Performance of the APR UV Air Disinfection System

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For

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Executive Summary

The APR UV air disinfection system has been evaluated and found to produce a UV dose in the airstream of **485 J/m^2**. This dose is sufficient to inactivate or destroy high percentages of bacteria and viruses. An average irradiance level of **998 W/m^2** is produced inside the UV chamber. The exposure time or dwell time min the UV chamber is 0.49 seconds at 700 cfm, which meets the suggested minimum dwell time per IUVA Guidelines. The estimated UVGI Rating Value (URV) is 22, which exceeds typical requirements. In combination with the MERV 6 filter, the unit is capable of removing high rates of fungal and bacterial spores also. Prediction removal rates are summarized for over 400 pathogens and a summary has been provided for Hospital-Acquired (nosocomial) pathogens. The average removal rate for nosocomial pathogens, including bacteria, viruses, and fungi is **99.1% on a single pass**, which includes the combined UV and filtration rates. The average single-pass removal rate for all bacteria is 99.6%. The average single-pass removal rate for all viruses is 96.1%. The average single-pass removal rate for all fungi and other pathogens is 93.6%. Multiple-pass removal rates will be much higher and depend on operating time and room air exchange rates.

System Description

The APR UV air disinfection system consists of a UV chamber with XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX. Six TUV PL-L ultraviolet lamps at 27 W of UV output each provide a total of 162 W of UV output. Four fans provide 175 cfm each for a total airflow of 700 cfm. The internal walls are polished anodized aluminum with a reflectivity of 86% (Liu 2009). A MERV 6 filter is present on the inlet. Also included are two interior baffles which enhance the turbulence and thereby guarantees all airborne microbes will achieve the stated UV dose. Manufacturer's data is summarized in Appendix A.

The physical parameters have been tabulated and summarized in Table 1 below. All dimensions are converted to metric for analysis. The air velocity is computed to be 453 fpm and the Exposure Time computes to be 0.49 seconds. The Exposure Time is meets the recommended minimum exposure time of 0.25 seconds per IUVA Guidelines.

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Table 1: System Parameters

There are six dual-tube type UV lamps. Each lamp is modeled as two separate cylindrical lamps of one-half the UV power. The tube coordinates are selected to match the actual physical dimensions of the dual-tube lamps. Table 2 summarizes the coordinates of the twelve lamp tubes in metric units. The

Width of the chamber is represented by direction of the x coordinates (x1 and x2). The Height of the chamber is represented by direction of the y coordinates (y1 and y2). The Length of the chamber is represented by the direction of the z coordinates (z1 and z2). The UV lamps are positioned at the base (x=0) and extend in the direction of the Width (arclength x=50.5 cm).

Table 2: UV Lamp Coordinates

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Analysis Results

System performance has been analyzed with a computer model of the specular UV irradiation chamber and the UV lamps. Appendix B shows the program input data and Appendix C shows a summary of the output data. Table 3 below summarizes the main output parameters. An Exposure Time of 0.49 seconds and a UV irradiance of 998 W/m^2 produces a UV Dose of 485 J/m^2. For the target microbe, *Serratia marcescens*, a disinfection rate (or kill rate) of 100% is achieved.

Table 3: Summary of Analysis Results

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Given the established UV dose of 485 J/m^2, we can compute the disinfection rates for all microbes with known UV rate constants, including bacteria, viruses, and fungi. Appendix D shows the disinfection rates (or kill rates) for all bacteria with known UV rate constants. It can be observed that very high kill rates, typically 90-100%, are obtained for all but the most resistant bacterial spores. The average single-pass removal rate for all bacteria is 99.6%.

Appendix E summarizes the kill rates against viruses, and it can be observed that very high kill rates are achieved. The average single-pass removal rate for all viruses is 96.1%.

Appendix F summarizes the kill rates for fungi, including fungal spores, and other microbes for which UV rate constants are known. The average single-pass removal rate for all fungi and other pathogens is 93.6%.

Figure 1 shows the irradiance field inside the chamber. The high average irradiance smooths out the intensity peaks which can barely be distinguished for each of the six UV lamps.

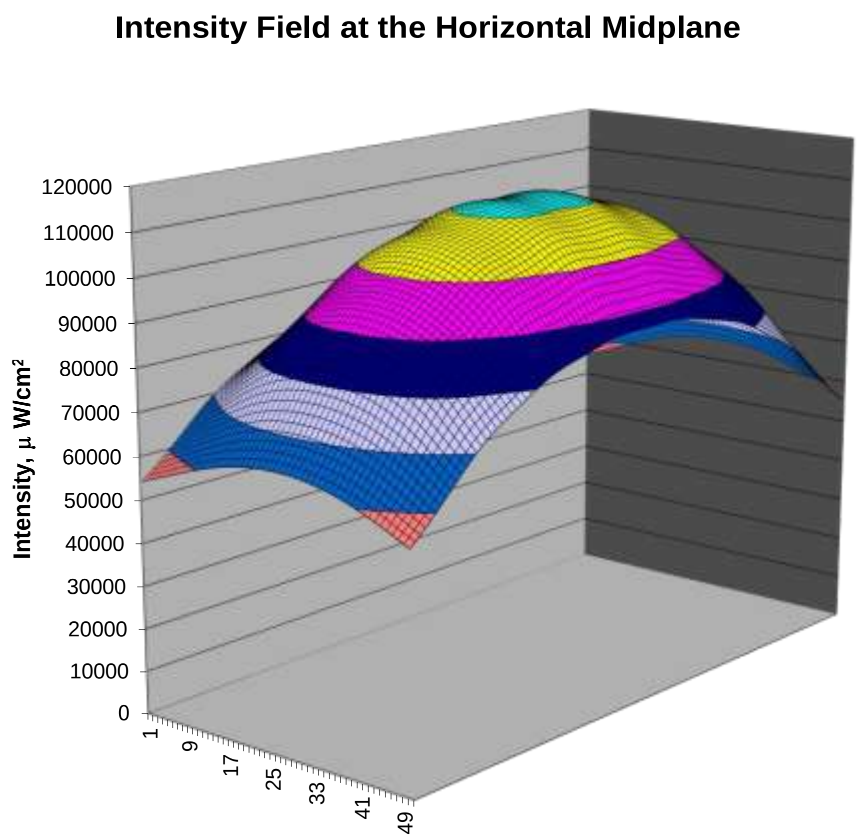

Figure 1: Irradiance field on the horizontal plane at midheight. The airflow is from left to right (near face to back face).

The MERV 6 filter at the entrance will contribute to removal of the larger particles, especially the spores. Figure 2 presents a model of the performance of a typical MERV 6 filter in which the performance curve has been extended into the virus size range. The MERV 6 filter will remove close to 50% of large particles in the size range of spores above 5 microns in size. This is an advantage because spores tend to be resistant to UV. The combined performance of the UV and filter will result in higher removal rates than the UV alone. The combined or total removal rates of bacteria, viruses, and fungi have been computed and are tabulated in Appendix G for bacteria, Appendix H for viruses, and Appendix I for fungi and other microbes. A few microbes have unknown diameters, and these are assumed as highlighted in red in the Appendices.

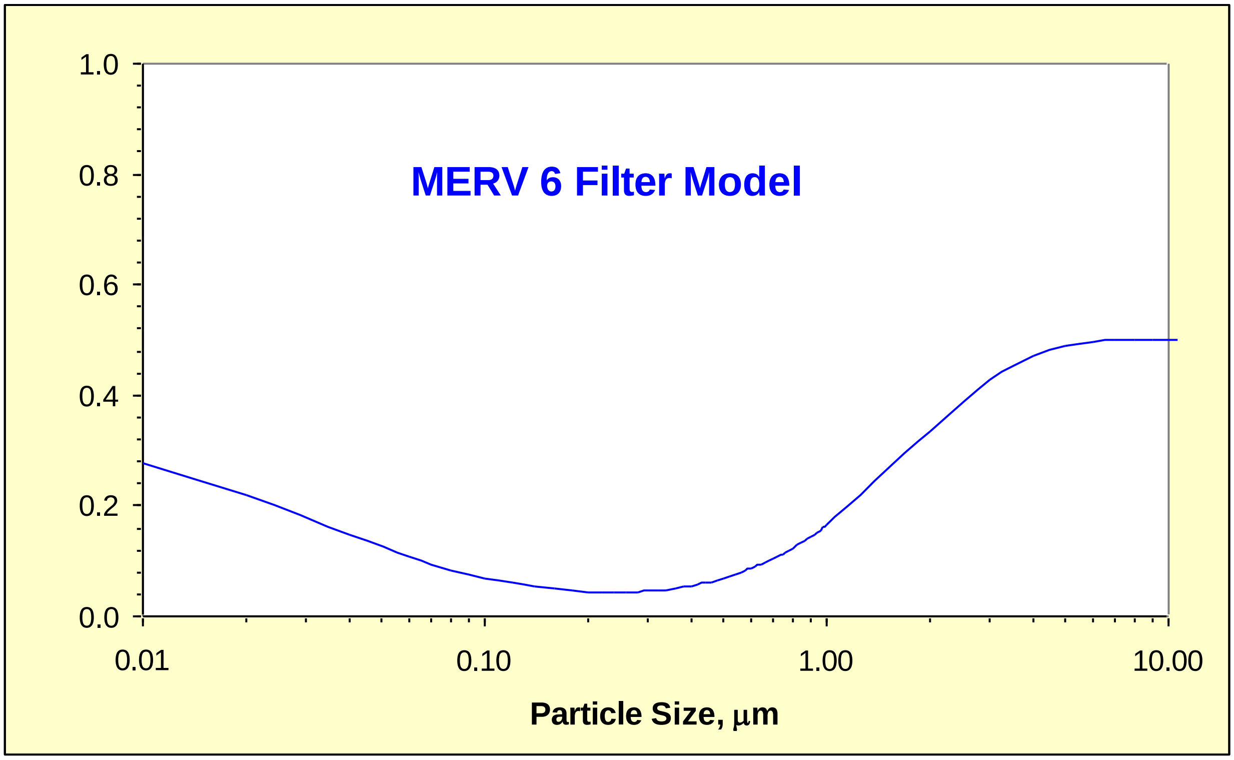

Figure 2: Performance of a typical MERV 6 Filter extended into the virus size range near 0.01 microns.

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Performance Against Hospital-Acquired Pathogens

Hospital-Acquired Infections (HAIs) are of particular concern and are summarized here separately. The primary nosocomial pathogens are mostly bacteria, with some viruses and fungi. Table 4 summarizes the combined UV and filter removal rates for all of the most common nosocomial pathogens. In cases where the UV susceptibility is unknown, a predicted value for the rate constant based on the author's genomic studies has been included (Kowalski 2009, 2011). The genomic predictions are identified with an asterisk. The predictive accuracy for the gnomically predicted UV rate constants is over 90% for viruses and over 80% for bacteria. It can be seen that very high removal rates are achieved against most of the hospital-acquired pathogens, with most of the removal due to the UV component. The net average single-pass removal rate for all nosocomial pathogens is 99.1%, which includes the combined rates of UV and filtration. The multiple pass removal rates will be much higher and depend on the operating time and number of room air changes per hour.

The UV lamps are responsible for most of the removal as illustrated in Figure 3 where the removal rates are broken down for each of the three types of nosocomial pathogens. It can be observed that the larger, more UV-resistant spores are subject to high filtration rates.

