Performance of the Airpura Air Disinfection Unit

Prepared for Airpura

by

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Executive Summary

The Airpura air disinfection unit consists of a charcoal filter, a HEPA filter and a UV lamp through which air is driven at airflows between 50 cfm and 340 cfm. Computer modeling and analysis of the Airpura UV disinfection unit indicates that it will remove pathogens from the air at high rates that approach 100%. The UV Dose produced by the unit at the operating airflow of **50 cfm** is **35.5 J/m^2** and the UV Dose produced at **340 cfm** is **5.22 J/m^2**. Eight bioweapon agents have been evaluated, these being TB bacilli (*Mycobacterium tuberculosis*), anthrax (*Bacillus anthacis* spores), smallpox (Variola virus), botulinum toxin, Influenza A virus, SARS virus, Ebola virus, and *Yersinia pestis* (plague), and high removal rates were found for all agents, these having an average removal rate of 99.999% at the operating airflow of 50 cfm, and 99.998% removal at the operating airflow of 340 cfm. Analysis of several hundred pathogens including bacteria, viruses, fungal spores and protozoa indicates that the net average removal rate for all pathogens exceeds **99.99%**. Modeling of the Airpura unit in a 400 ft^2 room indicates it will rapidly draw down the airborne concentrations of pathogens to harmless levels within a few hours.

Height:	16.3199 cm	6.42515 in
Length:	33.02 cm	13 in
Airflow:	1.41585 cu.m/min.	50.0007 cfm

Appendix B: Input Data for Computer Model – 340 cfm

---------- UV Program Input ----------

Filename: Airpura01.txt
Project Title: Airpura
Lamp Model: GUPH22-212T5L/4P
Number of Lamps: 3
Lamp Type: 1
UV Power: 2.832 Watts
Arclength: 16.57 cm 6.52362 in
Radius: 0.75 cm 0.295276 in
x1 coordinate: 3.19 cm 1.25591 in
y1 coordinate: 5.23 cm 2.05906 in
z1 coordinate: 3.625 cm 1.42717 in
x2 coordinate: 3.19 cm 1.25591 in
y2 coordinate: 11.75 cm 4.62598 in
z2 coordinate: 3.625 cm 1.42717 in
Lamp Type: 1
UV Power: 0.336 Watts
Arclength: 1.965 cm 0.773622 in
Radius: 0.75 cm 0.295276 in
x1 coordinate: 3.19 cm 1.25591 in
y1 coordinate: 5.23 cm 2.05906 in
z1 coordinate: 3.625 cm 1.42717 in
x2 coordinate: 3.96 cm 1.55906 in
y2 coordinate: 5.23 cm 2.05906 in
z2 coordinate: 3.625 cm 1.42717 in
Lamp Type: 1
UV Power: 2.832 Watts
Arclength: 16.57 cm 6.52362 in
Radius: 0.75 cm 0.295276 in
x1 coordinate: 4.06 cm 1.59843 in
y1 coordinate: 5.23 cm 2.05906 in
z1 coordinate: 3.625 cm 1.42717 in
x2 coordinate: 4.06 cm 1.59843 in
y2 coordinate: 11.75 cm 4.62598 in
z2 coordinate: 3.625 cm 1.42717 in
Reflectivity: 50 %
Width: 16.3199 cm 6.42515 in

Height:	16.3199 cm	6.42515 in
Length:	33.02 cm	13 in
Airflow:	9.62778 cu.m/min.	340.005 cfm

Appendix C: Analysis Results – 50 cfm

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

Target Microbe: Serratia marcescens

Rate Constant: 0.002909 cm2/microW-s

Logmean Diameter: 1.31 microns

Survival in Mixed Air: 0.00327309 %

Kill Rate in Mixed Air: 99.9967 % <

Survival in Unmixed Air: 0.0559744 %

Kill Rate in Unmixed Air: 99.944 % <

Configuration Efficiency: 5.84747 %

Exposure Time: 0.372687 sec

Average Direct Intensity: 3847.95 microW/cm2

Second Reflection : 1484.5 microW/cm2

Third Reflection : 421.705 microW/cm2

Fourth Reflection : 140.911 microW/cm2

Fifth Reflection : 55.9923 microW/cm2

6 etc. Reflections : 22.504 microW/cm2

Average Inter-reflection Intensity: 2148.11 microW/cm2

Total Average Intensity: 9525.64 microW/cm2

URV (UVGI Rating Value): 14

Appendix D: Analysis Results – 340 cfm

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

Target Microbe: Serratia marcescens

Rate Constant: 0.002909 cm2/microW-s

Logmean Diameter: 1.31 microns

Survival in Mixed Air: 21.8995 %

Kill Rate in Mixed Air: 78.1005 % <

Survival in Unmixed Air: 25.3391 %

Kill Rate in Unmixed Air: 74.6609 % <

Configuration Efficiency: 86.4257 %

Exposure Time: 0.0548069 sec

Average Direct Intensity: 3847.95 microW/cm2

Second Reflection : 1484.5 microW/cm2

Third Reflection : 421.705 microW/cm2

Fourth Reflection : 140.911 microW/cm2

Fifth Reflection : 55.9923 microW/cm2

6 etc. Reflections : 22.504 microW/cm2

Average Inter-reflection Intensity: 2148.11 microW/cm2

Total Average Intensity: 9525.64 microW/cm2

URV (UVGI Rating Value): 10

APPENDIX E: Total Removal Rates for Bacteria at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Acinetobacter baumannii	Veg	18	0.12800	1.225	98.9369	100.00	100.0000
Acinetobacter baumannii	Veg	33	0.19200	1.225	99.8904	100.00	100.0000
Aeromonas	Veg	11	0.20310	2.098	99.9261	100.00	100.0000
Aeromonas hydrophila	Veg	16	0.14100	2.098	99.3299	100.00	100.0000
B. atrophaeus (B. globigii)	Sp	144	0.01600	1.12	43.3342	100.00	100.0000
B. atrophaeus spores	Sp	1323	0.00174	1.12	5.9901	100.00	100.0000
Bacillus anthracis spores	Sp	411	0.00560	1.118	18.0286	100.00	100.0000
Bacillus anthracis spores	Sp	45	0.05094	1.118	83.6091	100.00	100.0000
Bacillus anthracis spores	Sp	743	0.00310	1.118	10.4211	100.00	100.0000
Bacillus cereus spores	Sp	267	0.00863	1.118	26.3882	100.00	100.0000
Bacillus cereus spores	Sp	210	0.01098	1.118	32.2876	100.00	100.0000
Bacillus cereus spores	Sp	116	0.01979	1.118	50.4668	100.00	100.0000
Bacillus cereus spores	Sp	408	0.00564	1.118	18.1377	100.00	100.0000
Bacillus megatherium	Sp	273	0.00843	1.12	25.8752	100.00	100.0000
Bacillus megatherium	Veg	113	0.02038	1.12	51.4889	100.00	100.0000
Bacillus pumilis spores	Sp	50	0.04600	1.12	80.4657	100.00	100.0000
Bacillus subtilis	Veg	25	0.09210	1.12	96.1976	100.00	100.0000
Bacillus subtilis	Veg	14	0.16858	1.12	99.7483	100.00	100.0000
Bacillus subtilis spores	Sp	250	0.00920	1.12	27.8628	100.00	100.0000
Bacillus subtilis spores	Sp	161	0.01430	1.12	39.8092	100.00	100.0000
Bacillus subtilis spores	Sp	116	0.01982	1.12	50.5218	100.00	100.0000
Bacillus subtilis spores	Sp	220	0.01047	1.12	31.0338	100.00	100.0000
Bacillus subtilis spores	Sp	199	0.01155	1.12	33.6366	100.00	100.0000
Bacillus subtilis spores	Sp	77	0.03000	1.12	65.5272	100.00	100.0000
Bacillus subtilis spores	Sp	155	0.01490	1.12	41.0777	100.00	100.0000
Bacillus subtilis spores	Sp	89	0.02580	1.12	59.9844	100.00	100.0000
Bacillus subtilis spores	Sp	200	0.01150	1.12	33.5187	100.00	100.0000
Bacillus subtilis spores	Sp	80	0.02880	1.12	64.0269	100.00	100.0000
Bacillus subtilis spores	Sp	94	0.02460	1.12	58.2429	100.00	100.0000
Bacillus subtilis spores	Sp	68	0.03370	1.12	69.7704	100.00	100.0000
Bacillus subtilis spores	Sp	113	0.02030	1.12	51.3564	100.00	100.0000
Bacillus subtilis spores	Sp	89	0.02600	1.12	60.2675	100.00	100.0000
Bacillus subtilis spores	Sp	149	0.01550	1.12	42.3194	100.00	100.0000
Bacillus subtilis spores	Sp	85	0.02700	1.12	61.6532	100.00	100.0000
Bacillus thuringiensis	Sp	2303	0.00100	1.120	3.4877	100.00	100.0000
Burkholderia cenocepacia	Veg	58	0.03956	0.707	75.4510	100.00	100.0000
Burkholderia cepacia	Veg	11	0.21150	0.77	99.9451	100.00	100.0000
Burkholderia cepacia	Veg	22	0.10520	0.77	97.6117	100.00	100.0000
Campylobacter jejuni	Veg	11	0.20933	2.12	99.9407	100.00	100.0000
Campylobacter jejuni	Veg	29	0.07940	2.12	94.0315	100.00	100.0000
Citrobacter diversus	Veg	32	0.07140	1.2	92.0714	100.00	100.0000
Citrobacter freundii	Veg	42	0.05482	1.2	85.7189	100.00	100.0000
Citrobacter freundii	Veg	46	0.05010	1.2	83.1117	100.00	100.0000
Clostridium difficile	Sp	128	0.01800	5	47.2180	100.00	100.0000
Clostridium perfringens	Veg	38	0.06000	5	88.1163	100.00	100.0000
Clostridium perfringens	Veg	135	0.01700	5	45.3106	100.00	100.0000

APPENDIX E: Total Removal Rates for Bacteria at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Clostridium tetani	Veg	49	0.04699	5	81.1414	100.00	100.0000
Corynebacterium diphtheriae	Veg	33	0.07010	0.698	91.6970	100.00	100.0000
Coxiella burnetii	Veg	15	0.15350	0.283	99.5700	99.96	99.9998
Deinococcus radiodurans	Veg	365	0.00630	1	20.0405	100.00	100.0000
Enterobacter cloacae	Veg	64	0.03598	1.414	72.1208	100.00	100.0000
Escherichia coli	Veg	21	0.10900	0.5	97.9131	100.00	100.0000
Escherichia coli	Veg	53	0.04320	0.5	78.4242	100.00	99.9999
Escherichia coli	Veg	20	0.11510	0.5	98.3195	100.00	100.0000
Escherichia coli	Veg	47	0.04940	0.5	82.6868	100.00	99.9999
Escherichia coli	Veg	43	0.05300	0.5	84.7639	100.00	99.9999
Escherichia coli	Veg	13	0.18000	0.5	99.8322	100.00	100.0000
Escherichia coli	Veg	20	0.11500	0.5	98.3135	100.00	100.0000
Escherichia coli	Veg	24	0.09600	0.5	96.6893	100.00	100.0000
Escherichia coli	Veg	81	0.02832	0.5	63.4114	100.00	99.9998
Escherichia coli	Veg	25	0.09398	0.5	96.4435	100.00	100.0000
Escherichia coli	Veg	19	0.12000	0.5	98.5878	100.00	100.0000
Escherichia coli	Veg	12	0.19300	0.5	99.8942	100.00	100.0000
Escherichia coli	Veg	25	0.09210	0.5	96.1981	100.00	100.0000
Escherichia coli	Veg	20	0.11670	0.5	98.4122	100.00	100.0000
Escherichia coli	Veg	51	0.04540	0.5	80.0452	100.00	99.9999
Escherichia coli	Veg	34	0.06720	0.5	90.7966	100.00	99.9999
Escherichia coli	Veg	55	0.04187	0.5	77.3772	100.00	99.9999
Escherichia coli	Veg	8	0.28300	0.5	99.9957	100.00	100.0000
Escherichia coli	Veg	3	0.72300	0.5	100.0000	100.00	100.0000
Escherichia coli	Veg	11	0.21800	0.5	99.9564	100.00	100.0000
Escherichia coli	Veg	11	0.21900	0.5	99.9580	100.00	100.0000
Escherichia coli	Veg	13	0.18100	0.5	99.8380	100.00	100.0000
Escherichia coli	Veg	15	0.15611	0.5	99.6082	100.00	100.0000
Escherichia coli	Veg	2	0.96500	0.5	100.0000	100.00	100.0000
Escherichia coli	Veg	11	0.20500	0.5	99.9309	100.00	100.0000
Francisella tularensis	Veg	256	0.00900	0.2	27.3488	99.95	99.9669
Francisella tularensis	Veg	288	0.00800	0.2	24.7233	99.95	99.9658
Haemophilus influenzae	Veg	38	0.05990	0.285	88.0740	99.96	99.9957
Haemophilus influenzae Rd	Veg	13	0.17700	0.285	99.8133	99.96	99.9999
Halobacterium sp. NRC-1	Veg	25	0.09210	1	96.1976	100.00	100.0000
Halobacterium salinarum	Veg	68	0.03390	1	69.9843	100.00	100.0000
Halomonas elongata	Veg	13	0.18090	1	99.8375	100.00	100.0000
Helicobacter pylori	Veg	33	0.06900	2.1	91.3663	100.00	100.0000
Klebsiella pneumoniae	Veg	42	0.05480	0.671	85.7070	100.00	100.0000
Klebsiella pneumoniae	Veg	68	0.03390	0.671	69.9843	100.00	100.0000
Klebsiella terrigena	Veg	33	0.07000	0.671	91.6674	100.00	100.0000
Legionella dumoffi	Veg	24	0.09594	0.52	96.6823	100.00	100.0000
Legionella bozemanii	Veg	19	0.17400	0.52	99.7923	100.00	100.0000
Legionella bozemanii	Veg	15	0.15351	0.52	99.5701	100.00	100.0000
Legionella gormanii	Veg	26	0.08856	0.52	95.6886	100.00	100.0000
Legionella jordanis	Veg	11	0.20933	0.52	99.9407	100.00	100.0000

APPENDIX E: Total Removal Rates for Bacteria at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Legionella longbeach	Veg	11	0.20933	0.52	99.9407	100.00	100.0000
Legionella micdadei	Veg	15	0.15351	0.52	99.5701	100.00	100.0000
Legionella oakridgensis	Veg	22	0.10466	0.52	97.5658	100.00	100.0000
Legionella pneumophila	Veg	13	0.17400	0.52	99.7923	100.00	100.0000
Legionella pneumophila	Veg	12	0.19298	0.52	99.8941	100.00	100.0000
Legionella pneumophila	Veg	9	0.24849	0.52	99.9852	100.00	100.0000
Legionella pneumophila	Veg	5	0.44613	0.52	100.0000	100.00	100.0000
Legionella pneumophila	Veg	25	0.09110	0.52	96.0602	100.00	100.0000
Legionella pneumophila	Veg	16	0.14390	0.52	99.3955	100.00	100.0000
Legionella pneumophila	Veg	19	0.12020	0.52	98.5978	100.00	100.0000
Legionella wadsworthii	Veg	4	0.57565	0.52	100.0000	100.00	100.0000
Listeria monocytogenes	Veg	73	0.03170	0.707	67.5461	100.00	100.0000
Listeria monocytogenes	Veg	156	0.01480	0.707	40.8681	100.00	100.0000
Listeria monocytogenes	Veg	10	0.23030	0.707	99.9719	100.00	100.0000
Micrococcus candidus	Veg	61	0.03806	1.2	74.1046	100.00	100.0000
Micrococcus piltonensis	Veg	81	0.02843	2.2	63.5474	100.00	100.0000
Micrococcus sphaeroides	Veg	100	0.02303	1.2	55.8430	100.00	100.0000
Moraxella	Veg	10965	0.00022	1.225	0.7780	100.00	100.0000
Mycobacterium avium-intra.	Veg	84	0.02740	1.118	62.1939	100.00	100.0000
Mycobacterium avium	Veg	60	0.03840	1.118	74.4159	100.00	100.0000
Mycobacterium avium	Veg	35	0.06580	1.118	90.3277	100.00	100.0000
Mycobacterium bovis BCG	Veg	22	0.10550	0.637	97.6370	100.00	100.0000
Mycobacterium bovis BCG	Veg	10	0.24200	0.637	99.9814	100.00	100.0000
Mycobacterium bovis BCG	Veg	12	0.19000	0.637	99.8823	100.00	100.0000
Mycobacterium bovis BCG	Veg	19	0.12000	0.637	98.5878	100.00	100.0000
Mycobacterium bovis BCG	Veg	33	0.07000	0.637	91.6674	100.00	100.0000
Mycobacterium flaviscens	Veg	120	0.01919	0.637	49.3981	100.00	100.0000
Mycobacterium fortuitum	Veg	68	0.03390	0.637	69.9843	100.00	100.0000
Mycobacterium fortuitum	Veg	96	0.02400	0.637	57.3439	100.00	100.0000
Mycobacterium kansasii	Veg	80	0.02880	0.637	64.0269	100.00	100.0000
Mycobacterium marinum	Veg	76	0.03030	0.637	65.8924	100.00	100.0000
Mycobacterium marinum	Veg	743	0.00310	0.637	10.4211	100.00	100.0000
Mycobacterium parafortuitum	Veg	13	0.18000	0.637	99.8322	100.00	100.0000
Mycobacterium parafortuitum	Veg	46	0.05000	0.637	83.0517	100.00	100.0000
Mycobacterium parafortuitum	Veg	19	0.12000	0.637	98.5878	100.00	100.0000
Mycobacterium phlei	Veg	76	0.03030	0.637	65.8924	100.00	100.0000
Mycobacterium phlei	Veg	63	0.03650	0.637	72.6307	100.00	100.0000
Mycobacterium phlei	Veg	23	0.10000	0.637	97.1275	100.00	100.0000
Mycobacterium phlei	Veg	16	0.14000	0.637	99.3057	100.00	100.0000
Mycobacterium smegmatis	Veg	108	0.02130	0.637	53.0530	100.00	100.0000
Mycobacterium smegmatis	Veg	1047	0.00220	0.637	7.5128	100.00	100.0000
Mycobacterium smegmatis	Veg	68	0.03400	0.637	70.0907	100.00	100.0000
Mycobacterium smegmatis	Veg	12	0.19000	0.637	99.8823	100.00	100.0000
Mycobacterium terrae	Veg	50	0.04610	0.637	80.5350	100.00	100.0000
Mycobacterium tuberculosis	Veg	28	0.08220	0.637	94.5964	100.00	100.0000
Mycobacterium tuberculosis	Veg	77	0.03000	0.637	65.5272	100.00	100.0000

Description of the System

The Airpura air disinfection system consists of an ultraviolet light in a cylindrical chamber into which air flows into the unit through a carbon filter and a HEPA filter before reaching the UV irradiation chamber. The UV lamp is a U-tube type lamp 7" long, Model GUPH22-212T5L/4P, with 19 W of power input and 6 W of UV output. It has a diameter of 15 mm (1.5 cm), or a radius of 7.5 mm (0.75 cm). Based on the vendor drawing (Light Sources GU22-212T5L) the arclength scales to approximately 29.2 cm. In the case of U-tube type lamps the arclength is not the length of the lamp body but about twice the body length plus the tip portion (the curved bend). The lamp rating is stated as 55 microW/cm^2. The lamp has a 1" (2.54 cm) base and sits 1.25" (3.175 cm) below the top of the chamber.

The UV chamber has an inside diameter of 7.25" (18.415 cm) and is 13" high (33.02 cm). The nominal flow rate through the chamber is 50 cfm and the highest flowrate is 300 cfm. The HEPA filter is a custom filter model 20510. The face area through which the airflow enters the UV chamber is Pi()(7.25)(13) = 296 in2 or 1910 cm^2. Table 1 summarizes the UV chamber dimensions and operating parameters. The Exposure Time at the lower airflow of 50 cfm is 0.373 seconds and this is within the minimum recommendation of 0.25 seconds per IUVA (2005). The Exposure Time at the higher airflow of 340 cfm is 0.055 seconds and this does not meet the minimum recommendation of 0.25 seconds. It can be seen in Table 1 that the air velocity through the HEPA filter is between 24 fpm (at 50 cfm) and 165 fpm (at 340 fpm). Since these face velocities are well within the minimum recommended face velocity of 250 fpm (ASHRAE) the HEPA filters will perform at least as well as their rating at 250 fpm.

