Prediction of Virus Inactivation by the UV400

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Executive Summary

This report reviews the capability of the UV400 air disinfection unit to inactivate airborne viruses, based on laboratory test data for bacteria. The UV400 has been certified as an FDA Class II Medical Device (for bacteria). Previous test results from Northeast Laboratories, Inc., indicate the UV400 unit produces a mean UV Dose of about 41 J/m^2. This dose would result in an estimated rating of URV 15 by the guidelines of the International Ultraviolet Association (IUVA). A prior report, “Selection of Microorganisms for UV Testing,” addressed the subject of the effectiveness of this air cleaning unit against bacteria and spores, and selection of appropriate bacteria for testing. This report specifically focuses on viruses and predicts the effectiveness for the UV400 unit against several airborne viruses for which UV exposure data is available, including H1N1 influenza (swine flu). Based on the analysis herein, the UV400 unit will have exceptional performance against common viral pathogens with single pass efficiencies for airborne viruses that vary from 89% to over 99%. H1N1 influenza will be removed at a 99.2 % rate. *Staphylococcus aureus* (MRSA) will be removed at a 99.3% rate.

Summary of Test Results

The test results from Northeast Laboratories are summarized in Table 1, which is repeated from the previous report on bacteria (Kowalski 2007). Based on the inactivation rates and known rate constants, the Effective Mean UV dose imparted to these microbes was estimated and averaged for all tests. This UV dose, **4100 μW/cm^2** (or 41 J/m^2), is used as a basis for estimating the inactivation rates of viruses. In Table 1 the Average % represents the average inactivation rate based on the test results, and is the value which will be used in later references.

Table 1: NorthEast Laboratories Test Results on the UV400 Unit

Microbe	Population Before	Population After	Inactivation %	Average %	k cm^2/μW-s	Effective Dose μW-s/cm^2
Bacillus subtilis	420	<1	99.76	99.71	0.001686	3583
	300	<1	99.67			3383
Pseudomonas aeruginosa	8370	29	99.65	99.72	0.002375	2385
	140,000	300	99.79			2588
Klebsiella pneumoniae	19,000	79	99.58	99.10	0.000548	10005
	20,360	280	98.62			7822
Staphylococcus aureus (MRSA)	600	7	98.83	99.30	0.003475	1281
	16,000	36	99.78			1754
Effective Mean UV Dose						**4100**
UVGI Rating Value (URV)						15

Note: Results for Bacillus represent a minimum.

UV Rate Constants of Airborne Viruses

Some 25 viruses are known or suspected to be transmissible by the airborne route. Table 2 summarizes all known airborne viruses, including those responsible for nosocomial infections, based on NNIS reports from the CDC and other sources. H1N1 influenza (swine flu) is physiologically identical to Influenza A and the UV susceptibility will be the same.

Table 2: Potentially Airborne Viruses

VIRUS	GROUP	Annual Cases	Nosocomial	PRIMARY INFECTION CAUSED
Influenza A (H1N1)	RNA Virus	2,000,000	Yes	flu, swine flu, secondary pneumonia
Measles virus	RNA Virus	500,000	Yes	measles (rubeola)
Respiratory Syncytial Virus	RNA Virus	75,000	Yes	pneumonia, bronchiolitis
Varicella-zoster virus	DNA Virus	46,016	Yes	chickenpox
Parainfluenza virus	RNA Virus	28,900	Yes	flu, colds, croup, pneumonia
Rubella virus	RNA Virus	3,000	Yes	rubella (German measles)
SARS virus	RNA Virus	10 (China)	Yes	Severe Acute Respiratory Syndrome
Adenovirus	DNA Virus	common	-	colds, fever
Coronavirus	RNA Virus	common	-	colds, fever
Coxsackievirus	RNA Virus	common	-	colds, fever
Echovirus	RNA Virus	common	-	colds, fever
Junin	RNA Virus	-	No	hemmorrhagic fever
Lassa	RNA Virus	-	No	Lassa fever
Machupo	RNA Virus	-	No	hemmorrhagic fever
Marburg	RNA Virus	-	No	hemmorrhagic fever
Mumps	RNA Virus	-	Yes	mumps
Norwalk	RNA Virus	-	No	gastroenteritis
Parvovirus	DNA Virus	-	-	fifth disease
Reovirus	RNA Virus	common	-	colds, fever
Rhinovirus	RNA Virus	common	-	colds, fever
Lymphocytic choriomenigitis	RNA Virus	-	-	LCV
Avian influenza	RNA Virus	-	-	flu
Hantaan virus	RNA Virus	-	-	hantavirus
Vaccinia	DNA Virus	-	-	cowpox
Variola (smallpox)	DNA Virus	-	No	smallpox

Less than half the known airborne viruses have been tested to the point that UV inactivation data is available and can be used to develop a UV rate constant. Only a handful of these tests were performed in air or on plates. Table 4 shows the microbes from Table 3 for which UV rate constants are known in air or on surfaces. See the References for the indicated UV rate constant source documents.