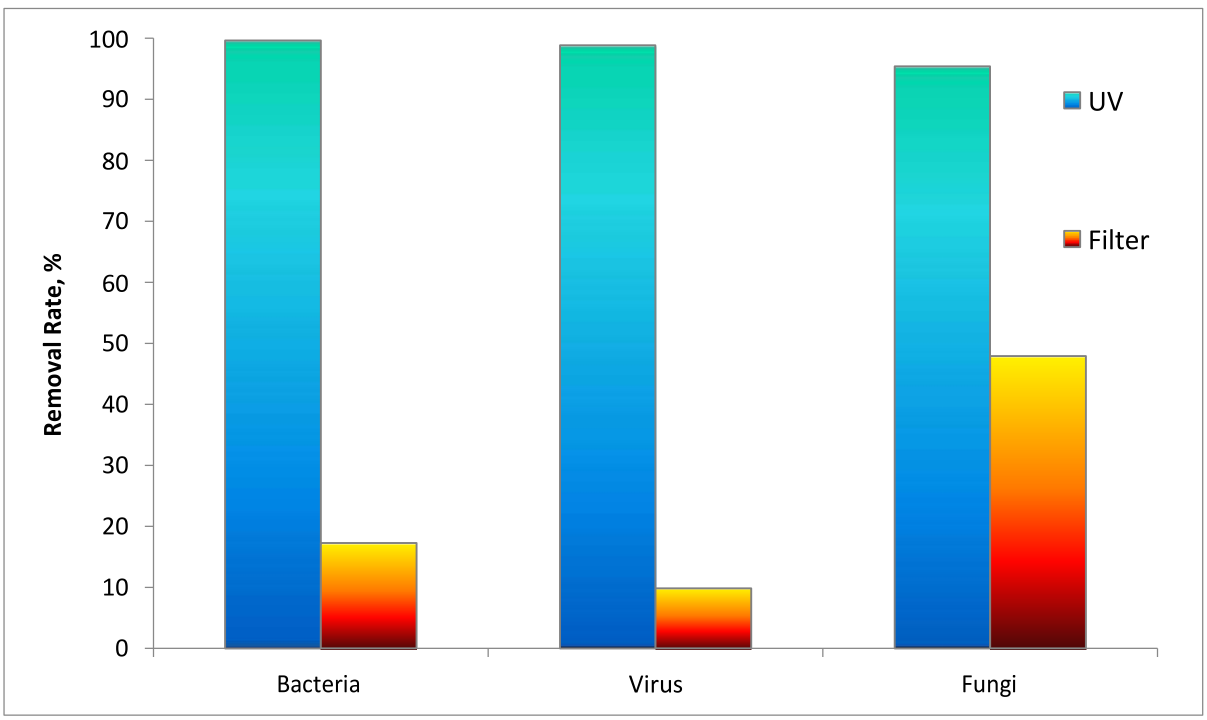

Figure 3: Comparison of removal rates of HAIs due to the UV and filtration components.

Table 4: Disinfection Rates of Airborne Nosocomial Pathogens

Microbe	Type	Size μm	UV k m^2/J	UV D90 J/m^2	UV Rate %	Filter %	Total %
Acinetobacter	Bacteria	1.225	0.16	14	100.00000	20.89	100
Adenovirus	Virus	0.079	0.054	43	100.00000	8.53	100
Aspergillus spores	Fungi	3.354	0.00894	258	98.69099	44.76	99.2769
Blastomyces dermatitidis spores	Bacteria	12.649	0.01645	140	99.96572	50	99.98286
Bordetella pertussis*	Bacteria	0.245	0.0364	63	100.00000	4.31	100
Clostridium difficile spores	Bacteria	5	0.0385	60	100.00000	48.83	100
Clostridium perfringens spores	Bacteria	5	0.0385	60	100.00000	48.83	100
Coronavirus (SARS)	Virus	0.11	0.377	6	100.00000	6.43	100
Corynebacterium diphtheriae	Bacteria	0.698	0.0701	33	100.00000	10.4	100
Coxsackievirus	Virus	0.027	0.111	21	100.00000	18.86	100
Cryptococcus neoformans spores	Fungi	4.899	0.0167	138	99.96963	48.72	99.98443
Ebola virus	Virus	0.08	0.04	58	100.00000	8.44	100
Enterobacter cloacae	Bacteria	1.414	0.03598	64	100.00000	24.42	100
Enterococcus*	Bacteria	1.414	0.0822	28	100.00000	24.42	100
Fusarium spores	Fungi	11.225	0.00855	269	98.41843	50	99.20921
Haemophilus influenzae	Bacteria	0.285	0.11845	19	100.00000	4.43	100
Haemophilus parainfluenzae*	Bacteria	0.02	0.03	77	99.99995	22.02	99.99996
Influenza A virus	Virus	0.098	0.119	19	100.00000	7.09	100
Klebsiella pneumoniae	Bacteria	0.671	0.04435	52	100.00000	9.88	100
Legionella pneumophila	Bacteria	0.52	0.2024	11	100.00000	7.21	100
Measles virus	Virus	0.158	0.1051	22	100.00000	4.93	100
MERS Virus	Virus	0.11	0.00725	318	97.02894	6.43	97.21998
Mucor spores	Fungi	7.071	0.01012	228	99.26142	49.83	99.62946
Mumps virus*	Virus	0.164	0.0766	30	100.00000	4.83	100
Mycobacterium avium	Bacteria	1.118	0.04387	52	100.00000	18.79	100
Mycobacterium tuberculosis	Bacteria	0.637	0.4721	5	100.00000	9.25	100
Mycoplasma pneumoniae	Bacteria	0.177	0.2791	8	100.00000	4.64	100
Neisseria meningitidis*	Bacteria	0.775	0.1057	22	100.00000	11.9	100
Nocardia asteroides	Bacteria	1.118	0.0822	28	100.00000	18.79	100
Norwalk virus*	Virus	0.029	0.0116	198	99.63970	18.09	99.70488
Parainfluenza virus*	Virus	0.194	0.1086	21	100.00000	4.47	100
Parvovirus B19	Virus	0.022	0.092	25	100.00000	21.04	100
Penicillium spores	Fungi	3.262	0.00307	750	77.43906	44.31	87.43581
Proteus mirabilis	Bacteria	0.494	0.289	8	100.00000	6.8	100
Pseudomonas aeruginosa	Bacteria	0.494	0.5721	4	100.00000	6.8	100
Reovirus	Virus	0.075	0.01459	158	99.91550	8.92	99.92304
RSV*	Virus	0.19	0.0917	25	100.00000	4.5	100
Rhinovirus*	Virus	0.023	0.0142	162	99.89790	20.57	99.9189
Rhizopus spores	Fungi	6.928	0.00861	267	98.46379	49.81	99.22897
Rotavirus	Virus	0.073	0.02342	98	99.99883	9.13	99.99894
Rubella virus*	Virus	0.061	0.0037	622	83.37895	10.62	85.1441
Serratia marcescens	Bacteria	0.632	0.221	10	100.00000	9.16	100
Staphylococcus aureus	Bacteria	0.866	0.5957	4	100.00000	13.72	100
Staphylococcus epidermis	Bacteria	0.866	0.09703	24	100.00000	13.72	100
Streptococcus pneumoniae	Bacteria	0.707	0.00492	468	90.80215	10.57	91.77436
Streptococcus pyogenes	Bacteria	0.894	0.8113	3	100.00000	14.28	100
VZV (Varicella surrogate k)	Virus	0.173	0.1305	18	100.00000	4.69	100

Asterisk = UV rate constant is predicted based on genomic analysis.

In-Place Performance

The previous performance parameters were based on a single pass through the APR disinfection unit. Much higher removal rates will actually occur because of the fact that the air in any room will be subject to multiple passes through the unit. Using a simple example in which a 1000 ft^2 room is initially contaminated with 10,000 cfu/m^3 of airborne viruses, 1000 cfu/m^3 of airborne bacteria, and 100 cfu/m^3 of airborne fungi, we can observe the ability of the APR disinfection unit to draw down the airborne concentrations. We assume the room has 15% unfiltered outside air and that the outside air is itself contaminated with 100 cfu/m^3 of bacteria, 400 cfu/m^3 of fungi and no viruses (there are no viruses in outdoor air). Figure 4 shows the results of this analysis. All three microbial groups are pulled down to very low airborne concentrations within one hour and the limiting level of fungi and bacteria seen here results from a steady state condition reached with the outside air intake concentrations. In hospital environments the outside air is normally filtered and so the airborne levels will ultimately approach zero.

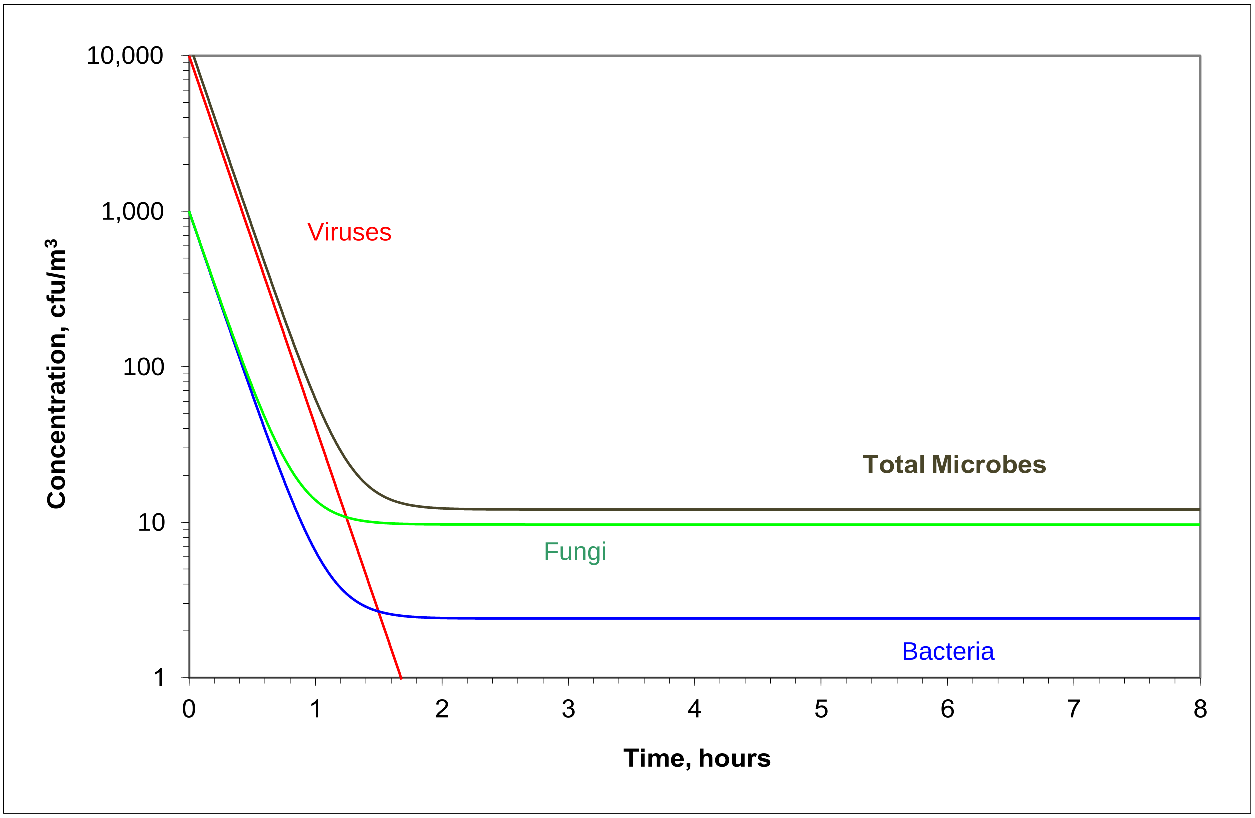

Figure 4: Reduction of airborne microbes in a 1000 ft^2 room with 15% outside air and the APR disinfection unit operating.

