivation in a medium-pressure UV disinfection reactor, J. AWWA, 101(4): 90–99.

Mamane, H.; Bohrerova, Z.; and Linden, K.G. 2009. Evaluation of *Bacillus* spore survival and surface morphology following chlorine and ultraviolet disinfection in water, J. Environ. Eng., 135(8): 692–699.

Mamane-Gravetz, H.; and Linden, K.G. 2004. UV disinfection of indigenous aerobic spores: implications for UV reactor validation in unfiltered waters, Water Res., 38: 2898–2906.

Mamane-Gravetz, H.; Linden, K.G.; Cabaj, A.; and Sommer, R. 2005. Spectral sensitivity of *Bacillus subtilis* spores and MS2 Coliphage for validation testing of ultraviolet reactors for water disinfection, Environ. Sci. Technol., 39(20): 7845–7852.

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.

Matafonova, G.G.; Batoev, V.B.; and Linden, K.G. 2012. Impact of scattering of UV radiation from an exciplex lamp on the efficacy of photocatalytic inactivation of *Escherichia coli* cells in water, J. Appl. Spect., 79(2): 296–301.

Maya, C.; Beltrán, N.; Jiménez, B.; and Bonilla, P. 2003. Evaluation of the UV disinfection process in bacteria and amphizoic amoeba inactivation. Water Sci. Technol.: Water Supply, 3(4): 285–291.

McKinney, C.W.; and Pruden, A. 2012. Ultraviolet disinfection of antibiotic resistant bacteria and their antibiotic resistance genes in water and wastewater, Environ. Sci. Technol., 46: 13393–13400.

Meng, Q.S.; and Gerba, C.P. 1996. Comparative inactivation of enteric adenoviruses, poliovirus and coliphages by ultraviolet irradiation, Water 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 (P-2951-01), Water Res., 36(8): 2098–2108.

Moreno-Andrés, J.; Romero-Martínez, L.; Acevedo-Merino, A.; and Nebot, E. 2016. Determining disinfection efficiency on *E. faecalis* in saltwater by photolysis of H_2O_2: Implications for ballast water treatment. Chem Eng. J., 283: 1339–1348.

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

Nicholson, W.L.; and Galeano, B. 2003. UV resistance of *Bacillus anthracis* spores revisited: validation of *Bacillus subtilis* spores as UV surrogates for spores of *B. anthracis Sterne*, Appl. Environ. Microbiol., 69(2): 1327–1330.

Nieuwstad, Th.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 Part A, 29(9): 1993–2007.

Nuanualsuwan, S.; Thongtha, P.; Kamolsiripichaiporn, S.; and Subharat, S. 2008. UV inactivation and model of UV inactivation of foot-and-mouth disease viruses in suspension, Int. J. Food Microbiol., 127(1–2): 84–90.

Nwachuku, N.; Gerba, C.P.; Oswald, A.; and Mashadi, F.D. 2005. Comparative inactivation of adenovirus serotypes by UV light disinfection, Appl. Environ. Microbiol., 71(9): 5633–5636.

Oguma, K.; Katayama, H.; Mitani, H.; Morita, S.; Hirata, T.; and Ohgaki, S. 2001. Determination of pyridine dimers in *Escherichia coli* and *Cryptosporidium* parvum during UV light inactivation, photoreactivation, and dark repair, Appl. Environ. Microbiol., 67(10): 4630–4637.

Oguma, K.; Katayama, H.; and Ohgaki, S. 2002. Photoreactivation of *Escherichia 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, Water Res., 38(11): 2757–2763.

Oguma, K.; Kita, R.; Sakai, H.; Murakami, M.; and Takizawa, S. 2013. Application of UV light emitting diodes to batch and flow-through water disinfection systems, Desalin., 328: 24–30.

Oguma, K.; Rattanakul, S.; and Bolton, J.R. 2015. Application of UV Light–Emitting Diodes to adenovirus in water, J. Environ. Eng., 142(3): 1–6.