Table 3: UV Rate Constants for Airborne Viruses & Test Bacteria

MICROBE	GROUP	Rate Constant k m^2/J	Media	UVGI D_{90} J/m^2	Reference
Klebsiella pneumoniae	Bacteria	0.05480	Air	42.0	Zemke 1990
Adenovirus	DNA virus	0.05500	Air	41.9	Jensen 1964
Varicella-zoster virus	DNA virus	0.05860	-	39.3	Lytle 1971
Coxsackievirus B-1	RNA virus	0.11081	Air	20.8	Jensen 1964
Influenza A (H1N1)	RNA virus	0.11868	Air	19.4	Jensen 1964
SARS coronavirus	RNA virus	0.01020	Water	225.7	Kariwa 2004
Variola (smallpox)	DNA virus	0.15280	-	15.1	(similar to Vaccinia)
Vaccinia	DNA virus	0.15277	Air	15.1	Jensen 1964
Vaccinia	DNA virus	0.15424	Plates	14.9	Galasso 1965
Bacillus subtilis	Bacteria	0.16860	Air	13.7	Nakamura 1987
Pseudomonas aeruginosa	Bacteria	0.23750	Air	9.7	Collins 1971
Staphylococcus aureus (MRSA)	Bacteria	0.34750	Air	6.6	Sharp 1940

Although the test media indicated in Table 3 are not all air, it is likely that the UV rate constants in other media such as plates are conservative for use in place of the airborne rate constant (Kowalski 2006). Water-based rate constants are not used here however, as water rate constants tend to be considerably lower than in air. Figure 1 illustrates the inactivation rates of the airborne viruses shown in Table 3, along with the test bacteria, in a single pass through the unit. Clearly, the viruses will virtually all be inactivated at rates comparable to the test viruses, and their decay curves are encompassed by the test bacteria curves.