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APPENDIX A: Computer Input Data

```
------------------------------ Input Data ----------------------------
---
              Filename: APR01.txt
         Project Title: Airborne Pathogen
            Removal Lamp Model: TUV PL-L
            95W/4P
       Number of Lamps:           12
             Lamp Type:            1
```

REDACTED

APPENDIX B: Program Output Data

```
------------------------UVGI ANALYSIS RESULTS ------------------------

                    Target Microbe: Serratia marcescens
                     Rate Constant:     0.002909 cm2/microW-s
                  Logmean Diameter:         1.31 microns
             Survival in Mixed Air:  5.2781e-060 %
            Kill Rate in Mixed Air:          100 % <
           Survival in Unmixed Air: 4.07742e-043 %
          Kill Rate in Unmixed Air:          100 % <
          Configuration Efficiency: 1.29447e-015 %

                     Exposure Time:     0.485744 sec
          Average Direct Intensity:       XXXX  microW/cm2
               Second Reflection :        XXXX microW/cm2
                  Third Reflection :      XXXX microW/cm2
                 Fourth Reflection :      XXXX  microW/cm2
                  Fifth Reflection :      XXXX microW/cm2
             6 etc. Reflections :         XXXX   microW/cm2
Average Inter-reflection Intensity:       XXXX microW/cm2
           Total Average Intensity:         XXXX microW/cm2
           URV (UVGI Rating Value):         XXXX


---------------------- FILTRATION ANALYSIS RESULTS -----------------------
    UVGI System Operating Velocity:       2.3008 m/s
                                         452.797 fpm
  ( Design velocity for filters may differ from UVGI system velocity )
  ( Refer to Manufacturer's catalogs for design velocity limits)

 Estimated filtration rates for nominal total arrestance indicated:
                     MERV 6 Filter:      20.2996 %

                       UVGI alone:          100 %
      MERV 6 Nominal Filter + UVGI:          100 %
```

APPENDIX D: UV Kill Rates for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Acinetobacter baumannii	Veg	18	0.12800	S	-	Rastogi 2007	100.0000
Acinetobacter baumannii	Veg	33	0.19200	W	-	Templeton 2009	100.0000
Aeromonas	Veg	11	0.20310	W	Wat	Sako 1985	100.0000
Aeromonas hydrophila	Veg	16	0.14100	W	Wat	Liltved 1996	100.0000
B. atrophaeus (B. globigii)	Sp	144	0.01600	Air	(Lo RH)	EPA 2006	99.9574
B. atrophaeus spores	Sp	1323	0.00174	W	Wat	Shafaat 2006	56.9970
Bacillus anthracis spores	Sp	411	0.00560	W	Wat	Nicholson 2003	93.3861
Bacillus anthracis spores	Sp	45	0.05094	S	-	Sharp 1939	100.0000
Bacillus anthracis spores	Sp	743	0.00310	S	-	Knudson 1986	77.7649
Bacillus cereus spores	Sp	267	0.00863	S	-	Weinberger 1984	98.4786
Bacillus cereus spores	Sp	210	0.01098	S	-	Weisova 1966	99.5140
Bacillus cereus spores	Sp	116	0.01979	S	-	Germaine 1973	99.9932
Bacillus cereus spores	Sp	408	0.00564	S	-	Benoit 1990	93.5053
Bacillus megatherium	Sp	273	0.00843	S	-	Hercik 1937	98.3272
Bacillus megatherium	Veg	113	0.02038	S	-	Hercik 1937	99.9949
Bacillus pumilis spores	Sp	50	0.04600	W	Wat	Newcombe 2005	100.0000
Bacillus subtilis	Veg	25	0.09210	W	Wat	Lojo 1995	100.0000
Bacillus subtilis	Veg	14	0.16858	Air	(Lo RH)	Nakamura 1987	100.0000
Bacillus subtilis spores	Sp	250	0.00920	W	Wat	Nicholson 2003	98.8461
Bacillus subtilis spores	Sp	161	0.01430	W	Wat	Hoyer 2000	99.9027
Bacillus subtilis spores	Sp	116	0.01982	W	Wat	Sommer 1989	99.9933
Bacillus subtilis spores	Sp	220	0.01047	W	Wat	Sommer 1998	99.3756
Bacillus subtilis spores	Sp	199	0.01155	W	Wat	Sommer 1999	99.6309
Bacillus subtilis spores	Sp	77	0.03000	W	Wat	Qualls 1983	100.0000
Bacillus subtilis spores	Sp	155	0.01490	W	Wat	Mamane-Gravetz 2005	99.9273
Bacillus subtilis spores	Sp	89	0.02580	W	Wat	Horneck 1985	99.9996
Bacillus subtilis spores	Sp	200	0.01150	W	Wat	Chang 1985	99.6218
Bacillus subtilis spores	Sp	80	0.02880	W	Wat	DeGuchi 2005	99.9999
Bacillus subtilis spores	Sp	94	0.02460	S	-	Rentschler 1941	99.9993
Bacillus subtilis spores	Sp	68	0.03370	S	-	Munakata 1975	100.0000
Bacillus subtilis spores	Sp	113	0.02030	S	-	Munakata 1972	99.9947
Bacillus subtilis spores	Sp	89	0.02600	Air	Hi RH	Peccia 2001a	99.9997
Bacillus subtilis spores	Sp	149	0.01550	Air	Lo RH	Ke 2009	99.9457
Bacillus subtilis spores	Sp	85	0.02700	Air	Lo RH	Peccia 2001a	99.9998
Bacillus thuringiensis	Sp	2303	0.00100	W	Wat	Griego 1978	38.4303
Burkholderia cenocepacia	Veg	58	0.03956	W	Wat	Abshire 1981	100.0000
Burkholderia cepacia	Veg	11	0.21150	Air	Lo RH	Fletcher 2004	100.0000
Burkholderia cepacia	Veg	22	0.10520	Air	Hi RH	Fletcher 2004	100.0000
Campylobacter jejuni	Veg	11	0.20933	W	Wat	Wilson 1992	100.0000
Campylobacter jejuni	Veg	29	0.07940	W	Wat	Butler 1987	100.0000
Citrobacter diversus	Veg	32	0.07140	W	Wat	Giese 2000	100.0000
Citrobacter freundii	Veg	42	0.05482	W	Wat	Zemke 1990	100.0000
Citrobacter freundii	Veg	46	0.05010	W	Wat	Giese 2000	100.0000
Clostridium difficile	Sp	128	0.01800	S	-	Nerandzic 2012	99.9838
Clostridium bot	Sp	60	0.03850	S	-	Durban 1969	100.0000
Clostridium perfringens	Veg	38	0.06000	W	Wat	Hijnen 2006	100.0000
Clostridium perfringens	Veg	135	0.01700	-	-	Jepson 1973	99.9737

APPENDIX D: UV Kill Rates for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Clostridium tetani	Veg	49	0.04699	-	-	Jepson 1973	100.0000
Corynebacterium diphtheriae	Veg	33	0.07010	S	-	Sharp 1939	100.0000
Coxiella burnetii	Veg	15	0.15350	W	Wat	Little 1980	100.0000
Deinococcus radiodurans	Veg	365	0.00630	W	Wat	Setlow 1964	95.2901
Enterobacter cloacae	Veg	64	0.03598	W	Wat	Zemke 1990	100.0000
Escherichia coli	Veg	21	0.10900	W	Wat	Zelle 1955	100.0000
Escherichia coli	Veg	53	0.04320	W	Wat	Tyrrell 1972	100.0000
Escherichia coli	Veg	20	0.11510	W	Wat	Oguma 2001	100.0000
Escherichia coli	Veg	47	0.04940	W	Wat	Kim 2002	100.0000
Escherichia coli	Veg	43	0.05300	W	Wat	Hofemeister 1975	100.0000
Escherichia coli	Veg	13	0.18000	W	Wat	Harris 1987	100.0000
Escherichia coli	Veg	20	0.11500	W	Wat	Harm 1968	100.0000
Escherichia coli	Veg	24	0.09600	W	Wat	David 1973	100.0000
Escherichia coli	Veg	81	0.02832	W	Wat	Abshire 1981	99.9999
Escherichia coli	Veg	25	0.09398	S	-	Sharp 1939	100.0000
Escherichia coli	Veg	19	0.12000	S	Hi RH	Rentschler 1942	100.0000
Escherichia coli	Veg	12	0.19300	S	Lo RH	Rentschler 1942	100.0000
Escherichia coli	Veg	25	0.09210	S	-	Rentschler 1941	100.0000
Escherichia coli	Veg	20	0.11670	S	-	Quek 2008	100.0000
Escherichia coli	Veg	51	0.04540	S	-	Luckiesh 1949	100.0000
Escherichia coli	Veg	34	0.06720	S	-	Kim 2002	100.0000
Escherichia coli	Veg	55	0.04187	S	-	Hollaender 1955	100.0000
Escherichia coli	Veg	8	0.28300	S	-	Collins 1971	100.0000
Escherichia coli	Veg	3	0.72300	Air	Lo RH	Webb 1970	100.0000
Escherichia coli	Veg	11	0.21800	Air	Hi RH	Webb 1970	100.0000
Escherichia coli	Veg	11	0.21900	Air	Hi RH	Rentschler 1942	100.0000
Escherichia coli	Veg	13	0.18100	Air	Lo RH	Rentschler 1942	100.0000
Escherichia coli	Veg	15	0.15611	Air	Lo RH	Luckiesh 1949	100.0000
Escherichia coli	Veg	2	0.96500	Air	Lo RH	Koller 1939	100.0000
Escherichia coli	Veg	11	0.20500	Air	Hi RH	Koller 1939	100.0000
Francisella tularensis	Veg	256	0.00900	Air	Lo RH	Beebe 1959	98.7285
Francisella tularensis	Veg	288	0.00800	Air	Hi RH	Beebe 1959	97.9349
Haemophilus influenzae	Veg	38	0.05990	S	-	Mongold 1992	100.0000
Haemophilus influenzae Rd	Veg	13	0.17700	W	Wat	Barnhart 1970	100.0000
Halobacterium sp. NRC-1	Veg	25	0.09210	S	-	Crow ley 2006	100.0000
Halobacterium salinarum	Veg	68	0.03390	-	-	Martin 2000	100.0000
Halomonas elongata	Veg	13	0.18090	-	-	Martin 2000	100.0000
Helicobacter pylori	Veg	33	0.06900	W	Wat	Hayes 2006	100.0000
Klebsiella pneumoniae	Veg	42	0.05480	W	Wat	Zemke 1990	100.0000
Klebsiella pneumoniae	Veg	68	0.03390	W	Wat	Giese 2000	100.0000
Klebsiella terrigena	Veg	33	0.07000	W	Wat	Wilson 1992	100.0000
Legionella dumoffi	Veg	24	0.09594	S	-	Knudson 1985	100.0000
Legionella bozemanii	Veg	19	0.17400	W	Wat	Yamamoto 1987	100.0000
Legionella bozemanii	Veg	15	0.15351	S	-	Knudson 1985	100.0000
Legionella gormanii	Veg	26	0.08856	S	-	Knudson 1985	100.0000
Legionella jordanis	Veg	11	0.20933	S	-	Knudson 1985	100.0000