Olsen, R.O.; Hess-Erga, O.-K.; Larsen, A.; Thuestad, G.; Tobiesen, A.; and Hoell, I.A. 2015. Flow cytometric applicability to evaluate UV inactivation of phytoplankton in marine water samples, Marine Pollut. Bull., 96: 279–285.

Oppenheimer, J.A.; Hoagland, J.E.; Laine, J.-M.; Jacangelo, J.G.; and Bhamrah, A. 1993. Microbial inactivation and characterization of toxicity and by-products occurring in reclaimed wastewater disinfected with UV radiation, in Water Environment Federation Plan, Description and Operations of Effluent Disinfection Systems, Water Environment Federation, 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, Water Sci. Technol., 47(3): 185–190.

Park, G.W.; Linden, K.G. and Sobsey, M.D. 2011. Inactivation of murine norovirus, feline calcivirus 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, Lett. Appl. Microbiol., 52: 162–167.

Pennell, K.G.; Naunovic, Z.; and Blatchley, III, E.R. 2008. Sequential inactivation of *Bacillus subtilis* spores with ultraviolet radiation and iodine, J. Environ. Eng., 134(7): 513–520.

Pereira, V.J.; Ricardo, J.; Galinha, R.; Benoliel, M.J.; and Barreto Crespo, M.T. 2013. Occurrence and low pressure ultraviolet inactivation of yeasts in real water sources, Photochem. Photobiol. Sci., 12: 626–630.

Qian, S.S.; Donnelly, M.; Schmelling, D.C.; Messner, M.; Linden, K.G.; and Cotton, C. 2004. Ultraviolet light inactivation of protozoa in drinking water: a Bayesian meta-analysis, Water Res., 38(2): 317–326.

Qian, S.S.; Linden, K.; and Donnelly, M. 2005. A Bayesian analysis of mouse infectivity data to evaluate the effectiveness of using ultraviolet light as a drinking water disinfectant, Water Res., 39(17): 4229–4239.

Qiu, X.; Sundin, G.W.; Chai, B.; and Tiedje, J.M. 2004. Survival of *Shewanella oneidensis* MR-1 after UV radiation exposure, Appl. Environ. Microbiol., 70(11): 6435–6443.

Quails, R.G.; and Johnson J.D. 1983. Bioassay and dose measurement in UV disinfection, Appl. Environ. Microbiol., 45(3): 872–877.

Quek, P.H.; and Hu, J. 2008. Indicators for photoreactivation and dark repair studies following ultraviolet disinfection, J. Ind. Microbiol. Biotechnol., 35: 533–541.

Rattanakul, S.; Oguma, K.; Sakai, H.; and Takizawa, S. 2014. Inactivation of viruses by combination processes of UV and chlorine, J. Water Environ. Technol., 12(6): 511–523.

Rattanakul, S.; Oguma, K.; and Takizawa, S. 2015. Sequential and simultaneous applications of UV and chlorine for Adenovirus inactivation, Food Environ. Virol., 7: 295–304.

Rauth, A.M. 1965. The physical state of viral nucleic acid and the sensitivity of viruses to ultraviolet light, Biophys. J., 5(3): 257–273.

Rodríguez, R.A.; Bounty, S.; and Linden, K.G. 2013. Long-range quantitative PCR for determining inactivation of adenovirus 2 by ultraviolet light, J. Appl. Microbiol., 114: 1854–1865.

Rodríguez, R.A.; Bounty, S.: Beck, S.; Chan, C.; McGuire, C.; and Linden, K.G. 2014. Photoreactivation of bacteriophages after UV disinfection: Role of genome structure and impacts of UV source, Water Res., 55: 143–149.

Rose, L.J.; and O'Connell, H. 2009. UV light inactivation of bacterial biothreat agents, Appl. Environ. Microbiol., 75,(9): 2987–2990.

Ryu, H.; Gerrity, D.; Crittenden, J.C.; and Abbaszadegan, M. 2008. Photocatalytic inactivation of *Cryptosporidium parvum* with TiO_2 and low-pressure ultraviolet irradiation, Water Res., 42(6-7): 1523–1530.