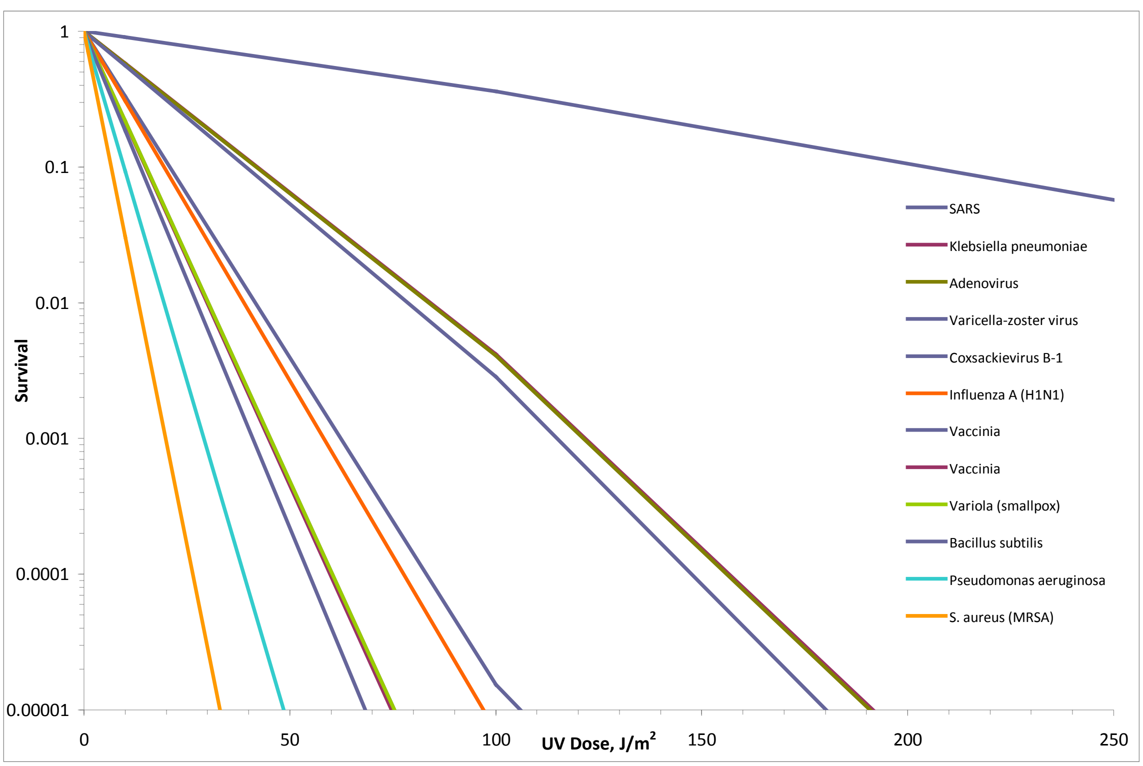

Figure 1: Inactivation of airborne viruses compared to the test bacteria, in a scale including the UV dose range produced by a single pass through the UV400.

It is clear from Figure 1 that all the indicated viruses will be inactivated as fast or faster than any of the airborne bacteria that were tested. This is expected since, in general, viruses are more fragile than bacteria and more susceptible to UV exposure. Therefore, the test results for bacteria shown previously (Kowalski 2006) provide strong indication that the subject UV dose, 41 J/m^2, will be as effective against viruses as it is against bacteria.

Table 4 summarizes the final inactivation rates for the viruses and bacteria in Figure 1 based on a combination of the predicted results from Table 3 and the actual test results from Table 1.

Table 4: Inactivation Rates for UV400

MICROBE	UVGI D_{90} J/m^2	k m^2/J	Source	Inactivation Rate %
SARS coronavirus	226	0.01020	Predicted	34.2
Adenovirus	42	0.05500	Predicted	89.5
Varicella-zoster virus	39	0.05860	Predicted	91.0
Coxsackievirus B-1	21	0.11081	Predicted	98.9
Klebsiella pneumoniae	42	0.05480	Test Results	99.104
Influenza A (H1N1)	19	0.11868	Predicted	99.2
Staphylococcus aureus (MRSA)	7	0.34750	Test Results	99.304
Bacillus subtilis	14	0.16860	Test Results	99.714
Pseudomonas aeruginosa	10	0.23750	Test Results	99.720
Variola (smallpox)	15	0.15280	Predicted	99.81
Vaccinia	15	0.15277	Predicted	99.81
Vaccinia	15	0.15424	Predicted	99.82

Figure 2 shows a comparison of the UV rate constants of the various viruses from Table 4, with the test bacteria highlighted in light blue. It can be observed in Figure 2 that the average inactivation rate for viruses is in excess of 89%, and that this is for a single pass through the unit. Multiple passes through the unit will occur in actual operation and therefore the total removal rates over time could greatly exceed the values shown in Table 4.