APPENDIX D: UV Kill Rates for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Legionella longbeach	Veg	11	0.20933	S	-	Knudson 1985	100.0000
Legionella micdadei	Veg	15	0.15351	S	-	Knudson 1985	100.0000
Legionella oakridgensis	Veg	22	0.10466	S	-	Knudson 1985	100.0000
Legionella pneumophila	Veg	13	0.17400	W	Wat	Yamamoto 1987	100.0000
Legionella pneumophila	Veg	12	0.19298	W	Wat	Gilpin 1985	100.0000
Legionella pneumophila	Veg	9	0.24849	W	Wat	Antopol 1979	100.0000
Legionella pneumophila	Veg	5	0.44613	S	-	Knudson 1985	100.0000
Legionella pneumophila	Veg	25	0.09110	W	Wat	Wilson 1992	100.0000
Legionella pneumophila	Veg	16	0.14390	W	Wat	Oguma 2004 (LP)	100.0000
Legionella pneumophila	Veg	19	0.12020	W	Wat	Oguma 2004 (MP)	100.0000
Legionella wadsworthii	Veg	4	0.57565	S	-	Knudson 1985	100.0000
Listeria monocytogenes	Veg	73	0.03170	W	Wat	Kim 2002	100.0000
Listeria monocytogenes	Veg	156	0.01480	S	-	Kim 2002	99.9237
Listeria monocytogenes	Veg	10	0.23030	S	-	Collins 1971	100.0000
Micrococcus candidus	Veg	61	0.03806	S	-	Hollaender 1955	100.0000
Micrococcus piltonensis	Veg	81	0.02843	S	-	Rentschler 1941	99.9999
Micrococcus sphaeroides	Veg	100	0.02303	S	-	Rentschler 1941	99.9986
Moraxella	Veg	10965	0.00022	W	Wat	Keller 1982	10.1205
Mycobacterium avium-intra.	Veg	84	0.02740	W	Wat	David 1973	99.9998
Mycobacterium avium	Veg	60	0.03840	W	Wat	Shin 2008	100.0000
Mycobacterium avium	Veg	35	0.06580	W	Wat	McCarthy 1974	100.0000
Mycobacterium bovis BCG	Veg	22	0.10550	S	-	Collins 1971	100.0000
Mycobacterium bovis BCG	Veg	10	0.24200	Air	50	Riley 1976	100.0000
Mycobacterium bovis BCG	Veg	12	0.19000	Air	-	Peccia 2002	100.0000
Mycobacterium bovis BCG	Veg	19	0.12000	Air	Lo RH	Ko 2000	100.0000
Mycobacterium bovis BCG	Veg	33	0.07000	Air	Hi RH	Ko 2000	100.0000
Mycobacterium flaviscens	Veg	120	0.01919	W	Wat	David 1973	99.9909
Mycobacterium fortuitum	Veg	68	0.03390	W	Wat	David 1973	100.0000
Mycobacterium fortuitum	Veg	96	0.02400	W	Wat	David 1971	99.9991
Mycobacterium kansasii	Veg	80	0.02880	W	Wat	David 1973	99.9999
Mycobacterium marinum	Veg	76	0.03030	W	Wat	David 1973	100.0000
Mycobacterium marinum	Veg	743	0.00310	W	Wat	David 1971	77.7649
Mycobacterium parafortuitum	Veg	13	0.18000	Air	50	Peccia 2001	100.0000
Mycobacterium parafortuitum	Veg	46	0.05000	Air	95	Peccia 2001	100.0000
Mycobacterium parafortuitum	Veg	19	0.12000	Air	50	Xu 2003	100.0000
Mycobacterium phlei	Veg	76	0.03030	W	Wat	David 1973	100.0000
Mycobacterium phlei	Veg	63	0.03650	Air	50	Riley 1976	100.0000
Mycobacterium phlei	Veg	23	0.10000	Air	50	Kethley 1973	100.0000
Mycobacterium phlei	Veg	16	0.14000	Air	50	Gillis 1974	100.0000
Mycobacterium smegmatis	Veg	108	0.02130	W	Wat	David 1973	99.9967
Mycobacterium smegmatis	Veg	1047	0.00220	W	Wat	David 1971	65.5961
Mycobacterium smegmatis	Veg	68	0.03400	W	Wat	Boshoff 2003	100.0000
Mycobacterium smegmatis	Veg	12	0.19000	Air	50	Gillis 1974	100.0000
Mycobacterium terrae	Veg	50	0.04610	W	Wat	Bohrerova 2006	100.0000
Mycobacterium tuberculosis	Veg	28	0.08220	W	Wat	David 1973	100.0000
Mycobacterium tuberculosis	Veg	77	0.03000	W	Wat	David 1971	100.0000

APPENDIX D: UV Kill Rates for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Mycobacterium tuberculosis	Veg	74	0.03100	W	Wat	Boshoff 2003	100.0000
Mycobacterium tuberculosis	Veg	11	0.21320	S	-	Collins 1971	100.0000
Mycobacterium tuberculosis	Veg	5	0.47210	Air	50	Riley 1976	100.0000
Mycoplasma arthritidis	Veg	7	0.31240	S	-	Furness 1977	100.0000
Mycoplasma fermentans	Veg	9	0.25220	S	-	Furness 1977	100.0000
Mycoplasma hominis	Veg	7	0.32710	S	-	Furness 1977	100.0000
Mycoplasma Orale type 1	Veg	11	0.21800	S	-	Furness 1977	100.0000
Mycoplasma Orale type 2	Veg	6	0.38760	S	-	Furness 1977	100.0000
Mycoplasma pneumoniae	Veg	8	0.27910	S	-	Furness 1977	100.0000
Mycoplasma salivarium	Veg	11	0.21140	S	-	Furness 1977	100.0000
Myxobolus cerebralis	Veg	10011	0.00023	W		Hedrick 2000	10.5553
Neisseria catarrhalis	Veg	44	0.05233	S	-	Rentschler 1941	100.0000
Nocardia asteroides	Veg	280	0.00822	S	-	Chick 1963	98.1471
Phytomonas tumefaciens	Veg	44	0.05233	S	-	Rentschler 1941	100.0000
Proteus mirabilis	Veg	8	0.28900	W	Wat	Hofemeister 1975	100.0000
Proteus vulgaris	Veg	30	0.07675	S	-	Rentschler 1941	100.0000
Pseudomonas aeruginosa	Veg	10	0.22692	W	Wat	Gilpin 1985	100.0000
Pseudomonas aeruginosa	Veg	172	0.01340	W	Wat	Dolman 1989	99.8495
Pseudomonas aeruginosa	Veg	36	0.06600	W	Wat	Abshire 1981	100.0000
Pseudomonas aeruginosa	Veg	55	0.04190	W	Wat	Zelle 1955	100.0000
Pseudomonas aeruginosa	Veg	55	0.04187	S	-	Hollaender 1955	100.0000
Pseudomonas aeruginosa	Veg	22	0.10470	S	-	Elasri 1999	100.0000
Pseudomonas aeruginosa	Veg	10	0.23750	S	-	Collins 1971	100.0000
Pseudomonas aeruginosa	Veg	4	0.57210	Air	(Lo RH)	Sharp 1940	100.0000
Pseudomonas diminuta	Veg	96	0.02391	W	Wat	Abshire 1981	99.9991
Pseudomonas fluorescens	Veg	35	0.06579	S	-	Rentschler 1941	100.0000
Pseudomonas fluorescens	Veg	3	0.47730	Air	50	vanOsdell 2002	100.0000
Pseudomonas maltophilia	Veg	70	0.03294	W	Wat	Abshire 1981	100.0000
Pseudomonas putrefaciens	Veg	87	0.02662	W	Wat	Abshire 1981	99.9998
Rickettsia prowazekii	Veg	13	0.17600	W	Wat	Allen 1954	100.0000
Salmonella spp.	Veg	11	0.21380	W	Wat	Yaun 2003	100.0000
Salmonella anatum	Veg	60	0.03840	W	Wat	Tosa 1998	100.0000
Salmonella derby	Veg	36	0.06360	W	Wat	Tosa 1998	100.0000
Salmonella enteritidis	Veg	10	0.22100	S	-	Collins 1971	100.0000
Salmonella enteritidis	Veg	33	0.07010	W	Wat	Tosa 1998	100.0000
Salmonella infantis	Veg	20	0.11510	W	Wat	Tosa 1998	100.0000
Salmonella typhi	Veg	21	0.10760	W	Wat	Zelle 1955	100.0000
Salmonella typhi	Veg	30	0.07675	W	Wat	Chang 1985	100.0000
Salmonella typhi	Veg	21	0.10760	S	-	Sharp 1939	100.0000
Salmonella typhi	Veg	9	0.25580	W	Wat	Wilson 1992	100.0000
Salmonella typhimurium	Veg	295	0.00780	W	Wat	Kim 2002	97.7246
Salmonella typhimurium	Veg	18	0.12830	W	Wat	Tosa 1998	100.0000
Sarcina lutea	Veg	197	0.01169	S	-	Rentschler 1941	99.6548
Serratia indica	Veg	209	0.01100	Air	42-51	Harstad 1954	99.5180
Serratia marcescens	Veg	22	0.10490	W	Wat	Zelle 1955	100.0000
Serratia marcescens	Veg	105	0.02194	W	Wat	Harris 1993	99.9976

APPENDIX D: UV Kill Rates for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Serratia marcescens	Veg	22	0.10470	S	-	Sharp 1939	100.0000
Serratia marcescens	Veg	22	0.10466	S	-	Rentschler 1941	100.0000
Serratia marcescens	Veg	8	0.27742	S	-	Hollaender 1955	100.0000
Serratia marcescens	Veg	10	0.22080	S	-	Collins 1971	100.0000
Serratia marcescens	Veg	2	0.93900	Air	Lo RH	Fletcher 2003	100.0000
Serratia marcescens	Veg	24	0.09500	Air	Hi RH	Fletcher 2003	100.0000
Serratia marcescens	Veg	8	0.28670	Air	25-57	UVDI 2001	100.0000
Serratia marcescens	Veg	4	0.57500	Air	22-33	Ko 2000	100.0000
Serratia marcescens	Veg	115	0.02000	Air	Hi RH	Ko 2000	99.9939
Serratia marcescens	Veg	5	0.44490	Air	(Lo RH)	Sharp 1940	100.0000
Serratia marcescens	Veg	20	0.11300	Air	(Lo RH)	Nakamura 1987	100.0000
Serratia marcescens	Veg	33	0.07000	Air	95	Peccia 2001	100.0000
Serratia marcescens	Veg	3	0.92000	Air	68	Lai 2004	100.0000
Serratia marcescens	Veg	3	0.43050	Air	50	vanOsdell 2002	100.0000
Serratia marcescens	Veg	5	0.45000	Air	50	Peccia 2001	100.0000
Serratia marcescens	Veg	1	2.20000	Air	36	Lai 2004	100.0000
Shigella dysenteriae	Veg	18	0.13080	W	Wat	Wilson 1992	100.0000
Shigella paradysenteriae	Veg	17	0.13706	S	-	Sharp 1939	100.0000
Shigella sonnei	Veg	18	0.12500	W	Wat	Chang 1985	100.0000
Spirillum rubrum	Veg	44	0.05233	S	-	Rentschler 1941	100.0000
Staphylococcus albus	Veg	18	0.12514	S	-	Sharp 1939	100.0000
Staphylococcus albus	Veg	33	0.06978	S	-	Rentschler 1941	100.0000
Staphylococcus albus (1)	Veg	23	0.09950	Air	(Lo RH)	Rentschler 1942	100.0000
Staphylococcus albus (2)	Veg	52	0.04400	Air	(Lo RH)	Rentschler 1942	100.0000
Staphylococcus aureus	Veg	52	0.04400	W	Wat	Dolman 1989	100.0000
Staphylococcus aureus	Veg	27	0.08531	W	Wat	Chang 1985	100.0000
Staphylococcus aureus	Veg	56	0.04134	W	Wat	Abshire 1981	100.0000
Staphylococcus aureus	Veg	30	0.07700	S	-	Sturm 1932	100.0000
Staphylococcus aureus	Veg	50	0.04652	S	-	Hollaender 1955	100.0000
Staphylococcus aureus	Veg	66	0.03500	S	-	Gates 1934	100.0000
Staphylococcus aureus	Veg	26	0.08860	S	-	Sharp 1939	100.0000
Staphylococcus aureus	Veg	37	0.06240	S	-	Luckiesh 1949	100.0000
Staphylococcus aureus	Veg	19	0.11840	S	-	Gates 1929	100.0000
Staphylococcus aureus	Veg	20	0.11300	Air	(Lo RH)	Nakamura 1987	100.0000
Staphylococcus aureus	Veg	7	0.34760	Air	(Lo RH)	Sharp 1940	100.0000
Staphylococcus aureus	Veg	2	0.96020	Air	-	Luckiesh 1949	100.0000
Staphylococcus aureus	Veg	2	0.96200	Air	(Lo RH)	Luckiesh 1946	100.0000
Staphylococcus epidermis	Veg	161	0.01433	W	Wat	Harris 1993	99.9041
Staphylococcus epidermis	Veg	14	0.16210	Air	50	vanOsdell 2002	100.0000
Staphylococcus epidermis	Veg	29	0.00800	Air	85	vanOsdell 2002	97.9349
Staphylococcus epidermis	Veg	20	0.11300	Air	(Lo RH)	Nakamura 1987	100.0000
Staphylococcus epidermis	Veg	22	0.10500	Air	(Lo RH)	Furuhashi 1989	100.0000
Streptococcus agalactiae	Veg	5	0.43420	Air	-	Luckiesh 1949	100.0000
Streptococcus faecalis	Veg	55	0.09200	W	Wat	Chang 1985	100.0000
Streptococcus faecalis	Veg	195	0.01180	W	Wat	Sanz 2007	99.6730
Streptococcus faecalis	Veg	31	0.07540	W	Wat	Harris 1987	100.0000