Table 1: UV Chamber Parameters

Height	13	in	33.02	cm
	1.083333	ft	0.3302	m
Diameter	7.25	in	18.415	cm
	0.604167	ft	0.18415	m
Base Area	41.28249	in^2	266.3381	cm^2
	0.286684	ft^2	0.026634	m^2
Equivalent side	6.425145	in	16.31987	cm
HEPA Face Area	296.0951	in^2	1910.287	cm^2
	2.056216	ft^2	0.191029	m^2
Airflow 1	50	cfm	1.41585	m^3/min
Velocity 1	174.4081	fpm	53.15987	m/min
	2.906801	fps	0.885998	m/s
Exposure Time 1	0.372689	sec	0.372687	sec
HEPA Velocity 1	24.31651	fpm	7.411713	m/min
Airflow 2	340	cfm	9.62778	m^3/min
Velocity 2	1185.975	fpm	361.4871	m/min
	19.76625	fps	6.024785	m/s
Exposure Time 2	0.054807	sec	0.054807	sec
HEPA Velocity 2	165.3523	fpm	50.39965	m/min

APPENDIX E: Total Removal Rates for Bacteria at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Mycobacterium tuberculosis	Veg	74	0.03100	0.637	66.7295	100.00	100.0000
Mycobacterium tuberculosis	Veg	11	0.21320	0.637	99.9484	100.00	100.0000
Mycobacterium tuberculosis	Veg	5	0.47210	0.637	100.0000	100.00	100.0000
Mycoplasma arthritidis	Veg	7	0.31240	0.177	99.9985	99.96	100.0000
Mycoplasma fermentans	Veg	9	0.25220	0.177	99.9871	99.96	100.0000
Mycoplasma hominis	Veg	7	0.32710	0.177	99.9991	99.96	100.0000
Mycoplasma Orale type 1	Veg	11	0.21800	0.177	99.9564	99.96	100.0000
Mycoplasma Orale type 2	Veg	6	0.38760	0.177	99.9999	99.96	100.0000
Mycoplasma pneumoniae	Veg	8	0.27910	0.177	99.9950	99.96	100.0000
Mycoplasma salivarium	Veg	11	0.21140	0.177	99.9450	99.96	100.0000
Myxobolus cerebralis	Veg	10011	0.00023	1	0.8132	100.00	100.0000
Neisseria catarrhalis	Veg	44	0.05233	0.177	84.3979	99.96	99.9941
Nocardia asteroides	Veg	280	0.00822	1.118	25.3183	100.00	100.0000
Phytomonas tumefaciens	Veg	44	0.05233	1	84.3979	100.00	100.0000
Proteus mirabilis	Veg	8	0.28900	0.494	99.9965	100.00	100.0000
Proteus vulgaris	Veg	30	0.07675	0.291	93.4436	99.97	99.9978
Pseudomonas aeruginosa	Veg	10	0.22692	0.494	99.9683	100.00	100.0000
Pseudomonas aeruginosa	Veg	172	0.01340	0.494	37.8550	100.00	99.9995
Pseudomonas aeruginosa	Veg	36	0.06600	0.494	90.3961	100.00	99.9999
Pseudomonas aeruginosa	Veg	55	0.04190	0.494	77.4052	100.00	99.9998
Pseudomonas aeruginosa	Veg	55	0.04187	0.494	77.3772	100.00	99.9998
Pseudomonas aeruginosa	Veg	22	0.10470	0.494	97.5690	100.00	100.0000
Pseudomonas aeruginosa	Veg	10	0.23750	0.494	99.9782	100.00	100.0000
Pseudomonas aeruginosa	Veg	4	0.57210	0.494	100.0000	100.00	100.0000
Pseudomonas diminuta	Veg	96	0.02391	0.5	57.2082	100.00	99.9997
Pseudomonas fluorescens	Veg	35	0.06579	0.5	90.3236	100.00	99.9999
Pseudomonas fluorescens	Veg	3	0.47730	0.5	100.0000	100.00	100.0000
Pseudomonas maltophilia	Veg	70	0.03294	0.5	68.9450	100.00	99.9998
Pseudomonas putrefaciens	Veg	87	0.02662	0.5	61.1317	100.00	99.9998
Rickettsia prowazekii	Veg	13	0.17600	0.6	99.8066	100.00	100.0000
Salmonella spp.	Veg	11	0.21380	0.8	99.9494	100.00	100.0000
Salmonella anatum	Veg	60	0.03840	0.8	74.4159	100.00	100.0000
Salmonella derby	Veg	36	0.06360	0.8	89.5420	100.00	100.0000
Salmonella enteritidis	Veg	10	0.22100	0.8	99.9608	100.00	100.0000
Salmonella enteritidis	Veg	33	0.07010	0.8	91.6970	100.00	100.0000
Salmonella infantis	Veg	20	0.11510	0.8	98.3195	100.00	100.0000
Salmonella typhi	Veg	21	0.10760	0.806	97.8068	100.00	100.0000
Salmonella typhi	Veg	30	0.07675	0.806	93.4436	100.00	100.0000
Salmonella typhi	Veg	21	0.10760	0.806	97.8066	100.00	100.0000
Salmonella typhi	Veg	9	0.25580	0.806	99.9886	100.00	100.0000
Salmonella typhimurium	Veg	295	0.00780	0.8	24.1870	100.00	100.0000
Salmonella typhimurium	Veg	18	0.12830	0.8	98.9482	100.00	100.0000
Sarcina lutea	Veg	197	0.01169	1.48	33.9615	100.00	100.0000
Serratia indica	Veg	209	0.01100	0.632	32.3282	100.00	100.0000
Serratia marcescens	Veg	22	0.10490	0.632	97.5862	100.00	100.0000
Serratia marcescens	Veg	105	0.02194	0.632	54.1072	100.00	100.0000

APPENDIX E: Total Removal Rates for Bacteria at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Serratia marcescens	Veg	22	0.10470	0.632	97.5690	100.00	100.0000
Serratia marcescens	Veg	22	0.10466	0.632	97.5658	100.00	100.0000
Serratia marcescens	Veg	8	0.27742	0.632	99.9947	100.00	100.0000
Serratia marcescens	Veg	10	0.22080	0.632	99.9606	100.00	100.0000
Serratia marcescens	Veg	2	0.93900	0.632	100.0000	100.00	100.0000
Serratia marcescens	Veg	24	0.09500	0.632	96.5696	100.00	100.0000
Serratia marcescens	Veg	8	0.28670	0.632	99.9962	100.00	100.0000
Serratia marcescens	Veg	4	0.57500	0.632	100.0000	100.00	100.0000
Serratia marcescens	Veg	115	0.02000	0.632	50.8356	100.00	100.0000
Serratia marcescens	Veg	5	0.44490	0.632	100.0000	100.00	100.0000
Serratia marcescens	Veg	20	0.11300	0.632	98.1894	100.00	100.0000
Serratia marcescens	Veg	33	0.07000	0.632	91.6674	100.00	100.0000
Serratia marcescens	Veg	3	0.92000	0.632	100.0000	100.00	100.0000
Serratia marcescens	Veg	3	0.43050	0.632	100.0000	100.00	100.0000
Serratia marcescens	Veg	5	0.45000	0.632	100.0000	100.00	100.0000
Serratia marcescens	Veg	1	2.20000	0.632	100.0000	100.00	100.0000
Shigella dysenteriae	Veg	18	0.13080	0.801	99.0375	100.00	100.0000
Shigella paradysenteriae	Veg	17	0.13706	0.801	99.2293	100.00	100.0000
Shigella sonnei	Veg	18	0.12500	0.801	98.8175	100.00	100.0000
Spirillum rubrum	Veg	44	0.05233	1	84.3979	100.00	100.0000
Staphylococcus albus	Veg	18	0.12514	1.06	98.8233	100.00	100.0000
Staphylococcus albus	Veg	33	0.06978	1.06	91.6007	100.00	100.0000
Staphylococcus albus (1)	Veg	23	0.09950	1.06	97.0761	100.00	100.0000
Staphylococcus albus (2)	Veg	52	0.04400	1.06	79.0284	100.00	100.0000
Staphylococcus aureus	Veg	52	0.04400	0.866	79.0284	100.00	100.0000
Staphylococcus aureus	Veg	27	0.08531	0.866	95.1618	100.00	100.0000
Staphylococcus aureus	Veg	56	0.04134	0.866	76.9508	100.00	100.0000
Staphylococcus aureus	Veg	30	0.07700	0.866	93.5009	100.00	100.0000
Staphylococcus aureus	Veg	50	0.04652	0.866	80.8209	100.00	100.0000
Staphylococcus aureus	Veg	66	0.03500	0.866	71.1338	100.00	100.0000
Staphylococcus aureus	Veg	26	0.08860	0.866	95.6946	100.00	100.0000
Staphylococcus aureus	Veg	37	0.06240	0.866	89.0868	100.00	100.0000
Staphylococcus aureus	Veg	19	0.11840	0.866	98.5052	100.00	100.0000
Staphylococcus aureus	Veg	20	0.11300	0.866	98.1894	100.00	100.0000
Staphylococcus aureus	Veg	7	0.34760	0.866	99.9996	100.00	100.0000
Staphylococcus aureus	Veg	2	0.96020	0.866	100.0000	100.00	100.0000
Staphylococcus aureus	Veg	2	0.96200	0.866	100.0000	100.00	100.0000
Staphylococcus epidermis	Veg	161	0.01433	0.866	39.8713	100.00	100.0000
Staphylococcus epidermis	Veg	14	0.16210	0.866	99.6832	100.00	100.0000
Staphylococcus epidermis	Veg	29	0.00800	0.866	24.7233	100.00	100.0000
Staphylococcus epidermis	Veg	20	0.11300	0.866	98.1894	100.00	100.0000
Staphylococcus epidermis	Veg	22	0.10500	0.866	97.5947	100.00	100.0000
Streptococcus agalactiae	Veg	5	0.43420	0.707	100.0000	100.00	100.0000
Streptococcus faecalis	Veg	55	0.09200	0.707	96.1841	100.00	100.0000
Streptococcus faecalis	Veg	195	0.01180	0.707	34.2230	100.00	100.0000
Streptococcus faecalis	Veg	31	0.07540	0.707	93.1206	100.00	100.0000

APPENDIX E: Total Removal Rates for Bacteria at 50 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Streptococcus faecalis	Veg	120	0.01919	0.707	49.3981	100.00	100.0000
Streptococcus faecium	Veg	45	0.05100	0.632	83.6428	100.00	100.0000
Streptococcus haemolyticus	Veg	22	0.10660	0.707	97.7276	100.00	100.0000
Streptococcus lactis	Veg	62	0.03744	0.707	73.5294	100.00	100.0000
Streptococcus pneumoniae	Veg	468	0.00492	0.707	16.0258	100.00	100.0000
Streptococcus pyogenes	Veg	4	0.06161	0.894	88.7764	100.00	100.0000
Streptococcus pyogenes	Veg	1	1.56100	0.894	100.0000	100.00	100.0000
Streptococcus viridans	Veg	20	0.11513	0.707	98.3212	100.00	100.0000
Streptomyces coelicolor	Veg	60	0.03840	0.707	74.4159	100.00	100.0000
Streptomyces griseus	Veg	129	0.01780	0.707	46.8419	100.00	100.0000
Streptomyces griseus	Veg	60	0.03840	0.707	74.4159	100.00	100.0000
Vibrio anguillarum (fish)	Veg	10	0.23820	2.12	99.9787	100.00	100.0000
Vibrio anguillarum (fish)	Veg	5	0.42600	2.12	100.0000	100.00	100.0000
Vibrio cholerae	Veg	17	0.13400	2.12	99.1409	100.00	100.0000
Vibrio ordalii	Veg	18	0.12560	2.12	98.8424	100.00	100.0000
Vibrio parahaemolyticus	Veg	8	0.30700	2.12	99.9982	100.00	100.0000
Vibrio salmonicida (fish)	Veg	5	0.42600	2.12	100.0000	100.00	100.0000
Yersinia enterocolitica	Veg	15	0.15351	0.707	99.5701	100.00	100.0000
Yersinia enterocolitica	Veg	28	0.08127	0.707	94.4145	100.00	100.0000
Yersinia enterocolitica	Veg	11	0.20467	0.707	99.9301	100.00	100.0000
Yersinia enterocolitica	Veg	13	0.17170	0.707	99.7747	100.00	100.0000
Yersinia ruckeri (fish)	Veg	5	0.42600	0.707	100.0000	100.00	100.0000
Yersinia ruckeri (fish)	Veg	10	0.23020	0.707	99.9718	100.00	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, WRH = Relative Humidity

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

See Kowalski (2009) for References

APPENDIX F: Total Removal Rates for Viruses at 50 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Adenovirus	dsDNA	34	0.06800	0.079	91.0543	100.00	99.9997
Adenovirus	dsDNA	59	0.03900	0.079	74.9551	100.00	99.9992
Adenovirus	dsDNA	42	0.05500	0.079	85.8081	100.00	99.9995
Adenovirus	dsDNA	903	0.00255	0.079	8.6549	100.00	99.9970
Adenovirus type 1	dsDNA	299	0.00770	0.079	23.9174	100.00	99.9975
Adenovirus type 1	dsDNA	350	0.00658	0.079	20.8280	100.00	99.9974
Adenovirus type 2	dsDNA	400	0.00576	0.079	18.4929	100.00	99.9973
Adenovirus type 2	dsDNA	640	0.00360	0.079	11.9971	100.00	99.9971
Adenovirus type 2	dsDNA	490	0.00470	0.079	15.3673	100.00	99.9972
Adenovirus type 2	dsDNA	533	0.00432	0.079	14.2179	100.00	99.9972
Adenovirus type 2	dsDNA	150	0.01540	0.079	42.1143	100.00	99.9981
Adenovirus type 2	dsDNA	300	0.00768	0.079	23.8633	100.00	99.9975
Adenovirus type 2	dsDNA	400	0.00576	0.079	18.4827	100.00	99.9973
Adenovirus type 2	dsDNA	276	0.00834	0.079	25.6265	100.00	99.9976
Adenovirus type 4	dsDNA	921	0.00250	0.079	8.4926	100.00	99.9970
Adenovirus type 15	dsDNA	396	0.00581	0.079	18.6374	100.00	99.9974
Adenovirus type 40	dsDNA	300	0.00768	0.069	23.8498	100.00	99.9984
Adenovirus type 40	dsDNA	546	0.00422	0.069	13.9128	100.00	99.9981
Adenovirus type 41	dsDNA	240	0.00976	0.069	29.2752	100.00	99.9985
Adenovirus type 41	dsDNA	425	0.00542	0.069	17.5031	100.00	99.9982
Adenovirus type 41	dsDNA	555	0.00415	0.069	13.6987	100.00	99.9981
Adenovirus type 41	dsDNA	600	0.00384	0.069	12.7437	100.00	99.9981
Adenovirus type 5	dsDNA	400	0.00576	0.084	18.4929	100.00	99.9968
Adenovirus type 5	dsDNA	541	0.00426	0.084	14.0350	100.00	99.9966
Adenovirus type 5	dsDNA	720	0.00320	0.084	10.7385	100.00	99.9965
Adenovirus type 6	dsDNA	390	0.00590	0.079	18.9087	100.00	99.9974
Adenovirus type 6	dsDNA	400	0.00576	0.079	18.4929	100.00	99.9973
AHNV (fish virus)	ssRNA	349	0.00660	0.1	20.8876	99.99	99.9944
Avian Influenza virus	ssRNA	22	0.10600	0.09	97.6786	100.00	99.9999
Avian Influenza virus	ssRNA	30	0.07680	0.098	93.4545	99.99	99.9996
Avian Leukosis virus (RSA)	ssRNA	631	0.00365	0.107	12.1531	99.99	99.9921
Avian Sarcoma virus	ssDNA	155	0.01490	0.098	41.0777	99.99	99.9961
Avian Sarcoma virus	ssDNA	381	0.00604	0.098	19.2991	99.99	99.9946
B. subtilis phage 029	dsDNA	70	0.03289	0.1	68.8931	99.99	99.9978
B. subtilis phage SP02c12	dsDNA	100	0.02303	0.087	55.8430	100.00	99.9980
B. subtilis phage SPP1	dsDNA	195	0.01181	0.087	34.2420	100.00	99.9971
Bacteriophage B40-8	dsDNA	137	0.01679	0.1	44.9014	99.99	99.9961
Bacteriophage F-specific	dsRNA	292	0.00789	0.025	24.4169	100.00	99.9997
Bacteriophage MS2	ssRNA	26	0.04800	0.02	81.8046	100.00	99.9999
Bacteriophage MS2	ssRNA	61	0.03800	0.02	74.0500	100.00	99.9999
Bacteriophage MS2	ssRNA	3	0.81000	0.02	100.0000	100.00	100.0000
Bacteriophage MS2	ssRNA	4	0.64000	0.02	100.0000	100.00	100.0000
Bacteriophage MS2	ssRNA	606	0.00380	0.02	12.6197	100.00	99.9996
Bacteriophage MS2	ssRNA	135	0.01710	0.02	45.5044	100.00	99.9997
Bacteriophage MS2	ssRNA	427	0.00539	0.02	17.4182	100.00	99.9996

APPENDIX F: Total Removal Rates for Viruses at 50 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Bacteriophage MS2	ssRNA	193	0.01190	0.02	34.4561	100.00	99.9997
Bacteriophage MS2	ssRNA	419	0.00550	0.02	17.7371	100.00	99.9996
Bacteriophage MS2	ssRNA	368	0.00625	0.02	19.8985	100.00	99.9996
Bacteriophage MS2	ssRNA	295	0.00780	0.02	24.1870	100.00	99.9996
Bacteriophage MS2	ssRNA	40	0.05760	0.02	87.0594	100.00	99.9999
Bacteriophage MS2	ssRNA	173	0.01330	0.02	37.6340	100.00	99.9997
Bacteriophage MS2	ssRNA	275	0.00837	0.02	25.7056	100.00	99.9996
Bacteriophage MS2	ssRNA	217	0.01060	0.02	31.3604	100.00	99.9996
Bacteriophage MS2	ssRNA	250	0.00920	0.02	27.8628	100.00	99.9996
Bacteriophage MS2	ssRNA	217	0.01060	0.02	31.3604	100.00	99.9996
Bacteriophage MS2	ssRNA	217	0.01063	0.02	31.4334	100.00	99.9996
Bacteriophage MS2	ssRNA	213	0.01080	0.02	31.8460	100.00	99.9997
Bacteriophage MS2	ssRNA	187	0.01230	0.02	35.3802	100.00	99.9997
Bacteriophage MS2	ssRNA	169	0.01360	0.02	38.2947	100.00	99.9997
Bacteriophage MS2	ssRNA	164	0.01402	0.02	39.2079	100.00	99.9997
Bacteriophage MS2	ssRNA	150	0.01540	0.02	42.1143	100.00	99.9997
Bacteriophage MS2	ssRNA	140	0.01640	0.02	44.1332	100.00	99.9997
Bacteriophage MS2	ssRNA	198	0.01160	0.02	33.7543	100.00	99.9997
Bacteriophage MS2	ssRNA	228	0.01010	0.02	30.1311	100.00	99.9996
Bacteriophage MS2	ssRNA	245	0.00940	0.02	28.3731	100.00	99.9996
Bacteriophage Qβ	ssRNA	125	0.01840	0.02	47.9622	100.00	99.9997
Bacteriophage Qβ	ssRNA	1919	0.00120	0.02	4.1705	100.00	99.9995
Berne virus	ssRNA	13	0.18420	0.13	99.8554	99.98	100.0000
BF-NNV (fish virus)	ssRNA	501	0.00460	0.1	15.0664	99.99	99.9940
BLV	ssRNA	1799	0.00128	0.1	4.4423	99.99	99.9932
BLV	ssRNA	221	0.01040	0.1	30.8713	99.99	99.9951
Boma virus	ssRNA	79	0.02920	0.09	64.5342	100.00	99.9982
Bovine Calicivirus	ssDNA	95	0.02420	0.02	57.6457	100.00	99.9998
Bovine Parvovirus	ssDNA	35	0.06580	0.02	90.3277	100.00	100.0000
Canine Calicivirus	ssRNA	67	0.03450	0.037	70.6169	100.00	99.9998
Canine hepatic Adenovirus	dsDNA	265	0.00869	0.08	26.5422	100.00	99.9975
CCHV (fish virus)	dsDNA	5	0.46050	0.1	100.0000	99.99	100.0000
Cholera phage Kappa	dsDNA	634	0.00363	0.1	12.0907	99.99	99.9938
Coliphage f2	ssRNA	310	0.00743	0.1	23.1783	99.99	99.9945
Coliphage fd	ssDNA	23	0.09940	0.1	97.0657	99.99	99.9998
Coliphage ϕX-174	ssDNA	3	0.71000	0.025	100.0000	100.00	100.0000
Coliphage ϕX-174	ssDNA	4	0.53000	0.025	100.0000	100.00	100.0000
Coliphage ϕX-174	ssDNA	18	0.12800	0.025	98.9369	100.00	100.0000
Coliphage ϕX-174	ssDNA	21	0.11140	0.025	98.0836	100.00	100.0000
Coliphage ϕX-174	ssDNA	21	0.11090	0.025	98.0492	100.00	100.0000
Coliphage ϕX-174	ssDNA	30	0.07650	0.025	93.3845	100.00	100.0000
Coliphage ϕX-174	ssDNA	25	0.09200	0.025	96.1841	100.00	100.0000
Coliphage ϕX-174	ssDNA	14	0.16060	0.025	99.6658	100.00	100.0000
Coliphage ϕX-174	ssDNA	25	0.09350	0.025	96.3820	100.00	100.0000
Coliphage ϕX-174	ssDNA	57	0.04013	0.025	75.9399	100.00	99.9999
Coliphage ϕX-174	ssDNA	177	0.01300	0.025	36.9663	100.00	99.9997