Ryu, H.; Cashdollar, J.L.; Fout, G.S.; Schrantz, K.A.; and Hayes, S. 2015. Applicability of integrated cell culture quantitative PCR (ICC-qPCR) for the detection of infectious adenovirus type 2 in UV disinfection studies, J. Environ. Sci. Health, Part A, 50(8): 777–787.

Sakai, H.; Katayama, H.; Oguma, K.; and Ohgaki, S. 2011. Effect of photoreactivation on ultraviolet inactivation of *Microcystis aeruginosa*, Water Sci. Technol., 63(6): 1224–1229.

Sarkar, P.; and Gerba, C.P. 2012. Inactivation of *Naegleria fowleri* by chlorine and ultraviolet light, J. AWWA, 104(3): E173–E180.

Sharp, D.G. 1939. The lethal action of short ultraviolet rays on several common pathogenic bacteria, J. Bacteriol., 37: 447–460.

Sherchan, S.P.; Snyder, S.A.; Gerba, C.P.; and Pepper, I.L. 2014. Inactivation of MS2 coliphage by UV and hydrogen peroxide: Comparison by cultural and molecular methodologies, J. Environ. Sci. Health, Part A, 49(4): 397–403.

Shin, G.-A.; Linden, K.G.; Arrowood, M.J.; and Sobsey, M.D. 2001. Low-Pressure UV inactivation and DNA repair potential of *Cryptosporidium 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. Eng. Sci., 4(Suppl. 1): S7–S11.

Shin, G.-A.; Lee, J.-K.; Freeman, R.; and Cangelosi, G.A. 2008. Inactivation of *Mycobacterium avium* complex by UV irradiation, Appl. Environ. Microbiol., 74(22): 7067–7069.

Shin, G.-A.; Lee, J.-K.; and Linden, K.G. 2009. Enhanced effectiveness of medium-pressure ultraviolet lamps on human adenovirus and its possible mechanism, Water Sci. Technol., 60(4): 851–857.

Sholtes, K.A.; Lowe, K.; Walters, G.W.; Sobsey, M.D.; Linden, K.G.; and Casanova, L.M. 2016. Comparison of ultraviolet light-emitting diodes and low-pressure mercury-arc lamps for disinfection of water, Environ. Technol., Online: DOI: 10.1080/09593330.2016.1144798

Simonet, J.; and Gantzer, C. 2006. Inactivation of poliovirus 1 and F-specific RNA phages and degradation of their genomes by UV irradiation at 254 nanometers, Appl. Environ. Microbiol., 72(12): 7671–7677.

Simons, R.; Gabbai, U.E.; and Moram, M.A. 2014. Optical fluence modelling for ultraviolet light emitting diode-based water treatment systems, Water Res., 66: 338–349.

Singh, P.K. 1975. Photoreactivation of UV-irradiated blue-green algae and algal virus LPP-1, Arch. Microbiol., 103: 297–302.

Sirikanchana, K.; Shisler, J.L.; and Mariñas, B.J. 2008. Effect of exposure to UV-C irradiation and monochloramine on adenovirus serotype 2 early protein expression and DNA replication, Appl. Environ. Microbiol., 74(12): 3774–3782.

Sommer, R.; Weber, G.; Cabaj, A.; Wekerle, J.; Keck, G.; and Schauberger, G. 1989. [UV-inactivation of microorganisms in water] (article in German), Zentralblatt für Hygiene und Umweltmedizin = Int. J. Hygiene Environ. Med., 189(3): 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. B: Biol., 53(1-3), 1–6.

Sommer, R.; Lhotsky, M.; Haider, T.; and Cabaj, A. 2000. UV inactivation, liquid-holding recovery, and photoreactivation of *Escherichia coli* O157 and other pathogenic *Escherichia coli* strains in water, J. Food Protect., 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, Water Res., 35(13): 3109–3116.

Song, A.; Liu, X.; Zhang, Y.; Liu, Y. 2015. Effect of sodium alginate on UVC inactivation of coliphage MS2, RSC Adv., 5(127): 104779-104784.

Stamm, L.V.; and Charon, N.W. 1988. Sensitivity of pathogenic and free-living *Leptospira spp.* to UV radiation and mitomycin C, Appl. Environ. Microbiol., 54(3): 728–733.