APPENDIX D: UV Kill Rates for Bacteria

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Streptococcus faecalis	Veg	120	0.01919	W	Wat	Abshire 1981	99.9909
Streptococcus faecium	Veg	45	0.05100	W	Wat	Martiny 1988	100.0000
Streptococcus haemolyticus	Veg	22	0.10660	S	-	Sharp 1939	100.0000
Streptococcus lactis	Veg	62	0.03744	S	-	Rentschler 1941	100.0000
Streptococcus pneumoniae	Veg	468	0.00492	S	-	Gritz 1990	90.8021
Streptococcus pyogenes	Veg	4	0.06161	S	-	Lidw ell 1950	100.0000
Streptococcus pyogenes	Veg	1	1.56100	Air	-	Luckiesh 1949	100.0000
Streptococcus viridans	Veg	20	0.11513	S	-	Sharp 1939	100.0000
Streptomyces coelicolor	Veg	60	0.03840	W	Wat	Jagger 1970	100.0000
Streptomyces griseus	Veg	129	0.01780	W	Wat	Kelner 1949	99.9822
Streptomyces griseus	Veg	60	0.03840	W	Wat	Jagger 1970	100.0000
Vibrio anguillarum (fish)	Veg	10	0.23820	W	Wat	Sako 1985	100.0000
Vibrio anguillarum (fish)	Veg	5	0.42600	W	Wat	Liltved 1995	100.0000
Vibrio cholerae	Veg	17	0.13400	W	Wat	Wilson 1992	100.0000
Vibrio ordalii	Veg	18	0.12560	W	Wat	Sako 1985	100.0000
Vibrio parahaemolyticus	Veg	8	0.30700	W	Wat	Nozu 1977	100.0000
Vibrio salmonicida (fish)	Veg	5	0.42600	W	Wat	Liltved 1995	100.0000
Yersinia enterocolitica	Veg	15	0.15351	W	Wat	Butler 1987	100.0000
Yersinia enterocolitica	Veg	28	0.08127	W	Wat	Carlson 1975	100.0000
Yersinia enterocolitica	Veg	11	0.20467	W	Wat	Butler 1987	100.0000
Yersinia enterocolitica	Veg	13	0.17170	W	Wat	Wilson 1992	100.0000
Yersinia ruckeri (fish)	Veg	5	0.42600	W	Wat	Liltved 1995	100.0000
Yersinia ruckeri (fish)	Veg	10	0.23020	W	Wat	Liltved 1996	100.0000

NOTES

Type: Sp = Spore, Veg = Vegetative, VegY = Vegetative yeast
D_{90}: UV Dose for 90% inactivation (10% survival)
UVGI k: UV rate constant at the given D_{90} (and below the UL)
UL: Upper Limit within which D_{90} and rate constants are applicable
Media: A = Air, S = Surface, W = Water
Sh = Shoulder in decay curve (shoulder is ignored for k and D_{90} values)
St = Number of stages in decay curve (k & D_{90} only applies to first stage)
Dia.: Logmean diameter in microns, including envelope for viruses if any
MP: Medium Pressure UV lamp, LP: Low Pressure UV lamp

APPENDIX E: UV Kill Rates for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Adenovirus	dsDNA	34	0.06800	Air	Hi RH	Walker 2007	100.0000
Adenovirus	dsDNA	59	0.03900	Air	Lo RH	Walker 2007	100.0000
Adenovirus	dsDNA	42	0.05500	Air	50	Jensen 1964	100.0000
Adenovirus	dsDNA	903	0.00255	W	Wat	Wasserman 1962	70.9674
Adenovirus type 1	dsDNA	299	0.00770	W	Wat	Battiggelli 1993	97.6115
Adenovirus type 1	dsDNA	350	0.00658	W	Wat	Nwachuku 2005	95.8858
Adenovirus type 2	dsDNA	400	0.00576	S	-	Day 1974	93.8800
Adenovirus type 2	dsDNA	640	0.00360	W	Wat	Rainbow 1970	82.5530
Adenovirus type 2	dsDNA	490	0.00470	W	Wat	Rainbow 1973	89.7665
Adenovirus type 2	dsDNA	533	0.00432	W	Wat	Linden 2007 (LP lamp)	87.6954
Adenovirus type 2	dsDNA	150	0.01540	W	Wat	Linden 2007 (MP lamp)	99.9430
Adenovirus type 2	dsDNA	300	0.00768	W	Wat	Shin 2005	97.5882
Adenovirus type 2	dsDNA	400	0.00576	W	Wat	Gerba 2002	93.8694
Adenovirus type 2	dsDNA	276	0.00834	W	Wat	Ballester 2004	98.2489
Adenovirus type 4	dsDNA	921	0.00250	W	Wat	Nwachuku 2005	70.2547
Adenovirus type 15	dsDNA	396	0.00581	W	Wat	Thompson 2003	94.0266
Adenovirus type 40	dsDNA	300	0.00768	S	-	Meng 1996	97.5824
Adenovirus type 40	dsDNA	546	0.00422	W	Wat	Thurston-Enriquez 2003	87.0840
Adenovirus type 41	dsDNA	240	0.00976	S	-	Meng 1996	99.1192
Adenovirus type 41	dsDNA	425	0.00542	W	Wat	Malley 2004	92.7828
Adenovirus type 41	dsDNA	555	0.00415	W	Wat	Ko 2005	86.6379
Adenovirus type 41	dsDNA	600	0.00384	W	Wat	Durance 2005	84.4701
Adenovirus type 5	dsDNA	400	0.00576	W	Wat	Durance 2005	93.8800
Adenovirus type 5	dsDNA	541	0.00426	W	Wat	Wang 2004	87.3321
Adenovirus type 5	dsDNA	720	0.00320	W	Wat	Nwachuku 2005	78.8176
Adenovirus type 6	dsDNA	390	0.00590	W	Wat	Nwachuku 2005	94.2930
Adenovirus type 6	dsDNA	400	0.00576	W	Wat	Battiggelli 1993	93.8800
AHNV (fish virus)	ssRNA	349	0.00660	W	Wat	Liltved 2005	95.9279
Avian Influenza virus	ssRNA	22	0.10600	W	Wat	Lucio-Forster 2006	100.0000
Avian Influenza virus	ssRNA	30	0.07680	W	Wat	Deshmukh 1968	100.0000
Avian Leukosis virus (RSA)	ssRNA	631	0.00365	W	Wat	Levinson 1966	82.9710
Avian Sarcoma virus	ssDNA	155	0.01490	W	Wat	Owada 1976	99.9273
Avian Sarcoma virus	ssDNA	381	0.00604	W	Wat	Bister 1977	94.6571
B. subtilis phage 029	dsDNA	70	0.03289	W	Wat	Freeman 1987	100.0000
B. subtilis phage SP02c12	dsDNA	100	0.02303	W	Wat	Freeman 1987	99.9986
B. subtilis phage SPP1	dsDNA	195	0.01181	W	Wat	Freeman 1987	99.6743
Bacteriophage B40-8	dsDNA	137	0.01679	W	Wat	Sommer 2001	99.9709
Bacteriophage F-specific	dsRNA	292	0.00789	W	Wat	Havelaar 1987	97.8171
Bacteriophage MS2	ssRNA	26	0.04800	Air	Hi RH	Walker 2007	100.0000
Bacteriophage MS2	ssRNA	61	0.03800	Air	Lo RH	Walker 2007	100.0000
Bacteriophage MS2	ssRNA	3	0.81000	Air	Lo RH	Tseng 2005	100.0000
Bacteriophage MS2	ssRNA	4	0.64000	Air	Hi RH	Tseng 2005	100.0000
Bacteriophage MS2	ssRNA	606	0.00380	W	Wat	Furuse 1971	84.1658
Bacteriophage MS2	ssRNA	135	0.01710	W	Wat	Tree 1997	99.9750
Bacteriophage MS2	ssRNA	427	0.00539	W	Wat	Sommer 2001	92.6806

APPENDIX E: UV Kill Rates for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Bacteriophage MS2	ssRNA	193	0.01190	W	Wat	Sommer 1998	99.6885
Bacteriophage MS2	ssRNA	419	0.00550	W	Wat	Mamane-Gravetz 2005	93.0574
Bacteriophage MS2	ssRNA	368	0.00625	W	Wat	Templeton 2006	95.1745
Bacteriophage MS2	ssRNA	295	0.00780	W	Wat	Ko 2005	97.7246
Bacteriophage MS2	ssRNA	40	0.05760	W	Wat	Weidenmann 1993	100.0000
Bacteriophage MS2	ssRNA	173	0.01330	W	Wat	Wilson 1992	99.8420
Bacteriophage MS2	ssRNA	275	0.00837	W	Wat	Thurston-Enriquez 2003	98.2741
Bacteriophage MS2	ssRNA	217	0.01060	W	Wat	Batch 2004	99.4148
Bacteriophage MS2	ssRNA	250	0.00920	W	Wat	Battiggelli 1993	98.8461
Bacteriophage MS2	ssRNA	217	0.01060	W	Wat	Simonet 2006	99.4148
Bacteriophage MS2	ssRNA	217	0.01063	W	Wat	deRodaHusman 2004	99.4233
Bacteriophage MS2	ssRNA	213	0.01080	W	Wat	Butkus 2004	99.4689
Bacteriophage MS2	ssRNA	187	0.01230	W	Wat	Oppenheimer 1997	99.7434
Bacteriophage MS2	ssRNA	169	0.01360	W	Wat	Nuanualsuw an 2002	99.8634
Bacteriophage MS2	ssRNA	164	0.01402	W	Wat	Rauth 1965	99.8886
Bacteriophage MS2	ssRNA	150	0.01540	W	Wat	Shin 2005	99.9430
Bacteriophage MS2	ssRNA	140	0.01640	W	Wat	Meng 1996	99.9649
Bacteriophage MS2	ssRNA	198	0.01160	W	Wat	Nieuwstad 1994	99.6397
Bacteriophage MS2	ssRNA	228	0.01010	W	Wat	Lazarova 2004	99.2542
Bacteriophage MS2	ssRNA	245	0.00940	W	Wat	Thompson 2003	98.9527
Bacteriophage Qβ	ssRNA	125	0.01840	W	Wat	Simonet 2006	99.9867
Bacteriophage Qβ	ssRNA	1919	0.00120	W	Wat	O'Hara 1980	44.1220
Berne virus	ssRNA	13	0.18420	W	Wat	Weiss 1986	100.0000
BF-NNV (fish virus)	ssRNA	501	0.00460	W	Wat	Yoshimizu 2005	89.2579
BLV	ssRNA	1799	0.00128	W	Wat	Shimizu 2004	46.2486
BLV	ssRNA	221	0.01040	W	Wat	Guillemain 1981	99.3552
Borna virus	ssRNA	79	0.02920	W	Wat	Danner 1979	99.9999
Bovine Calicivirus	ssDNA	95	0.02420	W	Wat	Malley 2004	99.9992
Bovine Parvovirus	ssDNA	35	0.06580	W	-	vonBrodorotti 1982	100.0000
Canine Calicivirus	ssRNA	67	0.03450	W	Wat	deRodaHusman 2004	100.0000
Canine hepatic Adenovirus	dsDNA	265	0.00869	W	Wat	vonBrodorotti 1982	98.5215
CCHV (fish virus)	dsDNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
Cholera phage Kappa	dsDNA	634	0.00363	W	Wat	Samad 1987	82.8050
Coliphage f2	ssRNA	310	0.00743	W	Wat	Severin 1983	97.2743
Coliphage fd	ssDNA	23	0.09940	W	Wat	Rauth 1965	100.0000
Coliphage ϕX-174	ssDNA	3	0.71000	Air	Lo RH	Tseng 2005	100.0000
Coliphage ϕX-174	ssDNA	4	0.53000	Air	Hi RH	Tseng 2005	100.0000
Coliphage ϕX-174	ssDNA	18	0.12800	W	Wat	Yarus 1964	100.0000
Coliphage ϕX-174	ssDNA	21	0.11140	W	Wat	Setlow 1960	100.0000
Coliphage ϕX-174	ssDNA	21	0.11090	W	Wat	Rauth 1965	100.0000
Coliphage ϕX-174	ssDNA	30	0.07650	W	Wat	Proctor 1972	100.0000
Coliphage ϕX-174	ssDNA	25	0.09200	W	Wat	Gurzadyan 1981	100.0000
Coliphage ϕX-174	ssDNA	14	0.16060	W	Wat	David 1964	100.0000
Coliphage ϕX-174	ssDNA	25	0.09350	W	Wat	Sommer 1998	100.0000
Coliphage ϕX-174	ssDNA	57	0.04013	W	Wat	Sommer 2001	100.0000
Coliphage ϕX-174	ssDNA	177	0.01300	W	Wat	Nuanualsuw an 2002	99.8173