APPENDIX F: Total Removal Rates for Viruses at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Coliphage ϕX-174	ssDNA	23	0.10230	0.025	97.3528	100.00	100.0000
Coliphage ϕX-174	ssDNA	40	0.05760	0.025	87.0594	100.00	99.9999
Coliphage ϕX-174	ssDNA	18	0.12910	0.025	98.9776	100.00	100.0000
Coliphage lambda	dsDNA	57	0.04050	0.05	76.2539	100.00	99.9998
Coliphage lambda	dsDNA	70	0.03310	0.05	69.1196	100.00	99.9997
Coliphage lambda	dsDNA	72	0.03200	0.05	67.8899	100.00	99.9997
Coliphage lambda	dsDNA	184	0.01250	0.05	35.8374	100.00	99.9994
Coliphage PRD1	dsDNA	87	0.02650	0.062	60.9665	100.00	99.9994
Coliphage PRD1	dsDNA	20	0.11500	0.062	98.3135	100.00	100.0000
Coliphage T1	dsDNA	6	0.36970	0.05	99.9998	100.00	100.0000
Coliphage T1	dsDNA	38	0.06000	0.05	88.1163	100.00	99.9999
Coliphage T1	dsDNA	40	0.05800	0.05	87.2419	100.00	99.9999
Coliphage T2	dsDNA	5	0.48400	0.065	100.0000	100.00	100.0000
Coliphage T2	dsDNA	9	0.25600	0.065	99.9887	100.00	100.0000
Coliphage T2	dsDNA	133	0.01730	0.065	45.8899	100.00	99.9990
Coliphage T3	dsDNA	10	0.23100	0.045	99.9725	100.00	100.0000
Coliphage T4	dsDNA	7	0.34500	0.089	99.9995	100.00	100.0000
Coliphage T4	dsDNA	14	0.16850	0.089	99.7476	100.00	100.0000
Coliphage T4	dsDNA	15	0.15400	0.089	99.5776	100.00	100.0000
Coliphage T4	dsDNA	29	0.08000	0.089	94.1574	100.00	99.9997
Coliphage T4	dsDNA	22	0.10700	0.089	97.7596	100.00	99.9999
Coliphage T4	dsDNA	12	0.20000	0.089	99.9175	100.00	100.0000
Coliphage T7	dsDNA	7	0.33000	0.063	99.9992	100.00	100.0000
Coliphage T7	dsDNA	10	0.22000	0.063	99.9594	100.00	100.0000
Coliphage T7	dsDNA	95	0.02420	0.063	57.6457	100.00	99.9993
Coliphage T7	dsDNA	53	0.04320	0.063	78.4242	100.00	99.9996
Coliphage T7	dsDNA	41	0.05600	0.063	86.3031	100.00	99.9998
Coliphage T7	dsDNA	38	0.06100	0.063	88.5307	100.00	99.9998
Coliphage T7	dsDNA	23	0.10000	0.063	97.1275	100.00	100.0000
Coliphage T7	dsDNA	11	0.20470	0.063	99.9302	100.00	100.0000
Coronavirus	ssRNA	3	0.37700	0.113	99.9998	99.99	100.0000
Coronavirus	ssRNA	7	0.32100	0.113	99.9989	99.99	100.0000
Coronavirus (SARS)	ssRNA	226	0.01000	0.113	29.8827	99.99	99.9925
Coronavirus (SARS)	ssRNA	3046	0.00076	0.113	2.6481	99.99	99.9895
Coxsackievirus	ssRNA	21	0.11100	0.027	98.0562	100.00	100.0000
Coxsackievirus	ssRNA	128	0.02000	0.027	50.8356	100.00	99.9998
Coxsackievirus	ssRNA	86	0.02684	0.027	61.4308	100.00	99.9998
Coxsackievirus B3	ssRNA	80	0.02878	0.027	64.0044	100.00	99.9998
Coxsackievirus B4	ssRNA	60	0.03840	0.027	74.4159	100.00	99.9999
Coxsackievirus B5	ssRNA	95	0.02424	0.027	57.7024	100.00	99.9998
Coxsackievirus B5	ssRNA	72	0.03180	0.027	67.6611	100.00	99.9999
CSV (fish virus)	dsRNA	501	0.00460	0.1	15.0664	99.99	99.9940
Echovirus (Parechovirus)	ssRNA	106	0.02190	0.024	54.0424	100.00	99.9998
Echovirus 1	ssRNA	80	0.02878	0.024	64.0044	100.00	99.9998
Echovirus 2	ssRNA	70	0.03289	0.024	68.8931	100.00	99.9999
Encephalomyocarditis virus	ssRNA	50	0.04650	0.025	80.8094	100.00	99.9999

APPENDIX F: Total Removal Rates for Viruses at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Encephalomyocarditis virus	ssRNA	52	0.04460	0.025	79.4703	100.00	99.9999
Encephalomyocarditis virus	ssRNA	65	0.03550	0.025	71.6417	100.00	99.9999
Epstein-Barr virus (EBV)	ssDNA	162	0.01420	0.1	39.5951	99.99	99.9957
Equine Herpes virus	dsDNA	25	0.09210	0.105	96.1976	99.99	99.9997
EVA (fish virus)	ssRNA	5	0.46050	0.06	100.0000	100.00	100.0000
EVEX (fish virus)	ssRNA	5	0.46050	0.06	100.0000	100.00	100.0000
Feline Calicivirus (FeCV)	ssRNA	434	0.00530	0.034	17.1510	100.00	99.9996
Feline Calicivirus (FeCV)	ssRNA	80	0.02880	0.034	64.0269	100.00	99.9998
Feline Calicivirus (FeCV)	ssRNA	40	0.05760	0.034	87.0594	100.00	99.9999
Feline Calicivirus (FeCV)	ssRNA	44	0.05270	0.034	84.6007	100.00	99.9999
Friend Murine Leukemia v.	ssRNA	320	0.00720	0.094	22.5548	99.99	99.9955
Frog virus 3	dsDNA	25	0.09210	0.167	96.1976	99.97	99.9987
Hepatitis A virus	dsDNA	40	0.05760	0.027	87.0594	100.00	99.9999
Hepatitis A virus	dsDNA	45	0.05120	0.027	83.7585	100.00	99.9999
Hepatitis A virus	dsDNA	50	0.04610	0.027	80.5350	100.00	99.9999
Hepatitis A virus	dsDNA	92	0.02500	0.027	58.8316	100.00	99.9998
Hepatitis A virus	dsDNA	98	0.02340	0.027	56.4256	100.00	99.9998
Hepatitis A virus	dsDNA	307	0.00750	0.027	23.3752	100.00	99.9997
Herpes simplex virus (HRE)	dsDNA	40	0.05760	0.18	87.0594	99.96	99.9949
Herpes simplex virus Type 1	dsDNA	71	0.03260	0.184	68.5666	99.96	99.9872
Herpes simplex virus Type 1	dsDNA	110	0.02090	0.184	52.3816	99.96	99.9806
Herpes simplex virus Type 1	dsDNA	25	0.09330	0.184	96.3562	99.96	99.9985
Herpes Simplex virus Type 1	dsDNA	35	0.06540	0.184	90.1893	99.96	99.9960
Herpes Simplex virus Type 1	dsDNA	21	0.11050	0.184	98.0213	99.96	99.9992
Herpes Simplex virus Type 1	dsDNA	41	0.05680	0.184	86.6866	99.96	99.9946
Herpes Simplex virus Type 2	dsDNA	40	0.05756	0.173	87.0431	99.96	99.9953
Herpes Simplex virus Type 2	dsDNA	41	0.05650	0.173	86.5441	99.96	99.9951
Herpes Simplex virus Type 2	dsDNA	75	0.03070	0.173	66.3733	99.96	99.9878
Herpes Simplex virus Type 2	dsDNA	20	0.11800	0.173	98.4839	99.96	99.9994
HIV-1	ssRNA	280	0.00822	0.125	25.3090	99.99	99.9888
HIRRV (fish virus)	ssRNA	5	0.46050	0.06	100.0000	100.00	100.0000
HP1c1 phage	dsDNA	40	0.05760	0.062	87.0594	100.00	99.9998
HTLV-1	ssRNA	20	0.11510	0.102	98.3195	99.99	99.9999
Human Cytomegalovirus	dsDNA	658	0.00350	0.1	11.6841	99.99	99.9937
Human Cytomegalovirus	dsDNA	50	0.04605	0.1	80.5004	99.99	99.9986
Influenza A virus	ssRNA	19	0.11900	0.098	98.5367	99.99	99.9999
Influenza A virus	ssRNA	20	0.11700	0.098	98.4291	99.99	99.9999
Influenza A virus	ssRNA	48	0.04800	0.098	81.8046	99.99	99.9988
Influenza A virus	ssRNA	17	0.13810	0.098	99.2572	99.99	100.0000
IHNV (fish virus)	ssRNA	5	0.46050	0.09	100.0000	100.00	100.0000
IHNV (fish virus)	ssRNA	7	0.34500	0.09	99.9995	100.00	100.0000
IPNV (fish virus)	dsRNA	397	0.00580	0.06	18.6086	100.00	99.9988
IPNV (fish virus)	dsRNA	407	0.00566	0.06	18.2030	100.00	99.9988
IPNV (fish virus)	dsRNA	501	0.00460	0.06	15.0664	100.00	99.9988
IPNV (fish virus)	dsRNA	626	0.00368	0.06	12.2466	100.00	99.9987
IPNV (fish virus)	dsRNA	583	0.00395	0.06	13.0837	100.00	99.9987

APPENDIX F: Total Removal Rates for Viruses at 50 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Iridovirus (Bohle) (fish virus)	dsDNA	83	0.02760	0.1	62.4614	99.99	99.9973
ISAV (fish virus)	ssRNA	11	0.20900	0.1	99.9401	99.99	100.0000
ISAV (fish virus)	ssRNA	26	0.08970	0.1	95.8595	99.99	99.9997
JF-LCDV (fish virus)	dsDNA	5	0.46050	0.14	100.0000	99.98	100.0000
Kemerovo (R-10 strain)	dsRNA	230	0.01000	0.075	29.8827	100.00	99.9981
Kilham Rat Virus (parvovirus)	ssDNA	30	0.07650	0.022	93.3845	100.00	100.0000
Lipovnik (Lip-91 strain)	dsRNA	299	0.00770	0.075	23.9174	100.00	99.9979
LLE46 (SV/Adeno hybrid)	dsDNA	606	0.00380	0.1	12.6197	99.99	99.9938
Measles virus	ssRNA	22	0.10510	0.329	97.6032	99.98	99.9995
Mengovirus	dsRNA	162	0.01420	0.1	39.5951	99.99	99.9957
Minute Virus of Mice (MVM)	ssDNA	28	0.08200	0.022	94.5579	100.00	100.0000
Minute Virus of Mice (MVM)	ssDNA	17	0.13500	0.022	99.1708	100.00	100.0000
Murine Cytomegalovirus	dsDNA	46	0.05000	0.104	83.0517	99.99	99.9986
Moloney Murine Leukemia v.	ssRNA	115	0.02000	0.094	50.8356	99.99	99.9972
Moloney Murine Leukemia v.	ssRNA	370	0.00622	0.094	19.8131	99.99	99.9954
Moloney Murine Leukemia v.	ssRNA	280	0.00822	0.094	25.3090	99.99	99.9957
Murine Norovirus (MNV)	ssRNA	76	0.03040	0.032	66.0133	100.00	99.9998
Murine sarcoma virus	ssRNA	237	0.00970	0.12	29.1319	99.99	99.9907
Murine sarcoma virus	ssRNA	144	0.01600	0.12	43.3342	99.99	99.9926
Murine sarcoma virus	ssRNA	299	0.00770	0.12	23.9174	99.99	99.9900
Mycobacteriophage D29	dsDNA	16	0.14300	0.065	99.3758	100.00	100.0000
Mycobacteriophage D29	dsDNA	324	0.00710	0.065	22.2794	100.00	99.9986
Mycobacteriophage D29A	dsDNA	268	0.00860	0.065	26.3098	100.00	99.9987
Mycobacteriophage D32	dsDNA	354	0.00650	0.07	20.6062	100.00	99.9982
Mycobacteriophage D4	dsDNA	245	0.00940	0.07	28.3731	100.00	99.9984
Mycoplasmavirus MVL2	dsDNA	154	0.01500	0.07	41.2865	100.00	99.9987
Mycoplasmavirus MVL51	ssDNA	79	0.02900	0.07	64.2814	100.00	99.9992
Newcastle Disease Virus	ssRNA	8	0.27600	0.212	99.9944	99.95	100.0000
Newcastle Disease Virus	ssRNA	45	0.05110	0.212	83.7007	99.95	99.9922
Newcastle Disease Virus	ssRNA	16	0.14400	0.212	99.3976	99.95	99.9997
OMV (fish virus)	ssRNA	5	0.46050	0.06	100.0000	100.00	100.0000
Parvovirus H-1	ssDNA	25	0.09200	0.022	96.1841	100.00	100.0000
PFRV (fish virus)	ssRNA	5	0.46050	0.06	100.0000	100.00	100.0000
phage GA	ssRNA	200	0.01150	0.1	33.5187	99.99	99.9953
phage phi 6	dsRNA	5	0.43000	0.1	100.0000	99.99	100.0000
phage phi 6	dsRNA	7	0.31000	0.1	99.9983	99.99	100.0000
phage B40-8 (B. fragilis)	dsDNA	67	0.03450	0.1	70.6169	99.99	99.9979
phage B40-8 (B. fragilis)	dsDNA	86	0.02690	0.1	61.5169	99.99	99.9973
Poliovirus	dsRNA	44	0.05230	0.0248	84.3805	100.00	99.9999
Poliovirus type 1	dsRNA	41	0.05620	0.0248	86.4000	100.00	99.9999
Poliovirus	dsRNA	71	0.03250	0.0248	68.4548	100.00	99.9999
Poliovirus	dsRNA	75	0.03070	0.0248	66.3733	100.00	99.9998
Poliovirus	dsRNA	95	0.02420	0.0248	57.6457	100.00	99.9998
Poliovirus	dsRNA	52	0.04460	0.0248	79.4703	100.00	99.9999
Poliovirus type 1	dsRNA	67	0.03450	0.0248	70.6169	100.00	99.9999
Poliovirus type 1	dsRNA	72	0.03200	0.0248	67.8899	100.00	99.9999

APPENDIX F: Total Removal Rates for Viruses at 50 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Poliovirus type 1	dsRNA	96	0.02400	0.0248	57.3439	100.00	99.9998
Poliovirus type 1	dsRNA	100	0.02300	0.0248	55.8024	100.00	99.9998
Poliovirus type 1	dsRNA	125	0.01840	0.0248	47.9622	100.00	99.9998
Poliovirus type 1	dsRNA	224	0.01030	0.0248	30.6254	100.00	99.9997
Poliovirus type 1	dsRNA	240	0.00960	0.0248	28.8799	100.00	99.9997
Poliovirus type 1	dsRNA	111	0.02080	0.0248	52.2122	100.00	99.9998
Poliovirus type 1	dsRNA	77	0.03000	0.0248	65.5272	100.00	99.9998
Poliovirus type 1	dsRNA	80	0.02878	0.0248	64.0044	100.00	99.9998
Poliovirus type 1	dsRNA	83	0.02760	0.0248	62.4614	100.00	99.9998
Poliovirus type 1	dsRNA	57	0.04010	0.0248	75.9143	100.00	99.9999
Poliovirus type 2	dsRNA	121	0.01910	0.0248	49.2394	100.00	99.9998
Poliovirus type 3	dsRNA	103	0.02240	0.0248	54.8509	100.00	99.9998
Polyomavirus	dsDNA	480	0.00480	0.0424	15.6673	100.00	99.9994
Polyomavirus	dsDNA	640	0.00360	0.0424	11.9971	100.00	99.9994
Polyomavirus	dsDNA	696	0.00331	0.0424	11.0864	100.00	99.9994
Polyomavirus	dsDNA	501	0.00460	0.0424	15.0664	100.00	99.9994
Polyomavirus (ssDNA)	ssDNA	120	0.01920	0.045	49.4193	100.00	99.9996
Porcine Parvovirus (PPV)	ssDNA	23	0.10230	0.021	97.3528	100.00	100.0000
Pseudorabies (PRV)	dsDNA	34	0.06760	0.194	90.9264	99.96	99.9960
Rabies virus (env)	ssRNA	10	0.21930	0.07	99.9584	100.00	100.0000
Rauscher Murine Leukemia v.	ssRNA	157	0.01470	0.094	40.6578	99.99	99.9966
Rauscher Murine Leukemia v.	ssRNA	480	0.00480	0.094	15.6673	99.99	99.9951
Rauscher Murine Leukemia v.	ssRNA	959	0.00240	0.094	8.1671	99.99	99.9947
Reovirus	dsRNA	175	0.01316	0.075	37.3180	100.00	99.9983
Reovirus	dsRNA	186	0.01240	0.075	35.6092	100.00	99.9982
Reovirus	dsRNA	69	0.03358	0.075	69.6407	100.00	99.9992
Reovirus	dsRNA	245	0.00940	0.075	28.3731	100.00	99.9980
Reovirus	dsRNA	121	0.01910	0.075	49.2394	100.00	99.9986
Reovirus	dsRNA	270	0.00853	0.075	26.1264	100.00	99.9980
Reovirus	dsRNA	174	0.01320	0.075	37.4122	100.00	99.9983
Reovirus type 1	dsRNA	153	0.01508	0.075	41.4580	100.00	99.9984
Reovirus 3	dsRNA	334	0.00690	0.075	21.7256	100.00	99.9978
Rotavirus	dsRNA	200	0.01150	0.07	33.5187	100.00	99.9985
Rotavirus SA11	dsRNA	89	0.02600	0.07	60.2675	100.00	99.9991
Rotavirus SA11	dsRNA	75	0.03070	0.07	66.3733	100.00	99.9992
Rotavirus SA11	dsRNA	105	0.02190	0.07	54.0424	100.00	99.9990
Rotavirus SA11	dsRNA	100	0.02300	0.07	55.8024	100.00	99.9990
Rotavirus SA11	dsRNA	84	0.02740	0.07	62.1939	100.00	99.9992
Rous Sarcoma virus (RSV)	ssRNA	720	0.00320	0.127	10.7385	99.98	99.9859
Rous Sarcoma virus (RSV)	ssRNA	240	0.00960	0.127	28.8799	99.98	99.9888
Rous Sarcoma virus (RSV)	ssRNA	200	0.01150	0.127	33.5187	99.98	99.9895
SBNN (fish virus)	ssRNA	698	0.00330	0.1	11.0548	99.99	99.9937
Semliki forest virus	ssRNA	25	0.09210	0.061	96.1976	100.00	99.9999
Simian virus 40	dsDNA	2503	0.00092	0.045	3.2132	100.00	99.9993
Simian virus 40	dsDNA	1599	0.00144	0.045	4.9835	100.00	99.9993
Simian virus 40	dsDNA	1439	0.00160	0.045	5.5217	100.00	99.9993