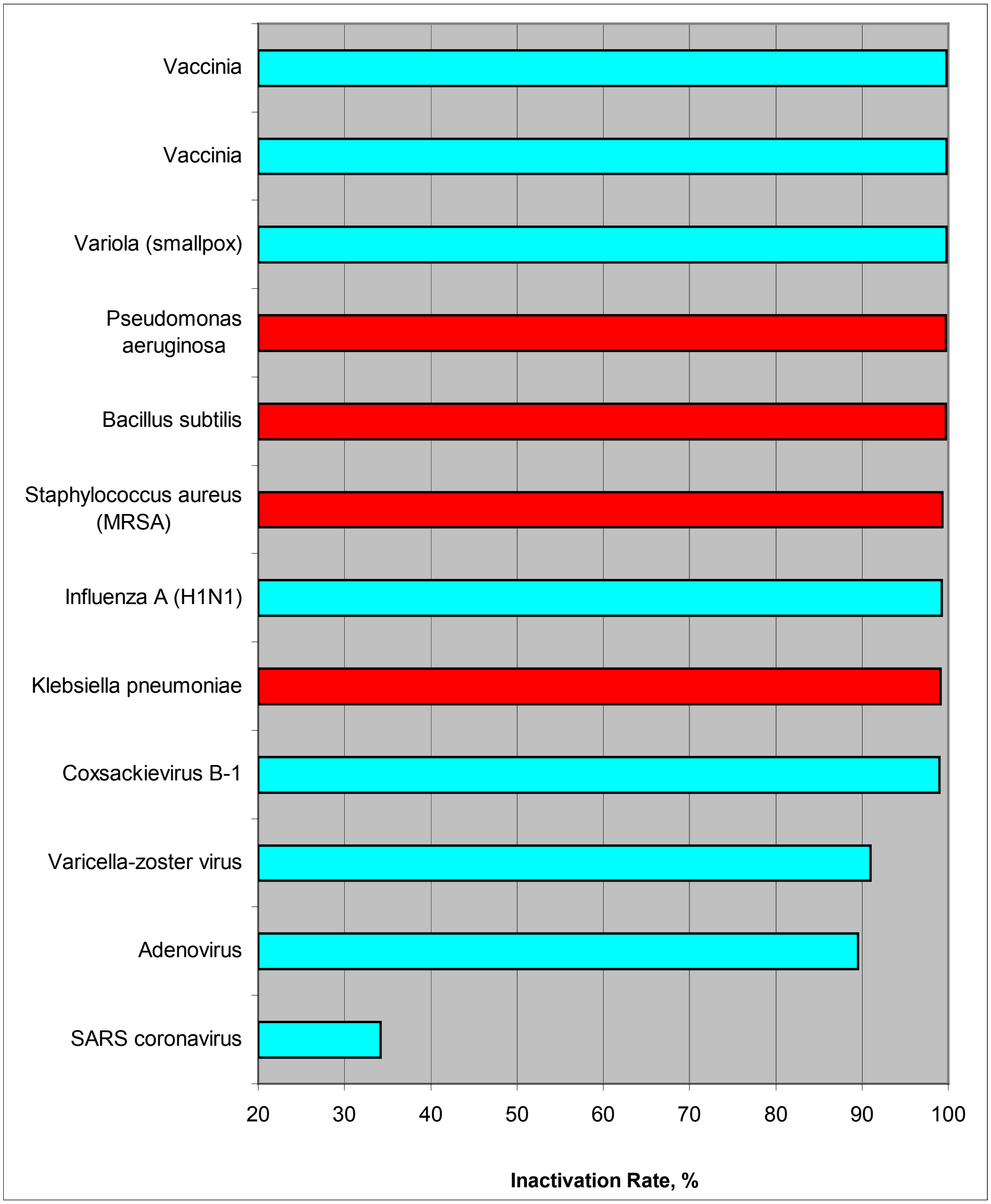

Figure 2: Comparison of predicted and measured UV inactivation rates for bacteria and viruses for which UV susceptibility data in air is available. Red bars represent test results from this report.

Multiple passes through the unit are likely to occur in any enclosed room, and the number of passes depend on the room air exchange rate and volume. Even if the room total air exchange rate is low the room air may pass many times through the unit in the course of a day. Table 5 shows the effect of multiple passes through the unit. It is clear that several logs of reduction can be achieved with as little as four passes through the unit. This might be the case in a residential application with little or no outside air exchange and is also true for the general wards, offices, and waiting areas of typical hospitals.

Table 5: Predicted Inactivation Rates for UV400 with Multiple Passes

MICROBE	Inactivation Rate			
	Pass 1 %	Pass 2 %	Pass 3 %	Pass 4 %
SARS coronavirus	34.2	56.67	81.23	>99.99
Adenovirus	89.5	98.90	99.99	>99.99
Varicella-zoster virus	91.0	99.18	>99.99	>99.99
Coxsackievirus B-1	98.9	99.99	>99.99	>99.99
Klebsiella pneumoniae	99.1	>99.99	>99.99	>99.99
Influenza A (H1N1)	99.2	>99.99	>99.99	>99.99
Staphylococcus aureus (MRSA)	99.3	>99.99	>99.99	>99.99
Bacillus subtilis	99.7	>99.99	>99.99	>99.99
Pseudomonas aeruginosa	99.7	>99.99	>99.99	>99.99
Variola (smallpox)	99.8	>99.99	>99.99	>99.99
Vaccinia	99.8	>99.99	>99.99	>99.99
Vaccinia	99.8	>99.99	>99.99	>99.99

Conclusion and Recommendations

The UV400 will produce a UV dose of about 41 J/m^2 and warrants a rating of URV 15. This UV dose is sufficient to inactivate viruses at high levels, mostly in excess of 90% for a single pass, based on the summaries provided in this report. All four test bacteria, *Klebsiella pneumoniae, Bacillus subtilis, Pseudomonas aeruginosa*, and *Staphylococcus aureus* (MRSA), were demonstrated to have removal rates in excess of 99%. For influenza A (H1N1) virus, the inactivation is predicted to be in excess of 99% in a single pass. For MRSA, the inactivation rate is also in excess of 99%. In actual operation, multiple passes through the unit will likely occur, producing removal rates that exceed 99%.

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