APPENDIX E: UV Kill Rates for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Coliphage ϕX-174	ssDNA	23	0.10230	W	Wat	Battigelli 1993	100.0000
Coliphage ϕX-174	ssDNA	40	0.05760	W	Wat	Oppenheimer 1993	100.0000
Coliphage ϕX-174	ssDNA	18	0.12910	W	Wat	Giese 2000	100.0000
Coliphage lambda	dsDNA	57	0.04050	W	Wat	Gurzadyan 1981	100.0000
Coliphage lambda	dsDNA	70	0.03310	W	Wat	Harm 1961	100.0000
Coliphage lambda	dsDNA	72	0.03200	W	Wat	Weigle 1953	100.0000
Coliphage lambda	dsDNA	184	0.01250	W	Wat	Davidovich 1991	99.7671
Coliphage PRD1	dsDNA	87	0.02650	S	-	Meng 1996	99.9997
Coliphage PRD1	dsDNA	20	0.11500	W	Wat	Shin 2005	100.0000
Coliphage T1	dsDNA	6	0.36970	W	Wat	Hotz 1969	100.0000
Coliphage T1	dsDNA	38	0.06000	W	Wat	Harm 1968	100.0000
Coliphage T1	dsDNA	40	0.05800	W	Wat	Fluke 1949 (265 nm)	100.0000
Coliphage T2	dsDNA	5	0.48400	W	Wat	Rauth 1965	100.0000
Coliphage T2	dsDNA	9	0.25600	W	Wat	Jagger 1956	100.0000
Coliphage T2	dsDNA	133	0.01730	W	Wat	Dulbecco 1952	99.9773
Coliphage T3	dsDNA	10	0.23100	W	Wat	Winkler 1962	100.0000
Coliphage T4	dsDNA	7	0.34500	W	Wat	Otaki 2003	100.0000
Coliphage T4	dsDNA	14	0.16850	W	Wat	Ross 1971	100.0000
Coliphage T4	dsDNA	15	0.15400	W	Wat	Harm 1968	100.0000
Coliphage T4	dsDNA	29	0.08000	W	Wat	Templeton 2006	100.0000
Coliphage T4	dsDNA	22	0.10700	W	Wat	Winkler 1962	100.0000
Coliphage T4	dsDNA	12	0.20000	W	Wat	Bohrerova 2008	100.0000
Coliphage T7	dsDNA	7	0.33000	Air	Lo RH	Tseng 2005	100.0000
Coliphage T7	dsDNA	10	0.22000	Air	Hi RH	Tseng 2005	100.0000
Coliphage T7	dsDNA	95	0.02420	W	Wat	Benzer 1952	99.9992
Coliphage T7	dsDNA	53	0.04320	W	Wat	Peak 1978 (B)	100.0000
Coliphage T7	dsDNA	41	0.05600	W	Wat	Bohrerova 2008 (LP)	100.0000
Coliphage T7	dsDNA	38	0.06100	W	Wat	Bohrerova 2008 (MP)	100.0000
Coliphage T7	dsDNA	23	0.10000	W	Wat	Ronto 1992	100.0000
Coliphage T7	dsDNA	11	0.20470	W	Wat	Peak 1978 (Bs-1)	100.0000
Coronavirus	ssRNA	3	0.37700	Air	50	Walker 2007	100.0000
Coronavirus	ssRNA	7	0.32100	W	Wat	Weiss 1986	100.0000
Coronavirus (SARS)	ssRNA	226	0.01000	W	Wat	Kariw a 2004	99.2172
Coronavirus (SARS)	ssRNA	3046	0.00076	W	Wat	Darnell 2004	30.6955
Coxsackievirus	ssRNA	21	0.11100	Air	60	Jensen 1964	100.0000
Coxsackievirus	ssRNA	128	0.02000	W	Wat	Hill 1970	99.9939
Coxsackievirus	ssRNA	86	0.02684	W	Wat	Havelaar 1987	99.9998
Coxsackievirus B3	ssRNA	80	0.02878	W	Wat	Gerba 2002	99.9999
Coxsackievirus B4	ssRNA	60	0.03840	W	Wat	Shin 2005	100.0000
Coxsackievirus B5	ssRNA	95	0.02424	W	Wat	Gerba 2002	99.9992
Coxsackievirus B5	ssRNA	72	0.03180	W	Wat	Battigelli 1993	100.0000
CSV (fish virus)	dsRNA	501	0.00460	W	Wat	Yoshimizu 2005	89.2579
Echovirus (Parechovirus)	ssRNA	106	0.02190	W	Wat	Hill 1970	99.9976
Echovirus 1	ssRNA	80	0.02878	W	Wat	Gerba 2002	99.9999
Echovirus 2	ssRNA	70	0.03289	W	Wat	Gerba 2002	100.0000
Encephalomyocarditis virus	ssRNA	50	0.04650	W	Wat	Ross 1971	100.0000

APPENDIX E: UV Kill Rates for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Encephalomyocarditis virus	ssRNA	52	0.04460	W	Wat	Rauth 1965	100.0000
Encephalomyocarditis virus	ssRNA	65	0.03550	W	Wat	Zavadova 1968	100.0000
Epstein-Barr virus (EBV)	ssDNA	162	0.01420	W	Wat	Henderson 1978	99.8979
Equine Herpes virus	dsDNA	25	0.09210	W	Wat	Weiss 1986	100.0000
EVA (fish virus)	ssRNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
EVEX (fish virus)	ssRNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
Feline Calicivirus (FeCV)	ssRNA	434	0.00530	W	Wat	Nuanualsuw an 2002	92.3503
Feline Calicivirus (FeCV)	ssRNA	80	0.02880	W	Wat	Thurston-Enriquez 2003	99.9999
Feline Calicivirus (FeCV)	ssRNA	40	0.05760	W	Wat	deRodaHusman 2004	100.0000
Feline Calicivirus (FeCV)	ssRNA	44	0.05270	W	Wat	Tree 2005	100.0000
Friend Murine Leukemia v.	ssRNA	320	0.00720	W	Wat	Yoshikura 1971	96.9560
Frog virus 3	dsDNA	25	0.09210	W	Wat	Martin 1982	100.0000
Hepatitis A virus	dsDNA	40	0.05760	W	Wat	Battigelli 1993	100.0000
Hepatitis A virus	dsDNA	45	0.05120	W	Wat	Wang 2004	100.0000
Hepatitis A virus	dsDNA	50	0.04610	W	Wat	Weidenmann 1993	100.0000
Hepatitis A virus	dsDNA	92	0.02500	W	Wat	Wang 1995	99.9995
Hepatitis A virus	dsDNA	98	0.02340	W	Wat	Wilson 1992	99.9988
Hepatitis A virus	dsDNA	307	0.00750	W	Wat	Nuanualsuw an 2002	97.3682
Herpes simplex virus (HRE)	dsDNA	40	0.05760	W	Wat	Pow ell 1959	100.0000
Herpes simplex virus Type 1	dsDNA	71	0.03260	W	Wat	Bockstahler 1976	100.0000
Herpes simplex virus Type 1	dsDNA	110	0.02090	W	Wat	Selsky 1978	99.9960
Herpes simplex virus Type 1	dsDNA	25	0.09330	W	Wat	Lytle 1971	100.0000
Herpes Simplex virus Type 1	dsDNA	35	0.06540	W	Wat	Ross 1971	100.0000
Herpes Simplex virus Type 1	dsDNA	21	0.11050	W	Wat	Albrecht 1974	100.0000
Herpes Simplex virus Type 1	dsDNA	41	0.05680	W	Wat	Henderson 1978	100.0000
Herpes Simplex virus Type 2	dsDNA	40	0.05756	W	Wat	Wolff 1973	100.0000
Herpes Simplex virus Type 2	dsDNA	41	0.05650	W	Wat	Ross 1971	100.0000
Herpes Simplex virus Type 2	dsDNA	75	0.03070	W	Wat	Ryan 1986	100.0000
Herpes Simplex virus Type 2	dsDNA	20	0.11800	W	Wat	Albrecht 1974	100.0000
HIV-1	ssRNA	280	0.00822	W	Wat	Yoshikura 1989	98.1439
HIRRV (fish virus)	ssRNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
HP1c1 phage	dsDNA	40	0.05760	W	Wat	Setlow 1972	100.0000
HTLV-1	ssRNA	20	0.11510	W	Wat	Shimizu 2004	100.0000
Human Cytomegalovirus	dsDNA	658	0.00350	S	-	Hirai 1977	81.6859
Human Cytomegalovirus	dsDNA	50	0.04605	S	-	Albrecht 1974	100.0000
Influenza A virus	ssRNA	19	0.11900	Air	68	Jensen 1964	100.0000
Influenza A virus	ssRNA	20	0.11700	W	Wat	Ross 1971	100.0000
Influenza A virus	ssRNA	48	0.04800	W	Wat	Hollaender 1944	100.0000
Influenza A virus	ssRNA	17	0.13810	W	Wat	Abraham 1979	100.0000
IHNV (fish virus)	ssRNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
IHNV (fish virus)	ssRNA	7	0.34500	W	Wat	Sako 1985	100.0000
IPNV (fish virus)	dsRNA	397	0.00580	W	Wat	Oye 2001	93.9975
IPNV (fish virus)	dsRNA	407	0.00566	W	Wat	Liltved 1995	93.5758
IPNV (fish virus)	dsRNA	501	0.00460	W	Wat	Yoshimizu 2005	89.2579
IPNV (fish virus)	dsRNA	626	0.00368	W	Wat	Ahne 1982	83.2169
IPNV (fish virus)	dsRNA	583	0.00395	W	Wat	Sako 1985	85.2769