APPENDIX F: Total Removal Rates for Viruses at 50 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Simian virus 40	dsDNA	1245	0.00185	0.045	6.3565	100.00	99.9993
Simian virus 40	dsDNA	886	0.00260	0.045	8.8168	100.00	99.9993
Simian virus 40	dsDNA	650	0.00354	0.045	11.8094	100.00	99.9993
Simian virus 40	dsDNA	443	0.00520	0.045	16.8563	100.00	99.9994
Simian virus 40	dsDNA	23	0.10040	0.045	97.1680	100.00	100.0000
Simian virus 40	dsDNA	17	0.13160	0.045	99.0645	100.00	100.0000
Sindbis virus	ssRNA	22	0.10400	0.075	97.5078	100.00	99.9999
Sindbis virus	ssRNA	60	0.03864	0.075	74.6373	100.00	99.9993
Sindbis virus	ssRNA	113	0.02030	0.075	51.3564	100.00	99.9987
Sindbis virus	ssRNA	50	0.04610	0.075	80.5350	100.00	99.9995
S. aureus phage	dsDNA	82	0.02800	0.1	62.9907	99.99	99.9974
S. aureus phage	dsDNA	77	0.03000	0.1	65.5272	99.99	99.9976
S. aureus phage A994	dsDNA	65	0.03542	0.1	71.5655	99.99	99.9980
SVCV (fish virus)	ssRNA	10	0.46050	0.06	100.0000	100.00	100.0000
Vaccinia virus	dsDNA	1	2.54000	0.307	100.0000	99.97	100.0000
Vaccinia virus	dsDNA	15	0.15300	0.307	99.5623	99.97	99.9999
Vaccinia virus	dsDNA	7	0.34900	0.307	99.9996	99.97	100.0000
Vaccinia virus	dsDNA	14	0.16450	0.307	99.7090	99.97	99.9999
Vaccinia virus	dsDNA	14	0.16040	0.307	99.6635	99.97	99.9999
Vaccinia virus	dsDNA	18	0.12792	0.307	98.9339	99.97	99.9997
Vaccinia virus	dsDNA	22	0.10500	0.307	97.5947	99.97	99.9993
Vaccinia virus	dsDNA	28	0.08290	0.307	94.7290	99.97	99.9985
Vaccinia virus	dsDNA	715	0.00322	0.307	10.8019	99.97	99.9748
Vaccinia virus	dsDNA	677	0.00340	0.307	11.3700	99.97	99.9749
VEE	ssRNA	55	0.04190	0.065	77.4052	100.00	99.9996
Vesicular Stomatitis virus	ssRNA	13	0.18060	0.104	99.8357	99.99	100.0000
Vesicular Stomatitis virus	ssRNA	12	0.19000	0.104	99.8823	99.99	100.0000
Vesicular Stomatitis virus	ssRNA	100	0.02300	0.104	55.8024	99.99	99.9964
Vesicular Stomatitis virus	ssRNA	6	0.38400	0.104	99.9999	99.99	100.0000
VHSV (fish virus)	ssRNA	3	0.87400	0.07	100.0000	100.00	100.0000
WEE	ssRNA	54	0.04300	0.07	78.2705	100.00	99.9995

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, RH = Relative Humidity

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

See Kowalski (2009) for References

APPENDIX G: Total Removal of Fungi and Other Microbes at 50 cfm

Fungi	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Aspergillus amstelodami	Sp	700	0.00329	3.354	11.0214	100.00	100.0000
Aspergillus amstelodami	Sp	258	0.00892	3.354	27.1422	100.00	100.0000
Aspergillus amstelodami	Sp	669	0.00344	3.354	11.4958	100.00	100.0000
Aspergillus flavus	Sp	349	0.00660	4.24	20.8876	100.00	100.0000
Aspergillus flavus	Sp	600	0.00384	4.24	12.7364	100.00	100.0000
Aspergillus flavus	Sp	853	0.00270	4.24	9.1400	100.00	100.0000
Aspergillus fumigatus	Sp	535	0.00430	4.24	14.1570	100.00	100.0000
Aspergillus fumigatus	Veg	560	0.00411	24.5	13.5814	100.00	100.0000
Aspergillus fumigatus	Sp	2240	0.00103	2.64	3.5834	100.00	100.0000
Aspergillus glaucus	Sp	440	0.00523	3.354	16.9541	100.00	100.0000
Aspergillus niger	Sp	1771	0.00130	3.354	4.5101	100.00	100.0000
Aspergillus niger	Sp	1439	0.00160	3.354	5.5217	100.00	100.0000
Aspergillus niger	Veg	4480	0.00051	3.354	1.8080	100.00	100.0000
Aspergillus niger	Sp	1000	0.00230	3.354	7.8490	100.00	100.0000
Aspergillus niger	Sp	315	0.00350	3.354	11.6841	100.00	100.0000
Aspergillus niger	Sp	1387	0.00166	3.354	5.7227	100.00	100.0000
Aspergillus niger	Sp	750	0.00386	3.354	12.8056	100.00	100.0000
Aspergillus niger	Sp	4480	0.00051	3.354	1.8080	100.00	100.0000
Aspergillus niger	Sp	3984	0.00058	3.354	2.0310	100.00	100.0000
Aspergillus niger	Sp	1320	0.00174	3.354	6.0047	100.00	100.0000
Aspergillus niger	Sp	1681	0.00137	3.354	4.7471	100.00	100.0000
Aspergillus versicolor	Sp	384	0.00600	3.354	19.1844	100.00	100.0000
Aspergillus versicolor	Sp	768	0.00300	3.354	10.1025	100.00	100.0000
Aspergillus versicolor	Sp	139	0.01660	3.354	44.5285	100.00	100.0000
Aspergillus versicolor	Veg	96	0.02400	3.354	57.3439	100.00	100.0000
Blastomyces dermatitidis	VegY	140	0.01645	11.000	44.2264	100.00	100.0000
Botrytis cinerea	Sp	250	0.00920	11.180	27.8628	100.00	100.0000
Candida albicans	VegY	230	0.01100	4.899	32.3282	100.00	100.0000
Candida albicans	VegY	447	0.00515	4.899	16.7122	100.00	100.0000
Candida albicans	VegY	750	0.00407	4.899	13.4532	100.00	100.0000
Candida albicans	VegY	280	0.00822	4.899	25.3183	100.00	100.0000
Candida parapsilosis	VegY	98	0.02360	4.800	56.7339	100.00	100.0000
Cladosporium herbarum	Sp	500	0.04605	8.062	80.5004	100.00	100.0000
Cladosporium herbarum	Sp	189	0.01220	8.062	35.1504	100.00	100.0000
Cladosporium herbarum	Sp	622	0.00370	8.062	12.3089	100.00	100.0000
Cladosporium trichoides	Veg	560	0.00411	8.062	13.5814	100.00	100.0000
Cladosporium trichoides	Sp	1120	0.00206	8.062	7.0384	100.00	100.0000
C. sphaerospermum	Sp	1439	0.00210	8.062	7.1839	100.00	100.0000
Cladosporium wernecki	Sp	4480	0.00051	8.062	1.8080	100.00	100.0000
Cladosporium wernecki	Veg	560	0.00411	8.062	13.5814	100.00	100.0000
Cryptococcus neoformans	Sp	138	0.01670	4.899	44.7250	100.00	100.0000
Cryptococcus neoformans	VegY	280	0.00822	4.899	25.3183	100.00	100.0000
Curvularia lunata	Veg	560	0.00411	17.100	13.5814	100.00	100.0000
Eurotium rubrum	Sp	434	0.00531	5.612	17.1804	100.00	100.0000
Fusarium oxysporum	Sp	260	0.01420	11.225	39.5951	100.00	100.0000

APPENDIX G: Total Removal of Fungi and Other Microbes at 50 cfm

Fungi	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Fusarium solani	Sp	313	0.00735	11.225	22.9625	100.00	100.0000
Fusarium spp.	Sp	560	0.00411	11.225	13.5814	100.00	100.0000
Fusarium spp.	Veg	1120	0.00206	34.300	7.0385	100.00	100.0000
Histoplasma capsulatum	Veg	140	0.01645	2.550	44.2264	100.00	100.0000
Monilinia fructigena	Sp	167	0.01380	10.300	38.7312	100.00	100.0000
Mucor mucedo	Sp	600	0.00384	7.071	12.7364	100.00	100.0000
Mucor mucedo	Sp	180	0.01280	7.071	36.5171	100.00	100.0000
Mucor mucedo	Sp	577	0.00399	7.071	13.2071	100.00	100.0000
Mucor racemosus	Sp	170	0.01354	7.071	38.1732	100.00	100.0000
Mucor spp.	Sp	140	0.01645	7.071	44.2264	100.00	100.0000
Mucor spp.	Veg	280	0.00822	31.600	25.3183	100.00	100.0000
Oospora lactis	Sp	28	0.08370	3.000	94.8766	100.00	100.0000
Penicillium chrysogenum	Sp	400	0.00576	3.262	18.4827	100.00	100.0000
Penicillium chrysogenum	Sp	148	0.01560	3.262	42.5238	100.00	100.0000
Penicillium chrysogenum	Sp	1645	0.00180	3.262	6.1901	100.00	100.0000
Penicillium chrysogenum	Sp	531	0.00434	3.262	14.2788	100.00	100.0000
Penicillium corylophilium	Sp	381	0.00604	3.262	19.2991	100.00	100.0000
Penicillium digitatum	Sp	321	0.00718	3.262	22.4998	100.00	100.0000
Penicillium digitatum	Sp	440	0.00523	3.262	16.9541	100.00	100.0000
Penicillium expansum	Sp	130	0.01771	3.262	46.6760	100.00	100.0000
Penicillium italicum	Sp	321	0.01140	3.262	33.2823	100.00	100.0000
Penicillium roquefortii	Sp	130	0.01771	3.262	46.6760	100.00	100.0000
Penicillium spp.	Sp	2240	0.00103	3.262	3.5834	100.00	100.0000
Penicillium spp.	Veg	280	0.00822	8.800	25.3183	100.00	100.0000
Rhizopus nigricans	Sp	3000	0.00077	6.928	2.6879	100.00	100.0000
Rhizopus nigricans	Sp	267	0.00861	6.928	26.3359	100.00	100.0000
Rhizopus nigricans	Sp	1110	0.00207	6.928	7.0995	100.00	100.0000
Rhizopus nigricans	Sp	173	0.01330	6.928	37.6340	100.00	100.0000
Rhizopus oryzae	Sp	4480	0.00051	6.928	1.8080	100.00	100.0000
Rhodotorula spp.	VegY	1120	0.00206	5.900	7.0384	100.00	100.0000
Saccharomyces spp.	VegY	44	0.05230	4.000	84.3805	100.00	100.0000
Saccharomyces ellipsoideus	VegY	33	0.06980	4.000	91.6081	100.00	100.0000
Scopulariopsis brevicaulis	Sp	650	0.01840	5.916	47.9622	100.00	100.0000
Scopulariopsis brevicaulis	Sp	226	0.01020	5.916	30.3787	100.00	100.0000
Scopulariopsis brevicaulis	Sp	2890	0.00344	5.916	11.4958	100.00	100.0000
Sporotrichum schenkii	VegY	280	0.00822	5.500	25.3183	100.00	100.0000
Stachybotrys chartarum	Sp	5575	0.00041	5.623	1.4555	100.00	100.0000
Torula bergeri	Veg	4480	0.00051	40	1.8080	100.00	100.0000
Torula sphaerica	VegY	23	0.09986	40	97.1132	100.00	100.0000
Torula sphaerica	VegY	78	0.02940	40	64.7851	100.00	100.0000
Trichophyton rubrum	Veg	560	0.00411	4.899	13.5814	100.00	100.0000
Trichophyton rubrum	Sp	560	0.00411	4.899	13.5814	100.00	100.0000
Ustilago zeae	VegY	1120	0.00206	5.916	7.0384	100.00	100.0000
Ustilago zeae	Sp	35	0.06580	5.916	90.3277	100.00	100.0000
Yeast	VegY	40	0.05756	4	87.0431	100.00	100.0000
Yeast (Brewer's)	VegY	100	0.02303	4	55.8430	100.00	100.0000

APPENDIX G: Total Removal of Fungi and Other Microbes at 50 cfm

Protozoa and Other Microbes							
Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Acanthameoba	Rhizopod	999	0.02100	3	52.5503	100.00	100.0000
Acanthameoba castellani	Rhizopod	992	0.00232	3	7.9060	100.00	100.0000
Algae	Algae	1000	0.00230	3	7.8490	100.00	100.0000
Algae, blue-green	Algae	450	0.00512	3	16.6105	100.00	100.0000
Cryptosporidium hominis	Protoz	30	0.07800	3	93.7275	100.00	100.0000
Cryptosporidium parvum	Protoz	7	0.31400	3	99.9986	100.00	100.0000
Cryptosporidium parvum	Protoz	20	0.11500	3	98.3135	100.00	100.0000
Cryptosporidium parvum	Protoz	10	0.23030	3	99.9719	100.00	100.0000
Cryptosporidium parvum	Protoz	50	0.04605	3	80.5004	100.00	100.0000
Cryptosporidium parvum	Protoz	10	0.23220	3	99.9737	100.00	100.0000
Cryptosporidium parvum	Protoz	5	0.45830	3	100.0000	100.00	100.0000
Encephalitozoon intestinalis	Protoz	29	0.07830	3	93.7940	100.00	100.0000
Encephalitozoon intestinalis	Protoz	15	0.15350	3	99.5700	100.00	100.0000
Encephalitozoon cuniculi	Protoz	43	0.05310	3	84.8179	100.00	100.0000
Encephalitozoon hellem	Protoz	80	0.02880	3	64.0269	100.00	100.0000
Giardia lamblia cysts	Protoz	50	0.04610	3	80.5350	100.00	100.0000
Giardia lamblia cysts	Protoz	3	0.92100	3	100.0000	100.00	100.0000
Giardia lamblia cysts	Protoz	20	0.11500	3	98.3135	100.00	100.0000
Giardia muris cysts	Protoz	10	0.23020	3	99.9718	100.00	100.0000
Giardia muris cysts	Protoz	7	0.34130	3	99.9995	100.00	100.0000
Protozoa	Protoz	80	0.02878	3	64.0044	100.00	100.0000
Protozoa	Protoz	240	0.00959	3	28.8650	100.00	100.0000
Prions (scrapie)	Prion	24315	0.00009	3	0.3356	100.00	100.0000
Prions (scrapie)	Prion	55618	0.00004	3	0.1469	100.00	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 RH = Relative Humidity

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

See Kowalski (2009) for References

APPENDIX H: Total Removal Rates for Bacteria at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Acinetobacter baumannii	Veg	18	0.12800	1.225	48.7396	100.00	100.0000
Acinetobacter baumannii	Veg	33	0.19200	1.225	63.2994	100.00	100.0000
Aeromonas	Veg	11	0.20310	2.098	65.3658	100.00	100.0000
Aeromonas hydrophila	Veg	16	0.14100	2.098	52.1032	100.00	100.0000
B. atrophaeus (B. globigii)	Sp	144	0.01600	1.12	8.0138	100.00	100.0000
B. atrophaeus spores	Sp	1323	0.00174	1.12	0.9043	100.00	100.0000
Bacillus anthracis spores	Sp	411	0.00560	1.118	2.8813	100.00	100.0000
Bacillus anthracis spores	Sp	45	0.05094	1.118	23.3526	100.00	100.0000
Bacillus anthracis spores	Sp	743	0.00310	1.118	1.6054	100.00	100.0000
Bacillus cereus spores	Sp	267	0.00863	1.118	4.4055	100.00	100.0000
Bacillus cereus spores	Sp	210	0.01098	1.118	5.5727	100.00	100.0000
Bacillus cereus spores	Sp	116	0.01979	1.118	9.8157	100.00	100.0000
Bacillus cereus spores	Sp	408	0.00564	1.118	2.9003	100.00	100.0000
Bacillus megatherium	Sp	273	0.00843	1.12	4.3078	100.00	100.0000
Bacillus megatherium	Veg	113	0.02038	1.12	10.0919	100.00	100.0000
Bacillus pumilis spores	Sp	50	0.04600	1.12	21.3493	100.00	100.0000
Bacillus subtilis	Veg	25	0.09210	1.12	38.1729	100.00	100.0000
Bacillus subtilis	Veg	14	0.16858	1.12	58.5267	100.00	100.0000
Bacillus subtilis spores	Sp	250	0.00920	1.12	4.6895	100.00	100.0000
Bacillus subtilis spores	Sp	161	0.01430	1.12	7.1938	100.00	100.0000
Bacillus subtilis spores	Sp	116	0.01982	1.12	9.8305	100.00	100.0000
Bacillus subtilis spores	Sp	220	0.01047	1.12	5.3176	100.00	100.0000
Bacillus subtilis spores	Sp	199	0.01155	1.12	5.8517	100.00	100.0000
Bacillus subtilis spores	Sp	77	0.03000	1.12	14.4972	100.00	100.0000
Bacillus subtilis spores	Sp	155	0.01490	1.12	7.4840	100.00	100.0000
Bacillus subtilis spores	Sp	89	0.02580	1.12	12.6017	100.00	100.0000
Bacillus subtilis spores	Sp	200	0.01150	1.12	5.8272	100.00	100.0000
Bacillus subtilis spores	Sp	80	0.02880	1.12	13.9599	100.00	100.0000
Bacillus subtilis spores	Sp	94	0.02460	1.12	12.0525	100.00	100.0000
Bacillus subtilis spores	Sp	68	0.03370	1.12	16.1330	100.00	100.0000
Bacillus subtilis spores	Sp	113	0.02030	1.12	10.0558	100.00	100.0000
Bacillus subtilis spores	Sp	89	0.02600	1.12	12.6929	100.00	100.0000
Bacillus subtilis spores	Sp	149	0.01550	1.12	7.7734	100.00	100.0000
Bacillus subtilis spores	Sp	85	0.02700	1.12	13.1475	100.00	100.0000
Bacillus thuringiensis	Sp	2303	0.00100	1.120	0.5207	100.00	100.0000
Burkholderia cenocepacia	Veg	58	0.03956	0.707	18.6614	100.00	100.0000
Burkholderia cepacia	Veg	11	0.21150	0.77	66.8518	100.00	100.0000
Burkholderia cepacia	Veg	22	0.10520	0.77	42.2600	100.00	100.0000
Campylobacter jejuni	Veg	11	0.20933	2.12	66.4734	100.00	100.0000
Campylobacter jejuni	Veg	29	0.07940	2.12	33.9344	100.00	100.0000
Citrobacter diversus	Veg	32	0.07140	1.2	31.1169	100.00	100.0000
Citrobacter freundii	Veg	42	0.05482	1.2	24.8901	100.00	100.0000
Citrobacter freundii	Veg	46	0.05010	1.2	23.0149	100.00	100.0000
Clostridium difficile	Sp	128	0.01800	5	8.9693	100.00	100.0000
Clostridium perfringens	Veg	38	0.06000	5	26.8928	100.00	100.0000
Clostridium perfringens	Veg	135	0.01700	5	8.4928	100.00	100.0000

APPENDIX H: Total Removal Rates for Bacteria at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Clostridium tetani	Veg	49	0.04699	5	21.7553	100.00	100.0000
Corynebacterium diphtheriae	Veg	33	0.07010	0.698	30.6478	100.00	100.0000
Coxiella burnetii	Veg	15	0.15350	0.283	55.1291	99.96	99.9836
Deinococcus radiodurans	Veg	365	0.00630	1	3.2356	100.00	100.0000
Enterobacter cloacae	Veg	64	0.03598	1.414	17.1254	100.00	100.0000
Escherichia coli	Veg	21	0.10900	0.5	43.3942	100.00	99.9996
Escherichia coli	Veg	53	0.04320	0.5	20.1911	100.00	99.9995
Escherichia coli	Veg	20	0.11510	0.5	45.1685	100.00	99.9997
Escherichia coli	Veg	47	0.04940	0.5	22.7330	100.00	99.9995
Escherichia coli	Veg	43	0.05300	0.5	24.1717	100.00	99.9995
Escherichia coli	Veg	13	0.18000	0.5	60.9267	100.00	99.9998
Escherichia coli	Veg	20	0.11500	0.5	45.1398	100.00	99.9997
Escherichia coli	Veg	24	0.09600	0.5	39.4190	100.00	99.9996
Escherichia coli	Veg	81	0.02832	0.5	13.7450	100.00	99.9995
Escherichia coli	Veg	25	0.09398	0.5	38.7777	100.00	99.9996
Escherichia coli	Veg	19	0.12000	0.5	46.5534	100.00	99.9997
Escherichia coli	Veg	12	0.19300	0.5	63.4905	100.00	99.9998
Escherichia coli	Veg	25	0.09210	0.5	38.1740	100.00	99.9996
Escherichia coli	Veg	20	0.11670	0.5	45.6246	100.00	99.9997
Escherichia coli	Veg	51	0.04540	0.5	21.1025	100.00	99.9995
Escherichia coli	Veg	34	0.06720	0.5	29.5898	100.00	99.9996
Escherichia coli	Veg	55	0.04187	0.5	19.6330	100.00	99.9995
Escherichia coli	Veg	8	0.28300	0.5	77.1784	100.00	99.9999
Escherichia coli	Veg	3	0.72300	0.5	97.7053	100.00	100.0000
Escherichia coli	Veg	11	0.21800	0.5	67.9578	100.00	99.9998
Escherichia coli	Veg	11	0.21900	0.5	68.1247	100.00	99.9998
Escherichia coli	Veg	13	0.18100	0.5	61.1301	100.00	99.9998
Escherichia coli	Veg	15	0.15611	0.5	55.7373	100.00	99.9997
Escherichia coli	Veg	2	0.96500	0.5	99.3513	100.00	100.0000
Escherichia coli	Veg	11	0.20500	0.5	65.7076	100.00	99.9998
Francisella tularensis	Veg	256	0.00900	0.2	4.5900	99.95	99.9566
Francisella tularensis	Veg	288	0.00800	0.2	4.0906	99.95	99.9564
Haemophilus influenzae	Veg	38	0.05990	0.285	26.8546	99.96	99.9738
Haemophilus influenzae Rd	Veg	13	0.17700	0.285	60.3099	99.96	99.9858
Halobacterium sp. NRC-1	Veg	25	0.09210	1	38.1729	100.00	100.0000
Halobacterium salinarum	Veg	68	0.03390	1	16.2205	100.00	100.0000
Halomonas elongata	Veg	13	0.18090	1	61.1098	100.00	100.0000
Helicobacter pylori	Veg	33	0.06900	2.1	30.2484	100.00	100.0000
Klebsiella pneumoniae	Veg	42	0.05480	0.671	24.8809	100.00	100.0000
Klebsiella pneumoniae	Veg	68	0.03390	0.671	16.2205	100.00	100.0000
Klebsiella terrigena	Veg	33	0.07000	0.671	30.6116	100.00	100.0000
Legionella dumoffi	Veg	24	0.09594	0.52	39.4004	100.00	99.9998
Legionella bozemanii	Veg	19	0.17400	0.52	59.6833	100.00	99.9998
Legionella bozemanii	Veg	15	0.15351	0.52	55.1304	100.00	99.9998
Legionella gormanii	Veg	26	0.08856	0.52	37.0199	100.00	99.9998
Legionella jordanis	Veg	11	0.20933	0.52	66.4734	100.00	99.9999