Sun, W.; and Liu, W. 2009. A pilot-scale study on ultraviolet disinfection system for drinking water, J. Water Supply: Res. Technol. – Aqua, 58(5): 346–353.

Taylor-Edmonds, L.; Lichi, T.; Rotstein-Mayer, A.; and Mamane, H. 2015. The impact of dose, irradiance and growth conditions on *Aspergillus niger* (renamed *A. brasiliensis*) spores low-pressure (LP) UV inactivation, J. Environ. Sci. Health, Part A, 50: 341–347.

Templeton, M.R.; Hofmann, R.; Andrews, R.C.; and Whitby, G.E. 2006. Biodosimetry testing of a simplified computational model for the UV disinfection of wastewater, J. Environ. Eng. Sci., 5(1): 29–36.

Templeton, M.; Oddy, F.; Leung, W.-K.; and Rogers, M. 2009. Chlorine and UV disinfection of ampicillin-resistant and trimethoprim-resistant *Escherichia coli*, Can. J. Civil Eng., 36(5): 889–894.

Thompson, S.S.; Jackson, J.L.; Suva-Castillo, M.; Yanko, W.A.; El Jack, Z.; 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, Water Environ. Res., 75(2): 163–170.

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

Timchak, E.; and Gitis, V. 2012. A combined degradation of dyes and inactivation of viruses by UV and UV/H_2O_2, Chem. Eng. J., 192: 164–170.

Tosa, K.; and Hirata, T. 1999. Photoreactivation of enterhemorrhagic *Escherichia coli* following UV disinfection, Water Res., 33(2): 361–366.

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(1): 155–162.

Wang, D.; Oppenländer, T.; Gamal El-Din, M.; and Bolton, J.R. 2010. Comparison of the disinfection effects of vacuum-UV (VUV) and UV light on *Bacillus subtilis* spores in aqueous suspensions at 172, 222, 254 nm, Photochem. Photobiol., 86(1): 176–181.

Ware, M.W.; Augustine, S.A.J.; Erisman, D.O.; See, M.J.; Wymer, L.; Hayes, S.L.; Dubey, J.P.; and Villegas, E.N. 2010. Determining UV inactivation of *Toxoplasma gondii* oocysts by using cell culture and a mouse bioassay, Appl. Environ. Microbiol., 76(15): 5140–5147.

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, Water Sci. Technol., 27(3-4): 335–338.

Wilson, B.R.; Roessler, P.F.; Van Dellen, E.; Abbaszadegan, M.; and Gerba, C.P. 1992. Coliphage MS2 as a UV water disinfection efficacy test surrogate for bacterial and viral pathogens, Proceedings of the American Water Works Association Water Quality Technology Conference, Nov 15–19, Toronto, Canada, 1992.

Wright. H.; and Sakamoto, G. 1999. UV dose required to achieve incremental log inactivation of bacteria, virus, and protozoa, Trojan Technologies, London, ON, Canada.

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.

Würtele, M.A.; Kolbe, T.; Lipsz, M.; Külberg, A.; Weyers, M.; Kneissl, M.; Jekel, M. 2010. Application of GaN-based ultraviolet-C light emitting diodes – UV LEDs – for water disinfection. Water Res., 45: 1481–1489.

Yaun, B.R.; Sumner, S.S.; Eifert, J.D.; and Marcy, J.E. 2003. Response of *Salmonella* and *Escherichia coli* O157:H7 to UV Energy, J. Food Protect., 66(6): 1071–1073.

Zhang, Y.; Zhang, Y.; Zhou, L.; and Tan, C. 2014. Factors affecting UV/H_2O_2 inactivation of *Bacillus atrophaeus* spores in drinking water, J. Photochem. Photobiol. B: Biol., 134: 9–15.

Zimmer, J.L. and Slawson, R.M. 2002. Potential repair of *Escherichia 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 *Cryptosporidium parvum* following low- and medium-pressure ultraviolet irradiation, Water Res., 37(14): 3517–3523.