APPENDIX E: UV Kill Rates for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Iridovirus (Bohle) (fish virus)	dsDNA	83	0.02760	W	Wat	Miocevic 1993	99.9998
ISAV (fish virus)	ssRNA	11	0.20900	W	Wat	Oye 2001	100.0000
ISAV (fish virus)	ssRNA	26	0.08970	W	Wat	Liltved 1995	100.0000
JF-LCDV (fish virus)	dsDNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
Kemerovo (R-10 strain)	dsRNA	230	0.01000	W	Wat	Zavadova 1975	99.2172
Kilham Rat Virus (parvovirus)	ssDNA	30	0.07650	W	Wat	Proctor 1972	100.0000
Lipovnik (Lip-91 strain)	dsRNA	299	0.00770	W	Wat	Zavadova 1975	97.6115
LLE46 (SV/Adeno hybrid)	dsDNA	606	0.00380	W	Wat	Defendi 1967	84.1658
Measles virus	ssRNA	22	0.10510	W	Wat	DiStefano 1976	100.0000
Mengovirus	dsRNA	162	0.01420	W	Wat	Miller 1974	99.8979
Minute Virus of Mice (MVM)	ssDNA	28	0.08200	W	Wat	Vos 1981	100.0000
Minute Virus of Mice (MVM)	ssDNA	17	0.13500	W	Wat	Rommelaere 1981	100.0000
Murine Cytomegalovirus	dsDNA	46	0.05000	W	Wat	Shanley 1982	100.0000
Moloney Murine Leukemia v.	ssRNA	115	0.02000	W	Wat	Nomura 1972	99.9939
Moloney Murine Leukemia v.	ssRNA	370	0.00622	W	Wat	Guillemain 1981	95.1037
Moloney Murine Leukemia v.	ssRNA	280	0.00822	W	Wat	Yoshikura 1989	98.1439
Murine Norovirus (MNV)	ssRNA	76	0.03040	W	Wat	Lee 2008	100.0000
Murine sarcoma virus	ssRNA	237	0.00970	W	Wat	Nomura 1972	99.0946
Murine sarcoma virus	ssRNA	144	0.01600	W	Wat	Kelloff 1970	99.9574
Murine sarcoma virus	ssRNA	299	0.00770	W	Wat	Yoshikura 1971	97.6115
Mycobacteriophage D29	dsDNA	16	0.14300	W	Wat	David 1973	100.0000
Mycobacteriophage D29	dsDNA	324	0.00710	W	Wat	Sellers 1970	96.8047
Mycobacteriophage D29A	dsDNA	268	0.00860	W	Wat	Sellers 1970	98.4563
Mycobacteriophage D32	dsDNA	354	0.00650	W	Wat	Sellers 1970	95.7255
Mycobacteriophage D4	dsDNA	245	0.00940	W	Wat	Sellers 1970	98.9527
Mycoplasmavirus MVL2	dsDNA	154	0.01500	W	Wat	Das 1977	99.9307
Mycoplasmavirus MVL51	ssDNA	79	0.02900	W	Wat	Das 1977	99.9999
Newcastle Disease Virus	ssRNA	8	0.27600	W	Wat	vonBrodorotti 1982	100.0000
Newcastle Disease Virus	ssRNA	45	0.05110	W	Wat	Levinson 1966	100.0000
Newcastle Disease Virus	ssRNA	16	0.14400	S	-	Rubin 1959	100.0000
OMV (fish virus)	ssRNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
Parvovirus H-1	ssDNA	25	0.09200	W	Wat	Cornellis 1982	100.0000
PFRV (fish virus)	ssRNA	5	0.46050	W	Wat	Yoshimizu 2005	100.0000
phage GA	ssRNA	200	0.01150	W	Wat	Simonet 2006	99.6218
phage phi 6	dsRNA	5	0.43000	Air	Lo RH	Tseng 2005	100.0000
phage phi 6	dsRNA	7	0.31000	Air	Hi RH	Tseng 2005	100.0000
phage B40-8 (B. fragilis)	dsDNA	67	0.03450	W	Wat	Sommer 2001	100.0000
phage B40-8 (B. fragilis)	dsDNA	86	0.02690	W	Wat	Sommer 1998	99.9998
Poliovirus	dsRNA	44	0.05230	S	-	Ma 1994	100.0000
Poliovirus type 1	dsRNA	41	0.05620	S	-	Meng 1996	100.0000
Poliovirus	dsRNA	71	0.03250	W	Wat	Helentjaris 1977	100.0000
Poliovirus	dsRNA	75	0.03070	W	Wat	Shin 2005	100.0000
Poliovirus	dsRNA	95	0.02420	W	Wat	Bishop 1967	99.9992
Poliovirus	dsRNA	52	0.04460	W	Wat	Dulbecco 1955	100.0000
Poliovirus type 1	dsRNA	67	0.03450	W	Wat	Chang 1985	100.0000
Poliovirus type 1	dsRNA	72	0.03200	W	Wat	Wilson 1992	100.0000

APPENDIX E: UV Kill Rates for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Poliovirus type 1	dsRNA	96	0.02400	W	Wat	Wetz 1982	99.9991
Poliovirus type 1	dsRNA	100	0.02300	W	Wat	Thompson 2003	99.9986
Poliovirus type 1	dsRNA	125	0.01840	W	Wat	Oppenheimer 1997	99.9867
Poliovirus type 1	dsRNA	224	0.01030	W	Wat	Nuanualsuw an 2003	99.3232
Poliovirus type 1	dsRNA	240	0.00960	W	Wat	Nuanualsuw an 2002	99.0496
Poliovirus type 1	dsRNA	111	0.02080	W	Wat	Hill 1970	99.9958
Poliovirus type 1	dsRNA	77	0.03000	W	Wat	Harris 1987	100.0000
Poliovirus type 1	dsRNA	80	0.02878	W	Wat	Gerba 2002	99.9999
Poliovirus type 1	dsRNA	83	0.02760	W	Wat	Simonet 2006	99.9998
Poliovirus type 1	dsRNA	57	0.04010	W	Wat	Tree 2005	100.0000
Poliovirus type 2	dsRNA	121	0.01910	W	Wat	Hill 1970	99.9905
Poliovirus type 3	dsRNA	103	0.02240	W	Wat	Hill 1970	99.9981
Polyomavirus	dsDNA	480	0.00480	W	Wat	vander Eb 1967	90.2509
Polyomavirus	dsDNA	640	0.00360	W	Wat	Defendi 1967	82.5530
Polyomavirus	dsDNA	696	0.00331	W	Wat	Rauth 1965	79.9181
Polyomavirus	dsDNA	501	0.00460	W	Wat	Latarjet 1967	89.2579
Polyomavirus (ssDNA)	ssDNA	120	0.01920	W	Wat	vander Eb 1967	99.9910
Porcine Parvovirus (PPV)	ssDNA	23	0.10230	W	Wat	Wang 2004	100.0000
Pseudorabies (PRV)	dsDNA	34	0.06760	W	Wat	Ross 1971	100.0000
Rabies virus (env)	ssRNA	10	0.21930	W	Wat	Weiss 1986	100.0000
Rauscher Murine Leukemia v.	ssRNA	157	0.01470	W	Wat	Kelloff 1970	99.9199
Rauscher Murine Leukemia v.	ssRNA	480	0.00480	W	Wat	Lovinger 1975	90.2509
Rauscher Murine Leukemia v.	ssRNA	959	0.00240	S	-	Stull 1976	68.7765
Reovirus	dsRNA	175	0.01316	W	Wat	Hill 1970	99.8307
Reovirus	dsRNA	186	0.01240	W	Wat	Wang 2004	99.7556
Reovirus	dsRNA	69	0.03358	W	Wat	vonBrodorotti 1982	100.0000
Reovirus	dsRNA	245	0.00940	W	Wat	Shaw 1973	98.9527
Reovirus	dsRNA	121	0.01910	W	Wat	Rauth 1965	99.9905
Reovirus	dsRNA	270	0.00853	W	Wat	McClain 1966	98.4030
Reovirus	dsRNA	174	0.01320	W	Wat	Hill 1970	99.8342
Reovirus type 1	dsRNA	153	0.01508	W	Wat	Harris 1987	99.9335
Reovirus 3	dsRNA	334	0.00690	W	Wat	Zavadova 1975	96.4793
Rotavirus	dsRNA	200	0.01150	W	Wat	Caballero 2004	99.6218
Rotavirus SA11	dsRNA	89	0.02600	W	Wat	Wilson 1992	99.9997
Rotavirus SA11	dsRNA	75	0.03070	W	Wat	Meng 1987	100.0000
Rotavirus SA11	dsRNA	105	0.02190	W	Wat	Battigelli 1993	99.9976
Rotavirus SA11	dsRNA	100	0.02300	W	Wat	Chang 1985	99.9986
Rotavirus SA11	dsRNA	84	0.02740	W	Wat	Sommer 1989	99.9998
Rous Sarcoma virus (RSV)	ssRNA	720	0.00320	W	Wat	Levinson 1966	78.8176
Rous Sarcoma virus (RSV)	ssRNA	240	0.00960	W	Wat	Golde 1961	99.0496
Rous Sarcoma virus (RSV)	ssRNA	200	0.01150	S	-	Rubin 1959	99.6218
SBNN (fish virus)	ssRNA	698	0.00330	W	Wat	Frerichs 2000	79.8204
Semliki forest virus	ssRNA	25	0.09210	W	Wat	Weiss 1986	100.0000
Simian virus 40	dsDNA	2503	0.00092	W	Wat	Bourre 1989	35.9944
Simian virus 40	dsDNA	1599	0.00144	W	Wat	Seemayer 1973	50.2620
Simian virus 40	dsDNA	1439	0.00160	W	Wat	Cornellis 1981	53.9757

APPENDIX E: UV Kill Rates for Viruses

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Simian virus 40	dsDNA	1245	0.00185	W	Wat	Bockstahler 1977	59.2311
Simian virus 40	dsDNA	886	0.00260	W	Wat	Defendi 1967	71.6629
Simian virus 40	dsDNA	650	0.00354	W	Wat	Sarasin 1978	82.0378
Simian virus 40	dsDNA	443	0.00520	W	Wat	Aaronson 1970	91.9701
Simian virus 40	dsDNA	23	0.10040	W	Wat	Cornellis 1982	100.0000
Simian virus 40	dsDNA	17	0.13160	W	Wat	Wang 2004	100.0000
Sindbis virus	ssRNA	22	0.10400	Air	62	Jensen 1964	100.0000
Sindbis virus	ssRNA	60	0.03864	W	Wat	vonBrodorotti 1982	100.0000
Sindbis virus	ssRNA	113	0.02030	W	Wat	Wang 2004	99.9947
Sindbis virus	ssRNA	50	0.04610	W	Wat	Zavadova 1975	100.0000
S. aureus phage	dsDNA	82	0.02800	S	-	Gates 1934	99.9999
S. aureus phage	dsDNA	77	0.03000	S	-	Sturm 1932	100.0000
S. aureus phage A994	dsDNA	65	0.03542	W	Wat	Sommer 1989	100.0000
SVCV (fish virus)	ssRNA	10	0.46050	W	Wat	Yoshimizu 2005	100.0000
Vaccinia virus	dsDNA	1	2.54000	Air	60	McDevitt 2007	100.0000
Vaccinia virus	dsDNA	15	0.15300	Air	65	Jensen 1964	100.0000
Vaccinia virus	dsDNA	7	0.34900	W	Wat	Galasso 1965	100.0000
Vaccinia virus	dsDNA	14	0.16450	W	Wat	Bossart 1978	100.0000
Vaccinia virus	dsDNA	14	0.16040	W	Wat	Ross 1971	100.0000
Vaccinia virus	dsDNA	18	0.12792	W	Wat	Klein 1994	100.0000
Vaccinia virus	dsDNA	22	0.10500	W	Wat	Zavadova 1971	100.0000
Vaccinia virus	dsDNA	28	0.08290	W	Wat	Rauth 1965	100.0000
Vaccinia virus	dsDNA	715	0.00322	W	Wat	Davidovich 1991	79.0221
Vaccinia virus	dsDNA	677	0.00340	W	Wat	Collier 1955	80.7758
VEE	ssRNA	55	0.04190	W	Wat	Smirnov 1992	100.0000
Vesicular Stomatitis virus	ssRNA	13	0.18060	W	Wat	Rauth 1965	100.0000
Vesicular Stomatitis virus	ssRNA	12	0.19000	W	Wat	Helentjaris 1977	100.0000
Vesicular Stomatitis virus	ssRNA	100	0.02300	W	Wat	Bay 1979	99.9986
Vesicular Stomatitis virus	ssRNA	6	0.38400	W	Wat	Shimizu 2004	100.0000
VHSV (fish virus)	ssRNA	3	0.87400	W	Wat	Oye 2001	100.0000
WEE	ssRNA	54	0.04300	W	Wat	Dubinin 1975	100.0000

NOTES

Type: Sp = Spore, Veg = Vegetative, VegY = Vegetative yeast
D_{90}: UV Dose for 90% inactivation (10% survival)
UVGI k: UV rate constant at the given D_{90} (and below the UL)
UL: Upper Limit within which D_{90} and rate constants are applicable
Media: A = Air, S = Surface, W = Water
Sh = Shoulder in decay curve (shoulder is ignored for k and D_{90} values)
St = Number of stages in decay curve (k & D_{90} only applies to first stage)
Dia.: Logmean diameter in microns, including envelope for viruses if any
MP: Medium Pressure UV lamp, LP: Low Pressure UV lamp