APPENDIX H: Total Removal Rates for Bacteria at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Legionella longbeach	Veg	11	0.20933	0.52	66.4734	100.00	99.9999
Legionella micdadei	Veg	15	0.15351	0.52	55.1304	100.00	99.9998
Legionella oakridgensis	Veg	22	0.10466	0.52	42.0979	100.00	99.9998
Legionella pneumophila	Veg	13	0.17400	0.52	59.6833	100.00	99.9998
Legionella pneumophila	Veg	12	0.19298	0.52	63.4865	100.00	99.9999
Legionella pneumophila	Veg	9	0.24849	0.52	72.6735	100.00	99.9999
Legionella pneumophila	Veg	5	0.44613	0.52	90.2616	100.00	100.0000
Legionella pneumophila	Veg	25	0.09110	0.52	37.8493	100.00	99.9998
Legionella pneumophila	Veg	16	0.14390	0.52	52.8229	100.00	99.9998
Legionella pneumophila	Veg	19	0.12020	0.52	46.6091	100.00	99.9998
Legionella wadsworthii	Veg	4	0.57565	0.52	95.0476	100.00	100.0000
Listeria monocytogenes	Veg	73	0.03170	0.707	15.2527	100.00	100.0000
Listeria monocytogenes	Veg	156	0.01480	0.707	7.4357	100.00	100.0000
Listeria monocytogenes	Veg	10	0.23030	0.707	69.9507	100.00	100.0000
Micrococcus candidus	Veg	61	0.03806	1.2	18.0202	100.00	100.0000
Micrococcus piltonensis	Veg	81	0.02843	2.2	13.7922	100.00	100.0000
Micrococcus sphaeroides	Veg	100	0.02303	1.2	11.3267	100.00	100.0000
Moraxella	Veg	10965	0.00022	1.225	0.1148	100.00	100.0000
Mycobacterium avium-intra.	Veg	84	0.02740	1.118	13.3287	100.00	100.0000
Mycobacterium avium	Veg	60	0.03840	1.118	18.1659	100.00	100.0000
Mycobacterium avium	Veg	35	0.06580	1.118	29.0733	100.00	100.0000
Mycobacterium bovis BCG	Veg	22	0.10550	0.637	42.3503	100.00	100.0000
Mycobacterium bovis BCG	Veg	10	0.24200	0.637	71.7313	100.00	100.0000
Mycobacterium bovis BCG	Veg	12	0.19000	0.637	62.9142	100.00	100.0000
Mycobacterium bovis BCG	Veg	19	0.12000	0.637	46.5534	100.00	100.0000
Mycobacterium bovis BCG	Veg	33	0.07000	0.637	30.6116	100.00	100.0000
Mycobacterium flaviscens	Veg	120	0.01919	0.637	9.5322	100.00	100.0000
Mycobacterium fortuitum	Veg	68	0.03390	0.637	16.2205	100.00	100.0000
Mycobacterium fortuitum	Veg	96	0.02400	0.637	11.7765	100.00	100.0000
Mycobacterium kansasii	Veg	80	0.02880	0.637	13.9599	100.00	100.0000
Mycobacterium marinum	Veg	76	0.03030	0.637	14.6311	100.00	100.0000
Mycobacterium marinum	Veg	743	0.00310	0.637	1.6054	100.00	100.0000
Mycobacterium parafortuitum	Veg	13	0.18000	0.637	60.9267	100.00	100.0000
Mycobacterium parafortuitum	Veg	46	0.05000	0.637	22.9747	100.00	100.0000
Mycobacterium parafortuitum	Veg	19	0.12000	0.637	46.5534	100.00	100.0000
Mycobacterium phlei	Veg	76	0.03030	0.637	14.6311	100.00	100.0000
Mycobacterium phlei	Veg	63	0.03650	0.637	17.3501	100.00	100.0000
Mycobacterium phlei	Veg	23	0.10000	0.637	40.6710	100.00	100.0000
Mycobacterium phlei	Veg	16	0.14000	0.637	51.8525	100.00	100.0000
Mycobacterium smegmatis	Veg	108	0.02130	0.637	10.5241	100.00	100.0000
Mycobacterium smegmatis	Veg	1047	0.00220	0.637	1.1420	100.00	100.0000
Mycobacterium smegmatis	Veg	68	0.03400	0.637	16.2643	100.00	100.0000
Mycobacterium smegmatis	Veg	12	0.19000	0.637	62.9142	100.00	100.0000
Mycobacterium terrae	Veg	50	0.04610	0.637	21.3903	100.00	100.0000
Mycobacterium tuberculosis	Veg	28	0.08220	0.637	34.8933	100.00	100.0000
Mycobacterium tuberculosis	Veg	77	0.03000	0.637	14.4972	100.00	100.0000

APPENDIX H: Total Removal Rates for Bacteria at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Mycobacterium tuberculosis	Veg	74	0.03100	0.637	14.9425	100.00	100.0000
Mycobacterium tuberculosis	Veg	11	0.21320	0.637	67.1447	100.00	100.0000
Mycobacterium tuberculosis	Veg	5	0.47210	0.637	91.4966	100.00	100.0000
Mycoplasma arthritidis	Veg	7	0.31240	0.177	80.4257	99.96	99.9926
Mycoplasma fermentans	Veg	9	0.25220	0.177	73.1972	99.96	99.9898
Mycoplasma hominis	Veg	7	0.32710	0.177	81.8717	99.96	99.9931
Mycoplasma Orale type 1	Veg	11	0.21800	0.177	67.9578	99.96	99.9878
Mycoplasma Orale type 2	Veg	6	0.38760	0.177	86.7815	99.96	99.9950
Mycoplasma pneumoniae	Veg	8	0.27910	0.177	76.7090	99.96	99.9911
Mycoplasma salivarium	Veg	11	0.21140	0.177	66.8345	99.96	99.9874
Myxobolus cerebralis	Veg	10011	0.00023	1	0.1200	100.00	100.0000
Neisseria catarrhalis	Veg	44	0.05233	0.177	23.9066	99.96	99.9711
Nocardia asteroides	Veg	280	0.00822	1.118	4.2024	100.00	100.0000
Phytomonas tumefaciens	Veg	44	0.05233	1	23.9066	100.00	100.0000
Proteus mirabilis	Veg	8	0.28900	0.494	77.8822	100.00	99.9998
Proteus vulgaris	Veg	30	0.07675	0.291	33.0152	99.97	99.9774
Pseudomonas aeruginosa	Veg	10	0.22692	0.494	69.4160	100.00	99.9998
Pseudomonas aeruginosa	Veg	172	0.01340	0.494	6.7567	100.00	99.9993
Pseudomonas aeruginosa	Veg	36	0.06600	0.494	29.1473	100.00	99.9995
Pseudomonas aeruginosa	Veg	55	0.04190	0.494	19.6476	100.00	99.9994
Pseudomonas aeruginosa	Veg	55	0.04187	0.494	19.6330	100.00	99.9994
Pseudomonas aeruginosa	Veg	22	0.10470	0.494	42.1091	100.00	99.9996
Pseudomonas aeruginosa	Veg	10	0.23750	0.494	71.0593	100.00	99.9998
Pseudomonas aeruginosa	Veg	4	0.57210	0.494	94.9550	100.00	100.0000
Pseudomonas diminuta	Veg	96	0.02391	0.5	11.7353	100.00	99.9994
Pseudomonas fluorescens	Veg	35	0.06579	0.5	29.0689	100.00	99.9996
Pseudomonas fluorescens	Veg	3	0.47730	0.5	91.7243	100.00	99.9999
Pseudomonas maltophilia	Veg	70	0.03294	0.5	15.8001	100.00	99.9995
Pseudomonas putrefaciens	Veg	87	0.02662	0.5	12.9748	100.00	99.9994
Rickettsia prowazekii	Veg	13	0.17600	0.6	60.1021	100.00	100.0000
Salmonella spp.	Veg	11	0.21380	0.8	67.2475	100.00	100.0000
Salmonella anatum	Veg	60	0.03840	0.8	18.1659	100.00	100.0000
Salmonella derby	Veg	36	0.06360	0.8	28.2540	100.00	100.0000
Salmonella enteritidis	Veg	10	0.22100	0.8	68.4558	100.00	100.0000
Salmonella enteritidis	Veg	33	0.07010	0.8	30.6478	100.00	100.0000
Salmonella infantis	Veg	20	0.11510	0.8	45.1685	100.00	100.0000
Salmonella typhi	Veg	21	0.10760	0.806	42.9789	100.00	100.0000
Salmonella typhi	Veg	30	0.07675	0.806	33.0152	100.00	100.0000
Salmonella typhi	Veg	21	0.10760	0.806	42.9782	100.00	100.0000
Salmonella typhi	Veg	9	0.25580	0.806	73.6963	100.00	100.0000
Salmonella typhimurium	Veg	295	0.00780	0.8	3.9904	100.00	100.0000
Salmonella typhimurium	Veg	18	0.12830	0.8	48.8198	100.00	100.0000
Sarcina lutea	Veg	197	0.01169	1.48	5.9197	100.00	100.0000
Serratia indica	Veg	209	0.01100	0.632	5.5810	100.00	100.0000
Serratia marcescens	Veg	22	0.10490	0.632	42.1695	100.00	100.0000
Serratia marcescens	Veg	105	0.02194	0.632	10.8225	100.00	100.0000

APPENDIX H: Total Removal Rates for Bacteria at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Serratia marcescens	Veg	22	0.10470	0.632	42.1091	100.00	100.0000
Serratia marcescens	Veg	22	0.10466	0.632	42.0979	100.00	100.0000
Serratia marcescens	Veg	8	0.27742	0.632	76.5038	100.00	100.0000
Serratia marcescens	Veg	10	0.22080	0.632	68.4228	100.00	100.0000
Serratia marcescens	Veg	2	0.93900	0.632	99.2570	100.00	100.0000
Serratia marcescens	Veg	24	0.09500	0.632	39.1019	100.00	100.0000
Serratia marcescens	Veg	8	0.28670	0.632	77.6150	100.00	100.0000
Serratia marcescens	Veg	4	0.57500	0.632	95.0308	100.00	100.0000
Serratia marcescens	Veg	115	0.02000	0.632	9.9148	100.00	100.0000
Serratia marcescens	Veg	5	0.44490	0.632	90.1991	100.00	100.0000
Serratia marcescens	Veg	20	0.11300	0.632	44.5640	100.00	100.0000
Serratia marcescens	Veg	33	0.07000	0.632	30.6116	100.00	100.0000
Serratia marcescens	Veg	3	0.92000	0.632	99.1795	100.00	100.0000
Serratia marcescens	Veg	3	0.43050	0.632	89.4339	100.00	100.0000
Serratia marcescens	Veg	5	0.45000	0.632	90.4566	100.00	100.0000
Serratia marcescens	Veg	1	2.20000	0.632	99.9990	100.00	100.0000
Shigella dysenteriae	Veg	18	0.13080	0.801	49.4835	100.00	100.0000
Shigella paradysenteriae	Veg	17	0.13706	0.801	51.1074	100.00	100.0000
Shigella sonnei	Veg	18	0.12500	0.801	47.9305	100.00	100.0000
Spirillum rubrum	Veg	44	0.05233	1	23.9066	100.00	100.0000
Staphylococcus albus	Veg	18	0.12514	1.06	47.9686	100.00	100.0000
Staphylococcus albus	Veg	33	0.06978	1.06	30.5301	100.00	100.0000
Staphylococcus albus (1)	Veg	23	0.09950	1.06	40.5159	100.00	100.0000
Staphylococcus albus (2)	Veg	52	0.04400	1.06	20.5237	100.00	100.0000
Staphylococcus aureus	Veg	52	0.04400	0.866	20.5237	100.00	100.0000
Staphylococcus aureus	Veg	27	0.08531	0.866	35.9431	100.00	100.0000
Staphylococcus aureus	Veg	56	0.04134	0.866	19.4119	100.00	100.0000
Staphylococcus aureus	Veg	30	0.07700	0.866	33.1016	100.00	100.0000
Staphylococcus aureus	Veg	50	0.04652	0.866	21.5612	100.00	100.0000
Staphylococcus aureus	Veg	66	0.03500	0.866	16.7003	100.00	100.0000
Staphylococcus aureus	Veg	26	0.08860	0.866	37.0328	100.00	100.0000
Staphylococcus aureus	Veg	37	0.06240	0.866	27.8031	100.00	100.0000
Staphylococcus aureus	Veg	19	0.11840	0.866	46.1050	100.00	100.0000
Staphylococcus aureus	Veg	20	0.11300	0.866	44.5640	100.00	100.0000
Staphylococcus aureus	Veg	7	0.34760	0.866	83.7117	100.00	100.0000
Staphylococcus aureus	Veg	2	0.96020	0.866	99.3349	100.00	100.0000
Staphylococcus aureus	Veg	2	0.96200	0.866	99.3411	100.00	100.0000
Staphylococcus epidermis	Veg	161	0.01433	0.866	7.2079	100.00	100.0000
Staphylococcus epidermis	Veg	14	0.16210	0.866	57.0992	100.00	100.0000
Staphylococcus epidermis	Veg	29	0.00800	0.866	4.0906	100.00	100.0000
Staphylococcus epidermis	Veg	20	0.11300	0.866	44.5640	100.00	100.0000
Staphylococcus epidermis	Veg	22	0.10500	0.866	42.1997	100.00	100.0000
Streptococcus agalactiae	Veg	5	0.43420	0.707	89.6360	100.00	100.0000
Streptococcus faecalis	Veg	55	0.09200	0.707	38.1406	100.00	100.0000
Streptococcus faecalis	Veg	195	0.01180	0.707	5.9745	100.00	100.0000
Streptococcus faecalis	Veg	31	0.07540	0.707	32.5398	100.00	100.0000

APPENDIX H: Total Removal Rates for Bacteria at 340 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Streptococcus faecalis	Veg	120	0.01919	0.707	9.5322	100.00	100.0000
Streptococcus faecium	Veg	45	0.05100	0.632	23.3758	100.00	100.0000
Streptococcus haemolyticus	Veg	22	0.10660	0.707	42.6808	100.00	100.0000
Streptococcus lactis	Veg	62	0.03744	0.707	17.7549	100.00	100.0000
Streptococcus pneumoniae	Veg	468	0.00492	0.707	2.5359	100.00	100.0000
Streptococcus pyogenes	Veg	4	0.06161	0.894	27.5047	100.00	100.0000
Streptococcus pyogenes	Veg	1	1.56100	0.894	99.9711	100.00	100.0000
Streptococcus viridans	Veg	20	0.11513	0.707	45.1768	100.00	100.0000
Streptomyces coelicolor	Veg	60	0.03840	0.707	18.1659	100.00	100.0000
Streptomyces griseus	Veg	129	0.01780	0.707	8.8742	100.00	100.0000
Streptomyces griseus	Veg	60	0.03840	0.707	18.1659	100.00	100.0000
Vibrio anguillarum (fish)	Veg	10	0.23820	2.12	71.1649	100.00	100.0000
Vibrio anguillarum (fish)	Veg	5	0.42600	2.12	89.1827	100.00	100.0000
Vibrio cholerae	Veg	17	0.13400	2.12	50.3204	100.00	100.0000
Vibrio ordalii	Veg	18	0.12560	2.12	48.0933	100.00	100.0000
Vibrio parahaemolyticus	Veg	8	0.30700	2.12	79.8660	100.00	100.0000
Vibrio salmonicida (fish)	Veg	5	0.42600	2.12	89.1827	100.00	100.0000
Yersinia enterocolitica	Veg	15	0.15351	0.707	55.1304	100.00	100.0000
Yersinia enterocolitica	Veg	28	0.08127	0.707	34.5757	100.00	100.0000
Yersinia enterocolitica	Veg	11	0.20467	0.707	65.6493	100.00	100.0000
Yersinia enterocolitica	Veg	13	0.17170	0.707	59.1963	100.00	100.0000
Yersinia ruckeri (fish)	Veg	5	0.42600	0.707	89.1827	100.00	100.0000
Yersinia ruckeri (fish)	Veg	10	0.23020	0.707	69.9350	100.00	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, WRH = Relative Humidity

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

See Kowalski (2009) for References

APPENDIX I: Total Removal Rates for Viruses at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	UV Rem %	Filter Rem %	Total Rem %
Adenovirus	dsDNA	34	0.06800	0.079	29.8833	100.00	99.9977
Adenovirus	dsDNA	59	0.03900	0.079	18.4218	100.00	99.9973
Adenovirus	dsDNA	42	0.05500	0.079	24.9593	100.00	99.9976
Adenovirus	dsDNA	903	0.00255	0.079	1.3225	100.00	99.9968
Adenovirus type 1	dsDNA	299	0.00770	0.079	3.9402	100.00	99.9969
Adenovirus type 1	dsDNA	350	0.00658	0.079	3.3763	100.00	99.9969
Adenovirus type 2	dsDNA	400	0.00576	0.079	2.9624	100.00	99.9968
Adenovirus type 2	dsDNA	640	0.00360	0.079	1.8619	100.00	99.9968
Adenovirus type 2	dsDNA	490	0.00470	0.079	2.4239	100.00	99.9968
Adenovirus type 2	dsDNA	533	0.00432	0.079	2.2301	100.00	99.9968
Adenovirus type 2	dsDNA	150	0.01540	0.079	7.7252	100.00	99.9970
Adenovirus type 2	dsDNA	300	0.00768	0.079	3.9302	100.00	99.9969
Adenovirus type 2	dsDNA	400	0.00576	0.079	2.9606	100.00	99.9968
Adenovirus type 2	dsDNA	276	0.00834	0.079	4.2607	100.00	99.9969
Adenovirus type 4	dsDNA	921	0.00250	0.079	1.2967	100.00	99.9968
Adenovirus type 15	dsDNA	396	0.00581	0.079	2.9877	100.00	99.9968
Adenovirus type 40	dsDNA	300	0.00768	0.069	3.9277	100.00	99.9979
Adenovirus type 40	dsDNA	546	0.00422	0.069	2.1791	100.00	99.9979
Adenovirus type 41	dsDNA	240	0.00976	0.069	4.9663	100.00	99.9980
Adenovirus type 41	dsDNA	425	0.00542	0.069	2.7900	100.00	99.9979
Adenovirus type 41	dsDNA	555	0.00415	0.069	2.1433	100.00	99.9979
Adenovirus type 41	dsDNA	600	0.00384	0.069	1.9848	100.00	99.9979
Adenovirus type 5	dsDNA	400	0.00576	0.084	2.9624	100.00	99.9962
Adenovirus type 5	dsDNA	541	0.00426	0.084	2.1995	100.00	99.9961
Adenovirus type 5	dsDNA	720	0.00320	0.084	1.6568	100.00	99.9961
Adenovirus type 6	dsDNA	390	0.00590	0.079	3.0353	100.00	99.9968
Adenovirus type 6	dsDNA	400	0.00576	0.079	2.9624	100.00	99.9968
AHNV (fish virus)	ssRNA	349	0.00660	0.1	3.3870	99.99	99.9931
Avian Influenza virus	ssRNA	22	0.10600	0.09	42.5006	100.00	99.9971
Avian Influenza virus	ssRNA	30	0.07680	0.098	33.0317	99.99	99.9956
Avian Leukosis virus (RSA)	ssRNA	631	0.00365	0.107	1.8875	99.99	99.9912
Avian Sarcoma virus	ssDNA	155	0.01490	0.098	7.4840	99.99	99.9939
Avian Sarcoma virus	ssDNA	381	0.00604	0.098	3.1041	99.99	99.9936
B. subtilis phage 029	dsDNA	70	0.03289	0.1	15.7794	99.99	99.9940
B. subtilis phage SP02c12	dsDNA	100	0.02303	0.087	11.3267	100.00	99.9961
B. subtilis phage SPP1	dsDNA	195	0.01181	0.087	5.9785	100.00	99.9958
Bacteriophage B40-8	dsDNA	137	0.01679	0.1	8.3924	99.99	99.9935
Bacteriophage F-specific	dsRNA	292	0.00789	0.025	4.0332	100.00	99.9996
Bacteriophage MS2	ssRNA	26	0.04800	0.02	22.1662	100.00	99.9996
Bacteriophage MS2	ssRNA	61	0.03800	0.02	17.9948	100.00	99.9996
Bacteriophage MS2	ssRNA	3	0.81000	0.02	98.5430	100.00	100.0000
Bacteriophage MS2	ssRNA	4	0.64000	0.02	96.4608	100.00	100.0000
Bacteriophage MS2	ssRNA	606	0.00380	0.02	1.9643	100.00	99.9995
Bacteriophage MS2	ssRNA	135	0.01710	0.02	8.5405	100.00	99.9995
Bacteriophage MS2	ssRNA	427	0.00539	0.02	2.7753	100.00	99.9995

Analysis Results

Two conditions were analyzed, an airflow of 50 cfm and an airflow of 340 cfm. Table 4 summarizes the results for both cases. At 50 cfm the UV Dose is 35.5 J/m^2 which rates an URV 14. At 340 cfm the UV Dose is 5.22 J/m^2 which rates an URV 10.

Table 4: Analysis Results

Airflow	50	cfm	340	cfm
Irradiance	95.256	W/m^2	95.256	W/m^2
Exposure Time	0.372689155	sec	0.054807229	sec
UV Dose	35.5008781	J/m^2	5.220717368	J/m^2
URV	14		10	

For this unit, the microbes and agents of most interest include TB bacilli, Anthrax, smallpox, and botulinum toxin. The removal rates of these agents are summarized in Table 5. The HEPA removal rates will be at least the rates shown in Table 5 because the air velocity through the HEPA filter is well below the minimum recommended for such filters. Also, the HEPA removal rates will be the same for both cases, 50 cfm and 340 cfm, although it is likely that slightly higher HEPA removal rates will occur at 50 cfm. Botulinum toxin is not susceptible to breakdown under UV exposure but it is removable by filtration. The carbon filter will also have some effect on removal of botulinum toxin (Gomez 1995)Toxins used as bioweapons are typically ground to a particle size of about 1-6 microns and a logmean diameter of 1.5 microns is used to assess the removal rates of this toxin by the HEPA filter.

Table 5: Removal Rates of Bioweapon Agents

Microbe/Agent	UV D90 J/m^2	UV k m^2/J	UV Kill Rate %	Diameter microns	HEPA Removal %	Total Removal %
Design Airflow 50 cfm						
Mycobacterium tuberculosis	5	0.4271	100.00	0.637	100.0000	100.0000
Bacillus anthrax	85	0.02702	61.68	1.118	100.0000	100.0000
Variola (smallpox)*	26	0.088561	95.69	0.224	99.9516	99.9979
Botulinum toxin	0	0	0.00	1.5	100.0000	100.0000
Influenza A	23	0.010103	30.14	0.098	99.9934	99.9954
SARS virus*	7	0.3289	100.00	0.113	99.9893	100.0000
Ebola virus	28.4	0.081	94.36	0.09	99.9950	99.9997
Yersinia pestis*	24	0.095941	96.68	0.7	100.0000	100.0000
Design Airflow 340 cfm						
Mycobacterium tuberculosis	5	0.4271	89.24	0.637	100.0000	100.0000
Bacillus anthrax	85	0.02702	13.16	1.118	100.0000	100.0000
Variola (smallpox)*	26	0.088561	37.02	0.224	99.9516	99.9979
Botulinum toxin	0	0	0.00	1.5	100.0000	100.0000
Influenza A	23	0.010103	5.14	0.098	99.9934	99.9937
SARS virus	7	0.3289	82.04	0.113	99.9893	99.9981
Ebola virus	28.4	0.081	34.48	0.09	99.9950	99.9967
Yersinia pestis	24	0.095941	39.40	0.7	100.0000	100.0000

NOTE: Asterisk indicates the UV rate constant is predicted genomically.

APPENDIX I: Total Removal Rates for Viruses at 340 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Bacteriophage MS2	ssRNA	193	0.01190	0.02	6.0236	100.00	99.9995
Bacteriophage MS2	ssRNA	419	0.00550	0.02	2.8306	100.00	99.9995
Bacteriophage MS2	ssRNA	368	0.00625	0.02	3.2103	100.00	99.9995
Bacteriophage MS2	ssRNA	295	0.00780	0.02	3.9904	100.00	99.9995
Bacteriophage MS2	ssRNA	40	0.05760	0.02	25.9710	100.00	99.9996
Bacteriophage MS2	ssRNA	173	0.01330	0.02	6.7080	100.00	99.9995
Bacteriophage MS2	ssRNA	275	0.00837	0.02	4.2756	100.00	99.9995
Bacteriophage MS2	ssRNA	217	0.01060	0.02	5.3836	100.00	99.9995
Bacteriophage MS2	ssRNA	250	0.00920	0.02	4.6895	100.00	99.9995
Bacteriophage MS2	ssRNA	217	0.01060	0.02	5.3836	100.00	99.9995
Bacteriophage MS2	ssRNA	217	0.01063	0.02	5.3984	100.00	99.9995
Bacteriophage MS2	ssRNA	213	0.01080	0.02	5.4824	100.00	99.9995
Bacteriophage MS2	ssRNA	187	0.01230	0.02	6.2197	100.00	99.9995
Bacteriophage MS2	ssRNA	169	0.01360	0.02	6.8540	100.00	99.9995
Bacteriophage MS2	ssRNA	164	0.01402	0.02	7.0580	100.00	99.9995
Bacteriophage MS2	ssRNA	150	0.01540	0.02	7.7252	100.00	99.9995
Bacteriophage MS2	ssRNA	140	0.01640	0.02	8.2057	100.00	99.9995
Bacteriophage MS2	ssRNA	198	0.01160	0.02	5.8763	100.00	99.9995
Bacteriophage MS2	ssRNA	228	0.01010	0.02	5.1363	100.00	99.9995
Bacteriophage MS2	ssRNA	245	0.00940	0.02	4.7890	100.00	99.9995
Bacteriophage Qβ	ssRNA	125	0.01840	0.02	9.1592	100.00	99.9995
Bacteriophage Qβ	ssRNA	1919	0.00120	0.02	0.6245	100.00	99.9995
Berne virus	ssRNA	13	0.18420	0.13	61.7741	99.98	99.9935
BF-NINV (fish virus)	ssRNA	501	0.00460	0.1	2.3729	99.99	99.9931
BLV	ssRNA	1799	0.00128	0.1	0.6660	99.99	99.9929
BLV	ssRNA	221	0.01040	0.1	5.2848	99.99	99.9933
Boma virus	ssRNA	79	0.02920	0.09	14.1394	100.00	99.9957
Bovine Calicivirus	ssDNA	95	0.02420	0.02	11.8686	100.00	99.9995
Bovine Parvovirus	ssDNA	35	0.06580	0.02	29.0733	100.00	99.9996
Canine Calicivirus	ssRNA	67	0.03450	0.037	16.4826	100.00	99.9995
Canine hepatic Adenovirus	dsDNA	265	0.00869	0.08	4.4349	100.00	99.9968
CCHV (fish virus)	dsDNA	5	0.46050	0.1	90.9657	99.99	99.9994
Cholera phage Kappa	dsDNA	634	0.00363	0.1	1.8773	99.99	99.9930
Coliphage f2	ssRNA	310	0.00743	0.1	3.8036	99.99	99.9932
Coliphage fd	ssDNA	23	0.09940	0.1	40.4849	99.99	99.9958
Coliphage ϕX-174	ssDNA	3	0.71000	0.025	97.5442	100.00	100.0000
Coliphage ϕX-174	ssDNA	4	0.53000	0.025	93.7149	100.00	100.0000
Coliphage ϕX-174	ssDNA	18	0.12800	0.025	48.7396	100.00	99.9998
Coliphage ϕX-174	ssDNA	21	0.11140	0.025	44.0990	100.00	99.9997
Coliphage ϕX-174	ssDNA	21	0.11090	0.025	43.9529	100.00	99.9997
Coliphage ϕX-174	ssDNA	30	0.07650	0.025	32.9268	100.00	99.9997
Coliphage ϕX-174	ssDNA	25	0.09200	0.025	38.1406	100.00	99.9997
Coliphage ϕX-174	ssDNA	14	0.16060	0.025	56.7619	100.00	99.9998
Coliphage ϕX-174	ssDNA	25	0.09350	0.025	38.6231	100.00	99.9997
Coliphage ϕX-174	ssDNA	57	0.04013	0.025	18.9016	100.00	99.9996
Coliphage ϕX-174	ssDNA	177	0.01300	0.025	6.5617	100.00	99.9996

APPENDIX I: Total Removal Rates for Viruses at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Coliphage ϕX-174	ssDNA	23	0.10230	0.025	41.3791	100.00	99.9997
Coliphage ϕX-174	ssDNA	40	0.05760	0.025	25.9710	100.00	99.9997
Coliphage ϕX-174	ssDNA	18	0.12910	0.025	49.0332	100.00	99.9998
Coliphage lambda	dsDNA	57	0.04050	0.05	19.0581	100.00	99.9992
Coliphage lambda	dsDNA	70	0.03310	0.05	15.8699	100.00	99.9992
Coliphage lambda	dsDNA	72	0.03200	0.05	15.3854	100.00	99.9992
Coliphage lambda	dsDNA	184	0.01250	0.05	6.3175	100.00	99.9991
Coliphage PRD1	dsDNA	87	0.02650	0.062	12.9205	100.00	99.9986
Coliphage PRD1	dsDNA	20	0.11500	0.062	45.1398	100.00	99.9991
Coliphage T1	dsDNA	6	0.36970	0.05	85.4866	100.00	99.9999
Coliphage T1	dsDNA	38	0.06000	0.05	26.8928	100.00	99.9993
Coliphage T1	dsDNA	40	0.05800	0.05	26.1254	100.00	99.9993
Coliphage T2	dsDNA	5	0.48400	0.065	92.0088	100.00	99.9999
Coliphage T2	dsDNA	9	0.25600	0.065	73.7237	100.00	99.9995
Coliphage T2	dsDNA	133	0.01730	0.065	8.6360	100.00	99.9983
Coliphage T3	dsDNA	10	0.23100	0.045	70.0603	100.00	99.9998
Coliphage T4	dsDNA	7	0.34500	0.089	83.4891	100.00	99.9992
Coliphage T4	dsDNA	14	0.16850	0.089	58.5089	100.00	99.9980
Coliphage T4	dsDNA	15	0.15400	0.089	55.2461	100.00	99.9979
Coliphage T4	dsDNA	29	0.08000	0.089	34.1412	100.00	99.9968
Coliphage T4	dsDNA	22	0.10700	0.089	42.8000	100.00	99.9973
Coliphage T4	dsDNA	12	0.20000	0.089	64.8007	100.00	99.9983
Coliphage T7	dsDNA	7	0.33000	0.063	82.1441	100.00	99.9997
Coliphage T7	dsDNA	10	0.22000	0.063	68.2906	100.00	99.9995
Coliphage T7	dsDNA	95	0.02420	0.063	11.8686	100.00	99.9985
Coliphage T7	dsDNA	53	0.04320	0.063	20.1911	100.00	99.9987
Coliphage T7	dsDNA	41	0.05600	0.063	25.3500	100.00	99.9988
Coliphage T7	dsDNA	38	0.06100	0.063	27.2735	100.00	99.9988
Coliphage T7	dsDNA	23	0.10000	0.063	40.6710	100.00	99.9990
Coliphage T7	dsDNA	11	0.20470	0.063	65.6539	100.00	99.9994
Coronavirus	ssRNA	3	0.37700	0.113	86.0293	99.99	99.9985
Coronavirus	ssRNA	7	0.32100	0.113	81.2851	99.99	99.9980
Coronavirus (SARS)	ssRNA	226	0.01000	0.113	5.0868	99.99	99.9898
Coronavirus (SARS)	ssRNA	3046	0.00076	0.113	0.3939	99.99	99.9893
Coxsackievirus	ssRNA	21	0.11100	0.027	43.9822	100.00	99.9997
Coxsackievirus	ssRNA	128	0.02000	0.027	9.9148	100.00	99.9996
Coxsackievirus	ssRNA	86	0.02684	0.027	13.0736	100.00	99.9996
Coxsackievirus B3	ssRNA	80	0.02878	0.027	13.9520	100.00	99.9996
Coxsackievirus B4	ssRNA	60	0.03840	0.027	18.1659	100.00	99.9996
Coxsackievirus B5	ssRNA	95	0.02424	0.027	11.8860	100.00	99.9996
Coxsackievirus B5	ssRNA	72	0.03180	0.027	15.2970	100.00	99.9996
CSV (fish virus)	dsRNA	501	0.00460	0.1	2.3729	99.99	99.9931
Echovirus (Parechovirus)	ssRNA	106	0.02190	0.024	10.8040	100.00	99.9996
Echovirus 1	ssRNA	80	0.02878	0.024	13.9520	100.00	99.9996
Echovirus 2	ssRNA	70	0.03289	0.024	15.7794	100.00	99.9996
Encephalomyocarditis virus	ssRNA	50	0.04650	0.025	21.5543	100.00	99.9996

APPENDIX I: Total Removal Rates for Viruses at 340 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Encephalomyocarditis virus	ssRNA	52	0.04460	0.025	20.7723	100.00	99.9996
Encephalomyocarditis virus	ssRNA	65	0.03550	0.025	16.9175	100.00	99.9996
Epstein-Barr virus (EBV)	ssDNA	162	0.01420	0.1	7.1453	99.99	99.9934
Equine Herpes virus	dsDNA	25	0.09210	0.105	38.1729	99.99	99.9948
EVA (fish virus)	ssRNA	5	0.46050	0.06	90.9657	100.00	99.9999
EVEX (fish virus)	ssRNA	5	0.46050	0.06	90.9657	100.00	99.9999
Feline Calicivirus (FeCV)	ssRNA	434	0.00530	0.034	2.7291	100.00	99.9995
Feline Calicivirus (FeCV)	ssRNA	80	0.02880	0.034	13.9599	100.00	99.9996
Feline Calicivirus (FeCV)	ssRNA	40	0.05760	0.034	25.9710	100.00	99.9996
Feline Calicivirus (FeCV)	ssRNA	44	0.05270	0.034	24.0528	100.00	99.9996
Friend Murine Leukemia v.	ssRNA	320	0.00720	0.094	3.6891	99.99	99.9944
Frog virus 3	dsDNA	25	0.09210	0.167	38.1729	99.97	99.9791
Hepatitis A virus	dsDNA	40	0.05760	0.027	25.9710	100.00	99.9997
Hepatitis A virus	dsDNA	45	0.05120	0.027	23.4557	100.00	99.9997
Hepatitis A virus	dsDNA	50	0.04610	0.027	21.3903	100.00	99.9996
Hepatitis A virus	dsDNA	92	0.02500	0.027	12.2359	100.00	99.9996
Hepatitis A virus	dsDNA	98	0.02340	0.027	11.4998	100.00	99.9996
Hepatitis A virus	dsDNA	307	0.00750	0.027	3.8399	100.00	99.9996
Herpes simplex virus (HRE)	dsDNA	40	0.05760	0.18	25.9710	99.96	99.9710
Herpes simplex virus Type 1	dsDNA	71	0.03260	0.184	15.6500	99.96	99.9657
Herpes simplex virus Type 1	dsDNA	110	0.02090	0.184	10.3371	99.96	99.9635
Herpes simplex virus Type 1	dsDNA	25	0.09330	0.184	38.5590	99.96	99.9750
Herpes Simplex virus Type 1	dsDNA	35	0.06540	0.184	28.9250	99.96	99.9711
Herpes Simplex virus Type 1	dsDNA	21	0.11050	0.184	43.8357	99.96	99.9771
Herpes Simplex virus Type 1	dsDNA	41	0.05680	0.184	25.6612	99.96	99.9697
Herpes Simplex virus Type 2	dsDNA	40	0.05756	0.173	25.9573	99.96	99.9731
Herpes Simplex virus Type 2	dsDNA	41	0.05650	0.173	25.5447	99.96	99.9729
Herpes Simplex virus Type 2	dsDNA	75	0.03070	0.173	14.8091	99.96	99.9690
Herpes Simplex virus Type 2	dsDNA	20	0.11800	0.173	45.9924	99.96	99.9804
HIV-1	ssRNA	280	0.00822	0.125	4.2007	99.99	99.9856
HIRRV (fish virus)	ssRNA	5	0.46050	0.06	90.9657	100.00	99.9999
HP1c1 phage	dsDNA	40	0.05760	0.062	25.9710	100.00	99.9988
HTLV-1	ssRNA	20	0.11510	0.102	45.1685	99.99	99.9958
Human Cytomegalovirus	dsDNA	658	0.00350	0.1	1.8107	99.99	99.9930
Human Cytomegalovirus	dsDNA	50	0.04605	0.1	21.3698	99.99	99.9944
Influenza A virus	ssRNA	19	0.11900	0.098	46.2736	99.99	99.9964
Influenza A virus	ssRNA	20	0.11700	0.098	45.7097	99.99	99.9964
Influenza A virus	ssRNA	48	0.04800	0.098	22.1662	99.99	99.9948
Influenza A virus	ssRNA	17	0.13810	0.098	51.3725	99.99	99.9968
IHNV (fish virus)	ssRNA	5	0.46050	0.09	90.9657	100.00	99.9996
IHNV (fish virus)	ssRNA	7	0.34500	0.09	83.4891	100.00	99.9992
IPNV (fish virus)	dsRNA	397	0.00580	0.06	2.9826	100.00	99.9986
IPNV (fish virus)	dsRNA	407	0.00566	0.06	2.9117	100.00	99.9986
IPNV (fish virus)	dsRNA	501	0.00460	0.06	2.3729	100.00	99.9986
IPNV (fish virus)	dsRNA	626	0.00368	0.06	1.9029	100.00	99.9986
IPNV (fish virus)	dsRNA	583	0.00395	0.06	2.0411	100.00	99.9986