APPENDIX F: UV Kill Rates for Fungi and Other Microbes

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kowalski 2009)	Kill Rate %
Aspergillus amstelodami	Sp	700	0.00329	W	Wat	Jepson 1973	79.71650
Aspergillus amstelodami	Sp	258	0.00892	S	-	Luckiesh 1949	98.67823
Aspergillus amstelodami	Sp	669	0.00344	Air	67	Luckiesh 1949	81.14515
Aspergillus flavus	Sp	349	0.00660	S	-	Green 2004	95.92785
Aspergillus flavus	Sp	600	0.00384	-	-	Nagy 1964	84.45228
Aspergillus flavus	Sp	853	0.00270	W	Wat	Begum 2009	73.00450
Aspergillus fumigatus	Sp	535	0.00430	S	-	Green 2004	87.57550
Aspergillus fumigatus	Veg	560	0.00411	S	-	Chick 1963	86.38779
Aspergillus fumigatus	Sp	2240	0.00103	S	-	Chick 1963	39.25898
Aspergillus glaucus	Sp	440	0.00523	-	-	Nagy 1964	92.09818
Aspergillus niger	Sp	1771	0.00130	S	Lo RH	Zahl 1939	46.76744
Aspergillus niger	Sp	1439	0.00160	S	-	Fulton 1929	53.97567
Aspergillus niger	Veg	4480	0.00051	S	-	Chick 1963	22.06347
Aspergillus niger	Sp	1000	0.00230	W	Wat	Jepson 1973	67.26593
Aspergillus niger	Sp	315	0.00350	S	-	Kowalski 2001	81.68592
Aspergillus niger	Sp	1387	0.00166	S	-	Luckiesh 1949	55.29568
Aspergillus niger	Sp	750	0.00386	S	-	Gritz 1990	84.61997
Aspergillus niger	Sp	4480	0.00051	S	-	Chick 1963	22.06347
Aspergillus niger	Sp	3984	0.00058	Air	55	Luckiesh 1949	24.44656
Aspergillus niger	Sp	1320	0.00174	-	-	Nagy 1964	57.08830
Aspergillus niger	Sp	1681	0.00137	W	Wat	Begum 2009	48.54435
Aspergillus versicolor	Sp	384	0.00600	Air	85	vanOsdell 2002	94.55243
Aspergillus versicolor	Sp	768	0.00300	Air	55	vanOsdell 2002	76.65996
Aspergillus versicolor	Sp	139	0.01660	Air	50	vanOsdell 2002	99.96812
Aspergillus versicolor	Veg	96	0.02400	Air	(Lo RH)	Nakamura 1987	99.99912
Blastomyces dermatitidis	VegY	140	0.01645	S	-	Chick 1963	99.96567
Botrytis cinerea	Sp	250	0.00920	S	-	Marquenie 2002	98.84607
Candida albicans	VegY	230	0.01100	W	Wat	Dolman 1989	99.51801
Candida albicans	VegY	447	0.00515	W	Wat	Abshire 1981	91.77779
Candida albicans	VegY	750	0.00407	S	-	Gritz 1990	86.10929
Candida albicans	VegY	280	0.00822	S	-	Chick 1963	98.14708
Candida parapsilosis	VegY	98	0.02360	W	Wat	Severin 1983	99.99893
Cladosporium herbarum	Sp	500	0.04605	W	Wat	Jepson 1973	100.00000
Cladosporium herbarum	Sp	189	0.01220	S	-	Luckiesh 1949	99.73067
Cladosporium herbarum	Sp	622	0.00370	Air	53	Luckiesh 1949	83.37895
Cladosporium trichoides	Veg	560	0.00411	S	-	Chick 1963	86.38779
Cladosporium trichoides	Sp	1120	0.00206	S	-	Chick 1963	63.10528
C. sphaerospermum	Sp	1439	0.00210	Air	50	vanOsdell 2002	63.88638
Cladosporium wernecki	Sp	4480	0.00051	S	-	Chick 1963	22.06347
Cladosporium wernecki	Veg	560	0.00411	S	-	Chick 1963	86.38779
Cryptococcus neoformans	Sp	138	0.01670	S	-	Wang 1994	99.96963
Cryptococcus neoformans	VegY	280	0.00822	S	-	Chick 1963	98.14708
Curvularia lunata	Veg	560	0.00411	S	-	Chick 1963	86.38779
Eurotium rubrum	Sp	434	0.00531	W	Wat	Begum 2009	92.38728
Fusarium oxysporum	Sp	260	0.01420	W	Wat	Asthana 1992	99.89790

APPENDIX F: UV Kill Rates for Fungi and Other Microbes

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Media	RH %	UV k Source (Kow alski 2009)	Kill Rate %
Fusarium solani	Sp	313	0.00735	W	Wat	Asthana 1992	97.16778
Fusarium spp.	Sp	560	0.00411	S	-	Chick 1963	86.38780
Fusarium spp.	Veg	1120	0.00206	S	-	Chick 1963	63.10564
Histoplasma capsulatum	Veg	140	0.01645	S	-	Chick 1963	99.96567
Monilinia fructigena	Sp	167	0.01380	S	-	Marquenie 2002	99.87604
Mucor mucedo	Sp	600	0.00384	W	Wat	Jepson 1973	84.45228
Mucor mucedo	Sp	180	0.01280	S	-	Luckiesh 1949	99.79867
Mucor mucedo	Sp	577	0.00399	Air	63	Luckiesh 1949	85.55974
Mucor racemosus	Sp	170	0.01354	-	-	Nagy 1964	99.85970
Mucor spp.	Sp	140	0.01645	S	-	Chick 1963	99.96567
Mucor spp.	Veg	280	0.00822	S	-	Chick 1963	98.14708
Oospora lactis	Sp	28	0.08370	-	-	Nagy 1964	100.00000
Penicillium chrysogenum	Sp	400	0.00576	W	Wat	Jepson 1973	93.86944
Penicillium chrysogenum	Sp	148	0.01560	S	-	Luckiesh 1949	99.94822
Penicillium chrysogenum	Sp	1645	0.00180	Air	50	vanOsdell 2002	58.23034
Penicillium chrysogenum	Sp	531	0.00434	Air	41	Luckiesh 1949	87.81421
Penicillium corylophilium	Sp	381	0.00604	W	Wat	Begum 2009	94.65709
Penicillium digitatum	Sp	321	0.00718	W	Wat	Asthana 1992	96.92634
Penicillium digitatum	Sp	440	0.00523	-	-	Nagy 1964	92.09818
Penicillium expansum	Sp	130	0.01771	-	-	Nagy 1964	99.98141
Penicillium italicum	Sp	321	0.01140	W	Wat	Asthana 1992	99.60300
Penicillium roquefortii	Sp	130	0.01771	-	-	Nagy 1964	99.98141
Penicillium spp.	Sp	2240	0.00103	S	-	Chick 1963	39.25898
Penicillium spp.	Veg	280	0.00822	S	-	Chick 1963	98.14708
Rhizopus nigricans	Sp	3000	0.00077	W	Wat	Jepson 1973	31.08188
Rhizopus nigricans	Sp	267	0.00861	Air	62	Luckiesh 1949	98.46379
Rhizopus nigricans	Sp	1110	0.00207	-	-	Nagy 1964	63.43521
Rhizopus nigricans	Sp	173	0.01330	S	-	Kow alski 2001	99.84203
Rhizopus oryzae	Sp	4480	0.00051	S	-	Chick 1963	22.06347
Rhodotorula spp.	VegY	1120	0.00206	S	-	Chick 1963	63.10528
Saccharomyces spp.	VegY	44	0.05230	-	-	Nagy 1964	100.00000
Saccharomyces ellipsoideus	VegY	33	0.06980	-	-	Nagy 1964	100.00000
Scopulariopsis brevicaulis	Sp	650	0.01840	W	Wat	Jepson 1973	99.98668
Scopulariopsis brevicaulis	Sp	226	0.01020	S	-	Luckiesh 1949	99.28953
Scopulariopsis brevicaulis	Sp	2890	0.00344	Air	79	Luckiesh 1949	81.14515
Sporotrichum schenkii	VegY	280	0.00822	S	-	Chick 1963	98.14708
Stachybotrys chartarum	Sp	5575	0.00041	S	-	Green 2005	18.15189
Torula bergeri	Veg	4480	0.00051	S	-	Chick 1963	22.06347
Torula sphaerica	VegY	23	0.09986	Air	65	Luckiesh 1949	100.00000
Torula sphaerica	VegY	78	0.02940	S	-	Luckiesh 1949	99.99994
Trichophyton rubrum	Veg	560	0.00411	S	-	Chick 1963	86.38779
Trichophyton rubrum	Sp	560	0.00411	S	-	Chick 1963	86.38779
Ustilago zeae	VegY	1120	0.00206	S	-	Chick 1963	63.10528
Ustilago zeae	Sp	35	0.06580	-	-	Sussman 1966	100.00000
Yeast	VegY	40	0.05756	W	Wat	Jepson 1973	100.00000
Yeast (Brewer's)	VegY	100	0.02303	W	Wat	Jepson 1973	99.99859

APPENDIX F: UV Kill Rates for Fungi and Other Microbes

Protozoa and Other Microbes							
Microbe	**Type**	**D_{90} J/m^2**	**UVGI k m^2/J**	**Media**	**RH %**	**UV k Source** (Kowalski 2009)	**Kill Rate %**
Acanthameoba	Rhizopod	999	0.02100	W	Wat	Maya 2003	99.99623
Acanthameoba castellani	Rhizopod	992	0.00232	S	-	Gritz 1990	67.54125
Algae	Algae	1000	0.00230	-	-	Summer 1962	67.26593
Algae, blue-green	Algae	450	0.00512	-	-	Jepson 1973	91.63969
Cryptosporidium hominis	Protoz	30	0.07800	-	-	Johnson 2005	100.00000
Cryptosporidium parvum	Protoz	7	0.31400	W	Wat	Oguma 2001	100.00000
Cryptosporidium parvum	Protoz	20	0.11500	W	Wat	Zimmer 2003	100.00000
Cryptosporidium parvum	Protoz	10	0.23030	W	Wat	Shin 2001	100.00000
Cryptosporidium parvum	Protoz	50	0.04605	W	Wat	Craik 2001	100.00000
Cryptosporidium parvum	Protoz	10	0.23220	W	Wat	Bukhari 2004	100.00000
Cryptosporidium parvum	Protoz	5	0.45830	W	Wat	Morita 2002	100.00000
Encephalitozoon intestinalis	Protoz	29	0.07830	W	Wat	Marshall 2003	100.00000
Encephalitozoon intestinalis	Protoz	15	0.15350	W	Wat	Huffman 2002	100.00000
Encephalitozoon cuniculi	Protoz	43	0.05310	W	Wat	Marshall 2003	100.00000
Encephalitozoon hellem	Protoz	80	0.02880	W	Wat	Marshall 2003	99.99991
Giardia lamblia cysts	Protoz	50	0.04610	W	Wat	Campbell 2002	100.00000
Giardia lamblia cysts	Protoz	3	0.92100	W	Wat	Shin 2005	100.00000
Giardia lamblia cysts	Protoz	20	0.11500	W	Wat	Li 2007	100.00000
Giardia muris cysts	Protoz	10	0.23020	W	Wat	Craik 2001	100.00000
Giardia muris cysts	Protoz	7	0.34130	W	Wat	Hayes 2000	100.00000
Protozoa	Protoz	80	0.02878	-	-	Jepson 1973	99.99991
Protozoa	Protoz	240	0.00959	-	-	Summer 1962	99.04684
Prions (scrapie)	Prion	24315	0.00009	-	-	Bellinger-Kaw ahara 1987	4.48907
Prions (scrapie)	Prion	55618	0.00004	-	-	Alper 1967	1.98788

NOTES

Type: Sp = Spore, Veg = Vegetative, VegY = Vegetative yeast
D_{90}: UV Dose for 90% inactivation (10% survival)
UVGI k: UV rate constant at the given D_{90} (and below the UL)
UL: Upper Limit within which D_{90} and rate constants are applicable
Media: A = Air, S = Surface, W = Water
Sh = Shoulder in decay curve (shoulder is ignored for k and D_{90} values)
St = Number of stages in decay curve (k & D_{90} only applies to first stage)
Dia.: Logmean diameter in microns, including envelope for viruses if any
MP: Medium Pressure UV lamp, LP: Low Pressure UV lamp

(Diameters shown in red are unverified.)