APPENDIX I: Total Removal Rates for Viruses at 340 cfm

Microbe	Type	D_{90} J/m²	UVGI k m²/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Iridovirus (Bohle) (fish virus)	dsDNA	83	0.02760	0.1	13.4192	99.99	99.9938
ISAV (fish virus)	ssRNA	11	0.20900	0.1	66.4163	99.99	99.9976
ISAV (fish virus)	ssRNA	26	0.08970	0.1	37.3933	99.99	99.9956
JF-LCDV (fish virus)	dsDNA	5	0.46050	0.14	90.9657	99.98	99.9981
Kemerovo (R-10 strain)	dsRNA	230	0.01000	0.075	5.0868	100.00	99.9974
Kilham Rat Virus (parvovirus)	ssDNA	30	0.07650	0.022	32.9268	100.00	99.9997
Lipovnik (Lip-91 strain)	dsRNA	299	0.00770	0.075	3.9402	100.00	99.9973
LLE46 (SV/Adeno hybrid)	dsDNA	606	0.00380	0.1	1.9643	99.99	99.9930
Measles virus	ssRNA	22	0.10510	0.329	42.2298	99.98	99.9878
Mengovirus	dsRNA	162	0.01420	0.1	7.1453	99.99	99.9934
Minute Virus of Mice (MVM)	ssDNA	28	0.08200	0.022	34.8253	100.00	99.9997
Minute Virus of Mice (MVM)	ssDNA	17	0.13500	0.022	50.5791	100.00	99.9998
Murine Cytomegalovirus	dsDNA	46	0.05000	0.104	22.9747	99.99	99.9937
Moloney Murine Leukemia v.	ssRNA	115	0.02000	0.094	9.9148	99.99	99.9948
Moloney Murine Leukemia v.	ssRNA	370	0.00622	0.094	3.1951	99.99	99.9944
Moloney Murine Leukemia v.	ssRNA	280	0.00822	0.094	4.2007	99.99	99.9945
Murine Norovirus (MNV)	ssRNA	76	0.03040	0.032	14.6756	100.00	99.9996
Murine sarcoma virus	ssRNA	237	0.00970	0.12	4.9380	99.99	99.9875
Murine sarcoma virus	ssRNA	144	0.01600	0.12	8.0138	99.99	99.9879
Murine sarcoma virus	ssRNA	299	0.00770	0.12	3.9402	99.99	99.9874
Mycobacteriophage D29	dsDNA	16	0.14300	0.065	52.6007	100.00	99.9991
Mycobacteriophage D29	dsDNA	324	0.00710	0.065	3.6389	100.00	99.9983
Mycobacteriophage D29A	dsDNA	268	0.00860	0.065	4.3905	100.00	99.9983
Mycobacteriophage D32	dsDNA	354	0.00650	0.07	3.3365	100.00	99.9978
Mycobacteriophage D4	dsDNA	245	0.00940	0.07	4.7890	100.00	99.9979
Mycoplasmavirus MVL2	dsDNA	154	0.01500	0.07	7.5323	100.00	99.9979
Mycoplasmavirus MVL51	ssDNA	79	0.02900	0.07	14.0497	100.00	99.9981
Newcastle Disease Virus	ssRNA	8	0.27600	0.212	76.3290	99.95	99.9887
Newcastle Disease Virus	ssRNA	45	0.05110	0.212	23.4158	99.95	99.9635
Newcastle Disease Virus	ssRNA	16	0.14400	0.212	52.8475	99.95	99.9775
OMV (fish virus)	ssRNA	5	0.46050	0.06	90.9657	100.00	99.9999
Parvovirus H-1	ssDNA	25	0.09200	0.022	38.1406	100.00	99.9997
PFRV (fish virus)	ssRNA	5	0.46050	0.06	90.9657	100.00	99.9999
phage GA	ssRNA	200	0.01150	0.1	5.8272	99.99	99.9933
phage phi 6	dsRNA	5	0.43000	0.1	89.4063	99.99	99.9992
phage phi 6	dsRNA	7	0.31000	0.1	80.1789	99.99	99.9986
phage B40-8 (B. fragilis)	dsDNA	67	0.03450	0.1	16.4826	99.99	99.9941
phage B40-8 (B. fragilis)	dsDNA	86	0.02690	0.1	13.1022	99.99	99.9938
Poliovirus	dsRNA	44	0.05230	0.0248	23.8940	100.00	99.9997
Poliovirus type 1	dsRNA	41	0.05620	0.0248	25.4280	100.00	99.9997
Poliovirus	dsRNA	71	0.03250	0.0248	15.6060	100.00	99.9996
Poliovirus	dsRNA	75	0.03070	0.0248	14.8091	100.00	99.9996
Poliovirus	dsRNA	95	0.02420	0.0248	11.8686	100.00	99.9996
Poliovirus	dsRNA	52	0.04460	0.0248	20.7723	100.00	99.9996
Poliovirus type 1	dsRNA	67	0.03450	0.0248	16.4826	100.00	99.9996
Poliovirus type 1	dsRNA	72	0.03200	0.0248	15.3854	100.00	99.9996

APPENDIX I: Total Removal Rates for Viruses at 340 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Poliovirus type 1	dsRNA	96	0.02400	0.0248	11.7765	100.00	99.9996
Poliovirus type 1	dsRNA	100	0.02300	0.0248	11.3147	100.00	99.9996
Poliovirus type 1	dsRNA	125	0.01840	0.0248	9.1592	100.00	99.9996
Poliovirus type 1	dsRNA	224	0.01030	0.0248	5.2353	100.00	99.9996
Poliovirus type 1	dsRNA	240	0.00960	0.0248	4.8884	100.00	99.9996
Poliovirus type 1	dsRNA	111	0.02080	0.0248	10.2903	100.00	99.9996
Poliovirus type 1	dsRNA	77	0.03000	0.0248	14.4972	100.00	99.9996
Poliovirus type 1	dsRNA	80	0.02878	0.0248	13.9520	100.00	99.9996
Poliovirus type 1	dsRNA	83	0.02760	0.0248	13.4192	100.00	99.9996
Poliovirus type 1	dsRNA	57	0.04010	0.0248	18.8889	100.00	99.9996
Poliovirus type 2	dsRNA	121	0.01910	0.0248	9.4905	100.00	99.9996
Poliovirus type 3	dsRNA	103	0.02240	0.0248	11.0365	100.00	99.9996
Polyomavirus	dsDNA	480	0.00480	0.0424	2.4748	100.00	99.9993
Polyomavirus	dsDNA	640	0.00360	0.0424	1.8619	100.00	99.9993
Polyomavirus	dsDNA	696	0.00331	0.0424	1.7132	100.00	99.9993
Polyomavirus	dsDNA	501	0.00460	0.0424	2.3729	100.00	99.9993
Polyomavirus (ssDNA)	ssDNA	120	0.01920	0.045	9.5378	100.00	99.9993
Porcine Parvovirus (PPV)	ssDNA	23	0.10230	0.021	41.3791	100.00	99.9997
Pseudorabies (PRV)	dsDNA	34	0.06760	0.194	29.7367	99.96	99.9691
Rabies virus (env)	ssRNA	10	0.21930	0.07	68.1745	100.00	99.9993
Rauscher Murine Leukemia v.	ssRNA	157	0.01470	0.094	7.3874	99.99	99.9947
Rauscher Murine Leukemia v.	ssRNA	480	0.00480	0.094	2.4748	99.99	99.9944
Rauscher Murine Leukemia v.	ssRNA	959	0.00240	0.094	1.2452	99.99	99.9943
Reovirus	dsRNA	175	0.01316	0.075	6.6386	100.00	99.9974
Reovirus	dsRNA	186	0.01240	0.075	6.2686	100.00	99.9974
Reovirus	dsRNA	69	0.03358	0.075	16.0802	100.00	99.9977
Reovirus	dsRNA	245	0.00940	0.075	4.7890	100.00	99.9974
Reovirus	dsRNA	121	0.01910	0.075	9.4905	100.00	99.9975
Reovirus	dsRNA	270	0.00853	0.075	4.3556	100.00	99.9974
Reovirus	dsRNA	174	0.01320	0.075	6.6593	100.00	99.9974
Reovirus type 1	dsRNA	153	0.01508	0.075	7.5721	100.00	99.9974
Reovirus 3	dsRNA	334	0.00690	0.075	3.5382	100.00	99.9973
Rotavirus	dsRNA	200	0.01150	0.07	5.8272	100.00	99.9979
Rotavirus SA11	dsRNA	89	0.02600	0.07	12.6929	100.00	99.9980
Rotavirus SA11	dsRNA	75	0.03070	0.07	14.8091	100.00	99.9981
Rotavirus SA11	dsRNA	105	0.02190	0.07	10.8040	100.00	99.9980
Rotavirus SA11	dsRNA	100	0.02300	0.07	11.3147	100.00	99.9980
Rotavirus SA11	dsRNA	84	0.02740	0.07	13.3287	100.00	99.9981
Rous Sarcoma virus (RSV)	ssRNA	720	0.00320	0.127	1.6568	99.98	99.9845
Rous Sarcoma virus (RSV)	ssRNA	240	0.00960	0.127	4.8884	99.98	99.9850
Rous Sarcoma virus (RSV)	ssRNA	200	0.01150	0.127	5.8272	99.98	99.9851
SBNN (fish virus)	ssRNA	698	0.00330	0.1	1.7081	99.99	99.9930
Semliki forest virus	ssRNA	25	0.09210	0.061	38.1729	100.00	99.9991
Simian virus 40	dsDNA	2503	0.00092	0.045	0.4792	100.00	99.9992
Simian virus 40	dsDNA	1599	0.00144	0.045	0.7490	100.00	99.9992
Simian virus 40	dsDNA	1439	0.00160	0.045	0.8318	100.00	99.9992

APPENDIX I: Total Removal Rates for Viruses at 340 cfm

Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Simian virus 40	dsDNA	1245	0.00185	0.045	0.9612	100.00	99.9992
Simian virus 40	dsDNA	886	0.00260	0.045	1.3482	100.00	99.9992
Simian virus 40	dsDNA	650	0.00354	0.045	1.8312	100.00	99.9992
Simian virus 40	dsDNA	443	0.00520	0.045	2.6783	100.00	99.9993
Simian virus 40	dsDNA	23	0.10040	0.045	40.7948	100.00	99.9995
Simian virus 40	dsDNA	17	0.13160	0.045	49.6940	100.00	99.9996
Sindbis virus	ssRNA	22	0.10400	0.075	41.8971	100.00	99.9984
Sindbis virus	ssRNA	60	0.03864	0.075	18.2704	100.00	99.9977
Sindbis virus	ssRNA	113	0.02030	0.075	10.0558	100.00	99.9975
Sindbis virus	ssRNA	50	0.04610	0.075	21.3903	100.00	99.9978
S. aureus phage	dsDNA	82	0.02800	0.1	13.5998	99.99	99.9939
S. aureus phage	dsDNA	77	0.03000	0.1	14.4972	99.99	99.9939
S. aureus phage A994	dsDNA	65	0.03542	0.1	16.8847	99.99	99.9941
SVCV (fish virus)	ssRNA	10	0.46050	0.06	90.9657	100.00	99.9999
Vaccinia virus	dsDNA	1	2.54000	0.307	99.9998	99.97	100.0000
Vaccinia virus	dsDNA	15	0.15300	0.307	55.0118	99.97	99.9873
Vaccinia virus	dsDNA	7	0.34900	0.307	83.8303	99.97	99.9954
Vaccinia virus	dsDNA	14	0.16450	0.307	57.6333	99.97	99.9880
Vaccinia virus	dsDNA	14	0.16040	0.307	56.7167	99.97	99.9878
Vaccinia virus	dsDNA	18	0.12792	0.307	48.7186	99.97	99.9855
Vaccinia virus	dsDNA	22	0.10500	0.307	42.1997	99.97	99.9836
Vaccinia virus	dsDNA	28	0.08290	0.307	35.1308	99.97	99.9816
Vaccinia virus	dsDNA	715	0.00322	0.307	1.6670	99.97	99.9722
Vaccinia virus	dsDNA	677	0.00340	0.307	1.7594	99.97	99.9722
VEE	ssRNA	55	0.04190	0.065	19.6476	100.00	99.9985
Vesicular Stomatitis virus	ssRNA	13	0.18060	0.104	61.0489	99.99	99.9968
Vesicular Stomatitis virus	ssRNA	12	0.19000	0.104	62.9142	99.99	99.9970
Vesicular Stomatitis virus	ssRNA	100	0.02300	0.104	11.3147	99.99	99.9928
Vesicular Stomatitis virus	ssRNA	6	0.38400	0.104	86.5307	99.99	99.9989
VHSV (fish virus)	ssRNA	3	0.87400	0.07	98.9568	100.00	100.0000
WEE	ssRNA	54	0.04300	0.07	20.1077	100.00	99.9982

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, WRH = Relative Humidity

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

See Kowalski (2009) for References

APPENDIX J: Total Removal of Fungi and Other Microbes at 340 cfm

Fungi	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Aspergillus amstelodami	Sp	700	0.00329	3.354	1.7026	100.00	100.0000
Aspergillus amstelodami	Sp	258	0.00892	3.354	4.5501	100.00	100.0000
Aspergillus amstelodami	Sp	669	0.00344	3.354	1.7799	100.00	100.0000
Aspergillus flavus	Sp	349	0.00660	4.24	3.3870	100.00	100.0000
Aspergillus flavus	Sp	600	0.00384	4.24	1.9836	100.00	100.0000
Aspergillus flavus	Sp	853	0.00270	4.24	1.3997	100.00	100.0000
Aspergillus fumigatus	Sp	535	0.00430	4.24	2.2199	100.00	100.0000
Aspergillus fumigatus	Veg	560	0.00411	24.5	2.1238	100.00	100.0000
Aspergillus fumigatus	Sp	2240	0.00103	2.64	0.5352	100.00	100.0000
Aspergillus glaucus	Sp	440	0.00523	3.354	2.6951	100.00	100.0000
Aspergillus niger	Sp	1771	0.00130	3.354	0.6764	100.00	100.0000
Aspergillus niger	Sp	1439	0.00160	3.354	0.8318	100.00	100.0000
Aspergillus niger	Veg	4480	0.00051	3.354	0.2680	100.00	100.0000
Aspergillus niger	Sp	1000	0.00230	3.354	1.1949	100.00	100.0000
Aspergillus niger	Sp	315	0.00350	3.354	1.8107	100.00	100.0000
Aspergillus niger	Sp	1387	0.00166	3.354	0.8629	100.00	100.0000
Aspergillus niger	Sp	750	0.00386	3.354	1.9950	100.00	100.0000
Aspergillus niger	Sp	4480	0.00051	3.354	0.2680	100.00	100.0000
Aspergillus niger	Sp	3984	0.00058	3.354	0.3013	100.00	100.0000
Aspergillus niger	Sp	1320	0.00174	3.354	0.9066	100.00	100.0000
Aspergillus niger	Sp	1681	0.00137	3.354	0.7127	100.00	100.0000
Aspergillus versicolor	Sp	384	0.00600	3.354	3.0839	100.00	100.0000
Aspergillus versicolor	Sp	768	0.00300	3.354	1.5540	100.00	100.0000
Aspergillus versicolor	Sp	139	0.01660	3.354	8.3015	100.00	100.0000
Aspergillus versicolor	Veg	96	0.02400	3.354	11.7765	100.00	100.0000
Blastomyces dermatitidis	VegY	140	0.01645	11.000	8.2282	100.00	100.0000
Botrytis cinerea	Sp	250	0.00920	11.180	4.6895	100.00	100.0000
Candida albicans	VegY	230	0.01100	4.899	5.5810	100.00	100.0000
Candida albicans	VegY	447	0.00515	4.899	2.6535	100.00	100.0000
Candida albicans	VegY	750	0.00407	4.899	2.1024	100.00	100.0000
Candida albicans	VegY	280	0.00822	4.899	4.2024	100.00	100.0000
Candida parapsilosis	VegY	98	0.02360	4.800	11.5921	100.00	100.0000
Cladosporium herbarum	Sp	500	0.04605	8.062	21.3698	100.00	100.0000
Cladosporium herbarum	Sp	189	0.01220	8.062	6.1707	100.00	100.0000
Cladosporium herbarum	Sp	622	0.00370	8.062	1.9131	100.00	100.0000
Cladosporium trichoides	Veg	560	0.00411	8.062	2.1238	100.00	100.0000
Cladosporium trichoides	Sp	1120	0.00206	8.062	1.0676	100.00	100.0000
C. sphaerospermum	Sp	1439	0.00210	8.062	1.0904	100.00	100.0000
Cladosporium wernecki	Sp	4480	0.00051	8.062	0.2680	100.00	100.0000
Cladosporium wernecki	Veg	560	0.00411	8.062	2.1238	100.00	100.0000
Cryptococcus neoformans	Sp	138	0.01670	4.899	8.3493	100.00	100.0000
Cryptococcus neoformans	VegY	280	0.00822	4.899	4.2024	100.00	100.0000
Curvularia lunata	Veg	560	0.00411	17.100	2.1238	100.00	100.0000
Eurotium rubrum	Sp	434	0.00531	5.612	2.7341	100.00	100.0000
Fusarium oxysporum	Sp	260	0.01420	11.225	7.1453	100.00	100.0000

APPENDIX J: Total Removal of Fungi and Other Microbes at 340 cfm

Fungi	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Fusarium solani	Sp	313	0.00735	11.225	3.7639	100.00	100.0000
Fusarium spp.	Sp	560	0.00411	11.225	2.1238	100.00	100.0000
Fusarium spp.	Veg	1120	0.00206	34.300	1.0676	100.00	100.0000
Histoplasma capsulatum	Veg	140	0.01645	2.550	8.2282	100.00	100.0000
Monilinia fructigena	Sp	167	0.01380	10.300	6.9512	100.00	100.0000
Mucor mucedo	Sp	600	0.00384	7.071	1.9836	100.00	100.0000
Mucor mucedo	Sp	180	0.01280	7.071	6.4641	100.00	100.0000
Mucor mucedo	Sp	577	0.00399	7.071	2.0615	100.00	100.0000
Mucor racemosus	Sp	170	0.01354	7.071	6.8270	100.00	100.0000
Mucor spp.	Sp	140	0.01645	7.071	8.2282	100.00	100.0000
Mucor spp.	Veg	280	0.00822	31.600	4.2024	100.00	100.0000
Oospora lactis	Sp	28	0.08370	3.000	35.4012	100.00	100.0000
Penicillium chrysogenum	Sp	400	0.00576	3.262	2.9606	100.00	100.0000
Penicillium chrysogenum	Sp	148	0.01560	3.262	7.8215	100.00	100.0000
Penicillium chrysogenum	Sp	1645	0.00180	3.262	0.9353	100.00	100.0000
Penicillium chrysogenum	Sp	531	0.00434	3.262	2.2403	100.00	100.0000
Penicillium corylophilium	Sp	381	0.00604	3.262	3.1041	100.00	100.0000
Penicillium digitatum	Sp	321	0.00718	3.262	3.6791	100.00	100.0000
Penicillium digitatum	Sp	440	0.00523	3.262	2.6951	100.00	100.0000
Penicillium expansum	Sp	130	0.01771	3.262	8.8324	100.00	100.0000
Penicillium italicum	Sp	321	0.01140	3.262	5.7780	100.00	100.0000
Penicillium roquefortii	Sp	130	0.01771	3.262	8.8324	100.00	100.0000
Penicillium spp.	Sp	2240	0.00103	3.262	0.5352	100.00	100.0000
Penicillium spp.	Veg	280	0.00822	8.800	4.2024	100.00	100.0000
Rhizopus nigricans	Sp	3000	0.00077	6.928	0.3999	100.00	100.0000
Rhizopus nigricans	Sp	267	0.00861	6.928	4.3955	100.00	100.0000
Rhizopus nigricans	Sp	1110	0.00207	6.928	1.0771	100.00	100.0000
Rhizopus nigricans	Sp	173	0.01330	6.928	6.7080	100.00	100.0000
Rhizopus oryzae	Sp	4480	0.00051	6.928	0.2680	100.00	100.0000
Rhodotorula spp.	VegY	1120	0.00206	5.900	1.0676	100.00	100.0000
Saccharomyces spp.	VegY	44	0.05230	4.000	23.8940	100.00	100.0000
Saccharomyces ellipsoideus	VegY	33	0.06980	4.000	30.5391	100.00	100.0000
Scopulariopsis brevicaulis	Sp	650	0.01840	5.916	9.1592	100.00	100.0000
Scopulariopsis brevicaulis	Sp	226	0.01020	5.916	5.1858	100.00	100.0000
Scopulariopsis brevicaulis	Sp	2890	0.00344	5.916	1.7799	100.00	100.0000
Sporotrichum schenkii	VegY	280	0.00822	5.500	4.2024	100.00	100.0000
Stachybotrys chartarum	Sp	5575	0.00041	5.623	0.2154	100.00	100.0000
Torula bergeri	Veg	4480	0.00051	40	0.2680	100.00	100.0000
Torula sphaerica	VegY	23	0.09986	40	40.6276	100.00	100.0000
Torula sphaerica	VegY	78	0.02940	40	14.2290	100.00	100.0000
Trichophyton rubrum	Veg	560	0.00411	4.899	2.1238	100.00	100.0000
Trichophyton rubrum	Sp	560	0.00411	4.899	2.1238	100.00	100.0000
Ustilago zeae	VegY	1120	0.00206	5.916	1.0676	100.00	100.0000
Ustilago zeae	Sp	35	0.06580	5.916	29.0733	100.00	100.0000
Yeast	VegY	40	0.05756	4	25.9573	100.00	100.0000
Yeast (Brewer's)	VegY	100	0.02303	4	11.3267	100.00	100.0000

APPENDIX J: Total Removal of Fungi and Other Microbes at 340 cfm

Protozoa and Other Microbes							
Microbe	Type	D_{90} J/m^2	UVGI k m^2/J	Dia. µm	Kill Rate %	Filter Rem %	Total Rem %
Acanthameoba	Rhizopod	999	0.02100	3	10.3839	100.00	100.0000
Acanthameoba castellani	Rhizopod	992	0.00232	3	1.2039	100.00	100.0000
Algae	Algae	1000	0.00230	3	1.1949	100.00	100.0000
Algae, blue-green	Algae	450	0.00512	3	2.6360	100.00	100.0000
Cryptosporidium hominis	Protoz	30	0.07800	3	33.4500	100.00	100.0000
Cryptosporidium parvum	Protoz	7	0.31400	3	80.5885	100.00	100.0000
Cryptosporidium parvum	Protoz	20	0.11500	3	45.1398	100.00	100.0000
Cryptosporidium parvum	Protoz	10	0.23030	3	69.9507	100.00	100.0000
Cryptosporidium parvum	Protoz	50	0.04605	3	21.3698	100.00	100.0000
Cryptosporidium parvum	Protoz	10	0.23220	3	70.2473	100.00	100.0000
Cryptosporidium parvum	Protoz	5	0.45830	3	90.8613	100.00	100.0000
Encephalitozoon intestinalis	Protoz	29	0.07830	3	33.5541	100.00	100.0000
Encephalitozoon intestinalis	Protoz	15	0.15350	3	55.1291	100.00	100.0000
Encephalitozoon cuniculi	Protoz	43	0.05310	3	24.2112	100.00	100.0000
Encephalitozoon hellem	Protoz	80	0.02880	3	13.9599	100.00	100.0000
Giardia lamblia cysts	Protoz	50	0.04610	3	21.3903	100.00	100.0000
Giardia lamblia cysts	Protoz	3	0.92100	3	99.1838	100.00	100.0000
Giardia lamblia cysts	Protoz	20	0.11500	3	45.1398	100.00	100.0000
Giardia muris cysts	Protoz	10	0.23020	3	69.9350	100.00	100.0000
Giardia muris cysts	Protoz	7	0.34130	3	83.1670	100.00	100.0000
Protozoa	Protoz	80	0.02878	3	13.9520	100.00	100.0000
Protozoa	Protoz	240	0.00959	3	4.8854	100.00	100.0000
Prions (scrapie)	Prion	24315	0.00009	3	0.0494	100.00	100.0000
Prions (scrapie)	Prion	55618	0.00004	3	0.0216	100.00	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 RH = Relative Humidity

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

See Kowalski (2009) for References

Figure 1 illustrates the percent removal rates at 50 cfm from Table 5 and Figure 2 illustrates the removal rates at 340 cfm.

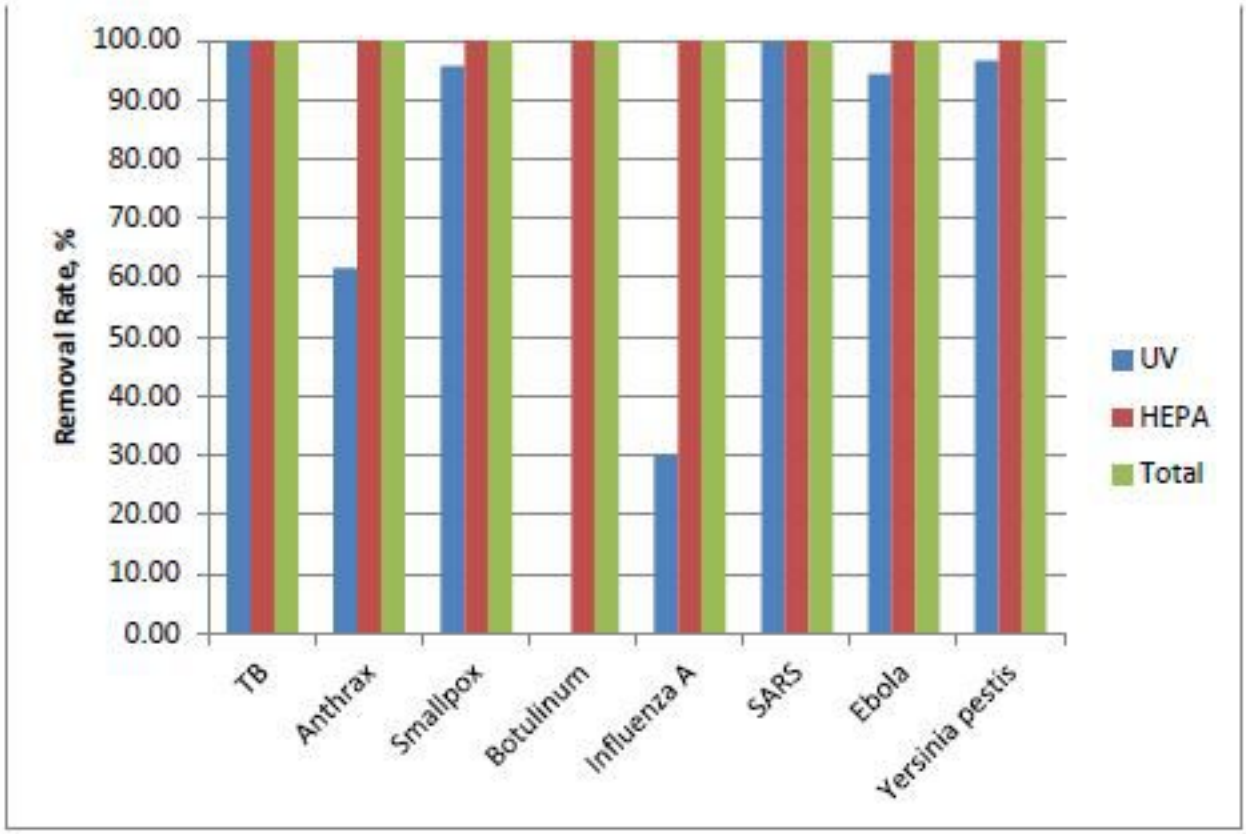

Figure 1: Removal Rates of bioweapon agents at 50 cfm, from Table 5.

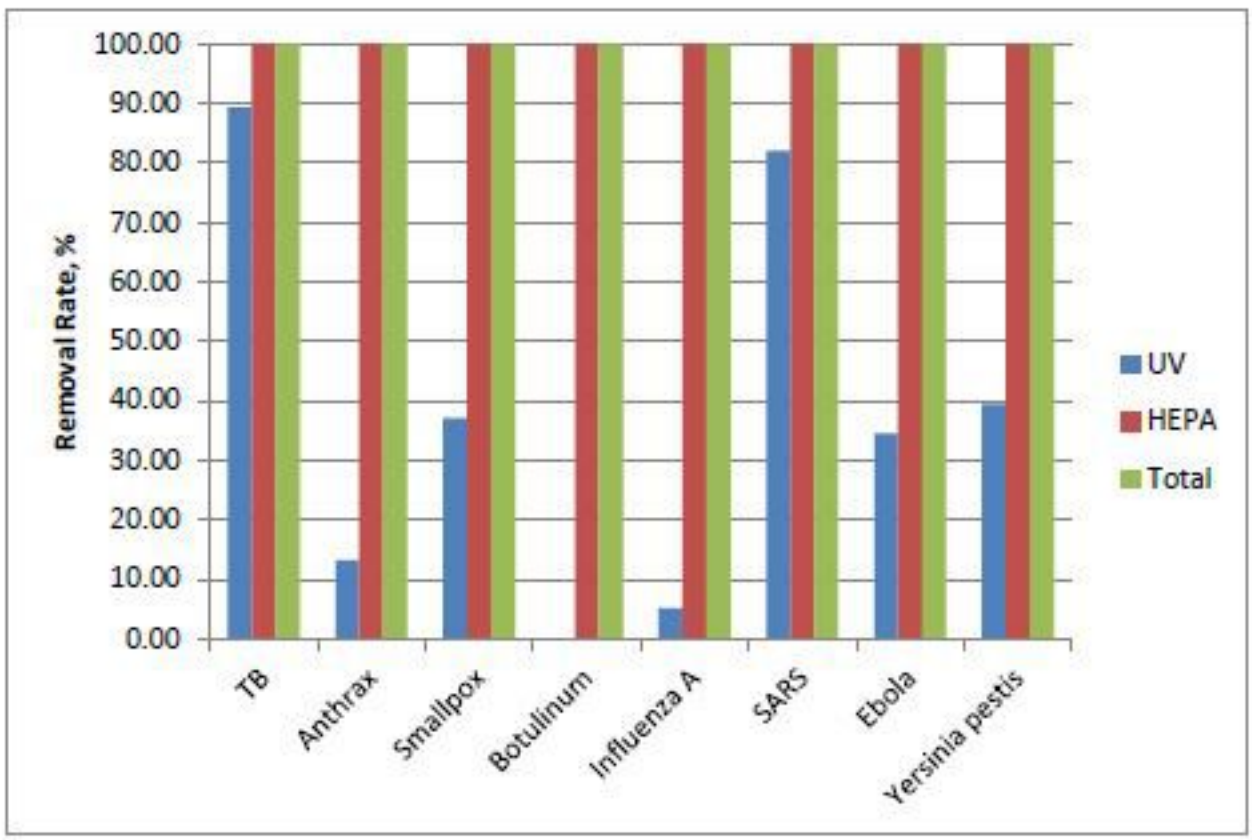

Figure 2: Removal Rates of bioweapon agents at 340 cfm, from Table 5.

Discussion

The previous analysis results indicate that the UV disinfection unit is quite capable of removing bioweapon agents from the airstream at very high rates. The combination of UV and the HEPA filter is effective at removing the subject bioweapon agents and should provide clean safe air for breathing. It can be observed in Table 5 that the UV removal rates at 50 cfm are quite high, and that the combined removal rates (HEPA + UV) are extremely high for both airflow cases. The average removal rate for these eight bioweapon agents is 99.999% for the 50 cfm case and 99.998% for the 340 cfm case. The botulinum toxin is removed by the HEPA filter at a rate that is based on a mean particle diameter of 1.5 microns, the size to which toxins are ground, and therefore this removal rate can be considered to apply to all toxins.

In addition to the eight bioweapon agents listed in Table 5, an extensive array of airborne pathogens is provided for all microbes for which laboratory test data on UV susceptibility exists. Appendix E gives the total removal rates (UV + HEPA) for the 50 cfm operating conditions for bacteria. Appendix F gives the same for viruses, and Appendix G gives the same for Fungi and other microbes. Table 6 summarizes the average removal rates for all microbes for both airflow conditions.

Table 6: Average Removal Rates for Microbial Groups

Microbe Group	% at 50 cfm			% at 340 cfm		
	UV	HEPA	Total	UV	HEPA	Total
Bacteria	80.34787	99.99775	99.99967	39.13044	99.99775	99.99891
Viruses	59.3298	99.99407	99.99828	24.10953	99.99407	99.99595
Fungi	25.91453	100	100	5.618245	100	100
Protozoa	69.65757	100	100	37.15021	100	100

Figure 3 illustrates the removal rates of the microbial groups from Table 6 at 50 cfm. Figure 4 illustrates the removal rates at 340 cfm.

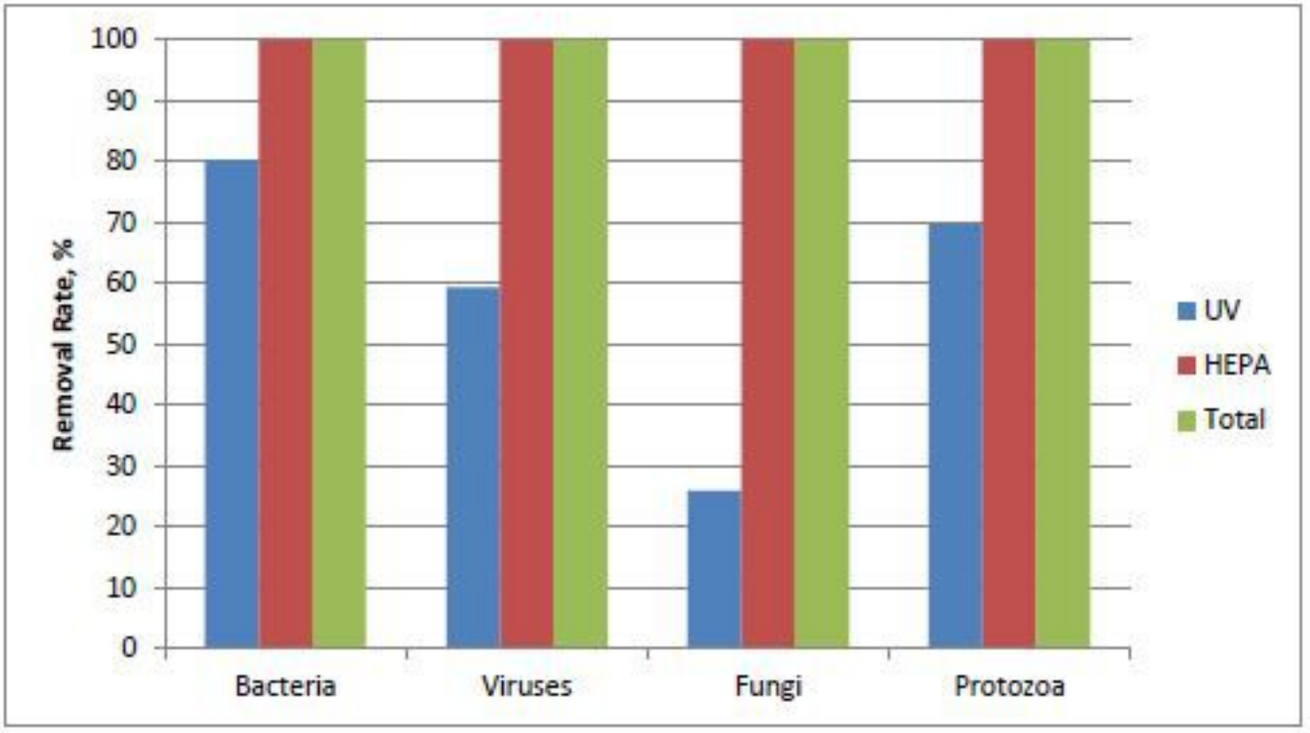

Figure 3: Average removal rates at 50 cfm, from Appendix E, F, & G.

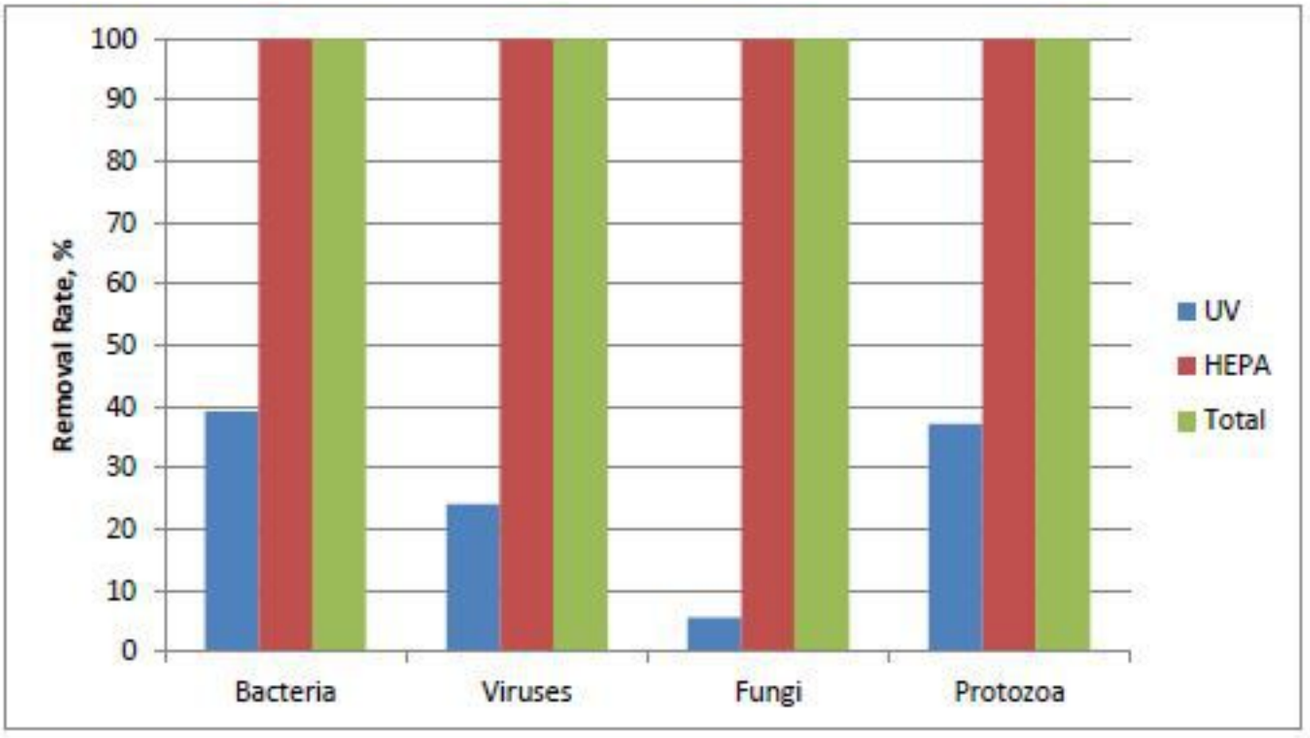

Figure 4: Average removal rates at 50 cfm, from Appendix H, I, & J.

In place performance of the Airpura Unit

To evaluate the performance of the Airpura unit in place a model is constructed consisting of a 400 ft2 room with 15% outside air. The model will compute the indoor airborne concentrations over 8 hours after beginning with high airborne concentrations of pathogens. It is assumed that the initial concentration of bacteria in the room is 1000 cfu/m^3, the viruses at 10,000 pfu/m^3, and the fungal spores at 1000 cfu/m^3. It is also assumed that the outdoor air contains 100 cfu/m^3 of bacteria and 400 cfu/m^3 of fungi. There are no viruses in outdoor air. The unit is placed into operation at time t=0 minutes and the airborne concentrations are computed minute-by-minute. The unit thereby removes microbes in each pass the rates that are summarized in Table 6. After 8 hours of operation the airborne concentrations of viruses are 7 pfu/m^3, the concentrations of bacteria are 48 cfu/m^3, and the concentrations of fungi are 191 cfu/m^3. These are, of course, harmless levels. Figure 5 illustrates the drawdown of the airborne concentrations as they approach steady state concentrations after 8 hours.

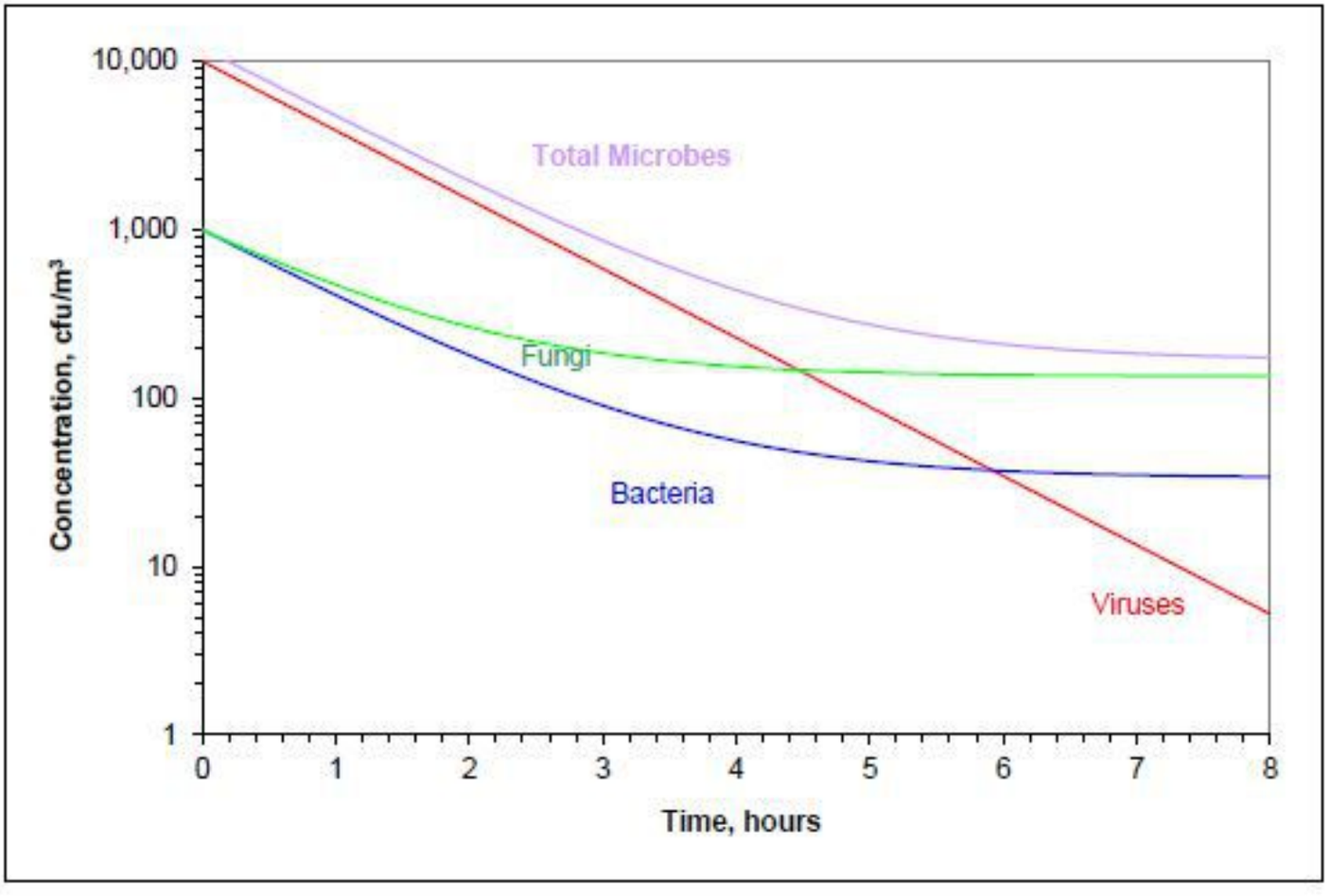

Figure 5: Drawdown model of in place performance of the Airpura unit. Room size is 400 ft^2.

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