Efficacy of the Plasma Air 603 against Aerosolized MS2 Virus in a Large Chamber

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Background: This in vitro study characterized the efficacy of the Plasma Air 603 at removing aerosolized MS2 Bacteriophage. The Plasma Air device is designed to reduce airborne bacteria, viruses, and fungal spores in order to decrease infections rates from airborne pathogens. For this study the Plasma Air device was challenged using aerosolized MS2 bacteriophage which has been historically used as a surrogate for influenza, and is now being considered as a surrogate for coronaviruses such as SARS-CoV-2 due to the size similarity to influenza and RNA genome. This study evaluated the efficacy of the device against aerosolized MS2 bacteriophage in an air duct system installed on the stainless steel bioaerosol chamber. The study consisted of a total of three (3) live bioaerosol trials, and a single (1) bioaerosol control run.

Methods: MS2 bacteriophage was aerosolized into a sealed environmental bioaerosol chamber equipped with an air duct system containing the Plasma Air device. AGI Impinger samples were taken from the chamber in order to quantify the reduction speed and capabilities of the Plasma Air device. AGI impingers were used to sample chamber bioaerosol concentrations, all impinger samples were serially diluted, plated and enumerated in triplicate to yield viable bioaerosol concentration at each sampling point and time. The chamber control trial data was subtracted from the Plasma air trial data to yield net LOG reduction in the chamber for the bioaerosol challenges.

Results: When tested against the MS2 bacteriophage, the Plasma Air 603 device showed a consistent net LOG reduction throughout the testing. The average net LOG reduction went from 0.63 at the 120-minute time point down to 2.24 at the 240-minute time point to end the trial. A net LOG reduction of 2.24 over 240 minutes point indicates the efficacy of this device against the MS2 bacteriophage when compared to a natural reduction rate.

This study was conducted in compliance with FDA Good Laboratory Practices (GLP) as defined in 21 CFR, Part 58.

Introduction

This study was conducted to evaluate the efficacy of the Plasma Air 603 at reducing aerosolized MS2 bacteriophage. The Plasma Air device is an air purification system intended to be used in an air duct systems such as air handling units and furnaces in both commercial and residential buildings. The units were used at full capacity for testing.

This Plasma Air device is a needle point brush type ion generator that introduces positive and negative ions into duct systems to reduce contaminants flowing through the system into the air. The test plan incorporated challenging the Plasma Air device in a duct system attached to an otherwise closed environmental chamber to determine the destruction rate of MS2 bacteriophage by the Plasma Air device. A picture of the Plasma Air 603 is shown in **Figure 1,** on the following page.

Study Overview

The effectiveness of the Plasma Air device was evaluated against a single RNA virus which was MS2 bacteriophage. For more information on the MS2 bacteriophage please see species selection section in the body of this report.

Testing was conducted to characterize four Plasma air units against MS2 with triplicate (3) independent trials as well as a single (1) control trial to demonstrate the capability of the Plasma Air device to reduce viable bioaerosol concentrations therefore theoretically reducing chances of airborne infection. This study does not make any claims regarding the efficacy of this device at reducing airborne infections.

Figure 1*: Plasma Air 603 Device*

Bioaerosol Testing Chamber

A large sealed aerosol test chamber was used to replicate a potentially contaminated room environment and to contain any potential release of aerosols into the surrounding environment.

The aerosol test chamber is constructed of 304 stainless steel and is equipped with three viewing windows and an air-tight lockable chamber door for system setup and general ingress and egress. The test chamber internal dimensions are 9.1ft x 9.1ft x 7ft, with a displacement volume of 579 cubic feet, or 16,000 liters. **Figure 2** shows the bioaerosol chamber used for all testing in this study.

The chamber is equipped with filtered HEPA inlets, digital internal temperature and humidity monitor, external humidifiers (for humidity control), lighting system, multiple sampling ports, aerosol mixing fans, and a HEPA filtered exhaust system that are operated with wireless remote control. For testing, the chamber was equipped with four 3/8-inch diameter stainless steel probes for aerosol sampling, a 1-inch diameter port for bio-aerosol dissemination into the chamber using a Collison 24-jet nebulizer for the aerosolization of the bacteriophage.

A ¼ inch diameter probe was used for continuous aerosol particle size monitoring via a TSI Aerodynamic Particle Sizer (APS) Model 3321. All sample and dissemination ports were inserted approximately 18 inches from the interior walls of the chamber to avoid wall effects and at a height of approximately 40 inches from the floor.

An HVAC air duct, 12” x 24” in size, was installed on top of the chamber for testing of the Plasma Air 603. The inlet / outlet to the chamber from the HVAC consisted of two 6-inch diameter ports for air exchange within the chamber. The ports for the duct system are located centrally on the chamber 7ft. apart. The blower connected to the system was set to an equivalent velocity corresponding to 4 turnover rates per hour in the chamber. The duct system blower was ran continuously for all control and PA603 bioaerosol trials.

The aerosol sampling and aerosol dissemination probes are stainless steel and bulk headed through the chamber walls to provide external remote access to the aerosol generator and samplers during testing.

Figure 2*: Bioaerosol Test Chamber Equipped.*

The test chamber is equipped with two high-flow HEPA filters for the introduction of filtered purified air into the test chamber during aerosol evacuation/purging of the system between test trials and a HEPA filtered exhaust blower with a 500 ft^3/min rated flow capability for rapid evacuation of remaining bioaerosols.

A Magnehelic gauge with a range of 0.0 +/- 0.5 inch H_2O (Dwyer instruments, Michigan City IN) was used to monitor and balance the system pressure during aerosol generation, aerosol purge and testing cycles.

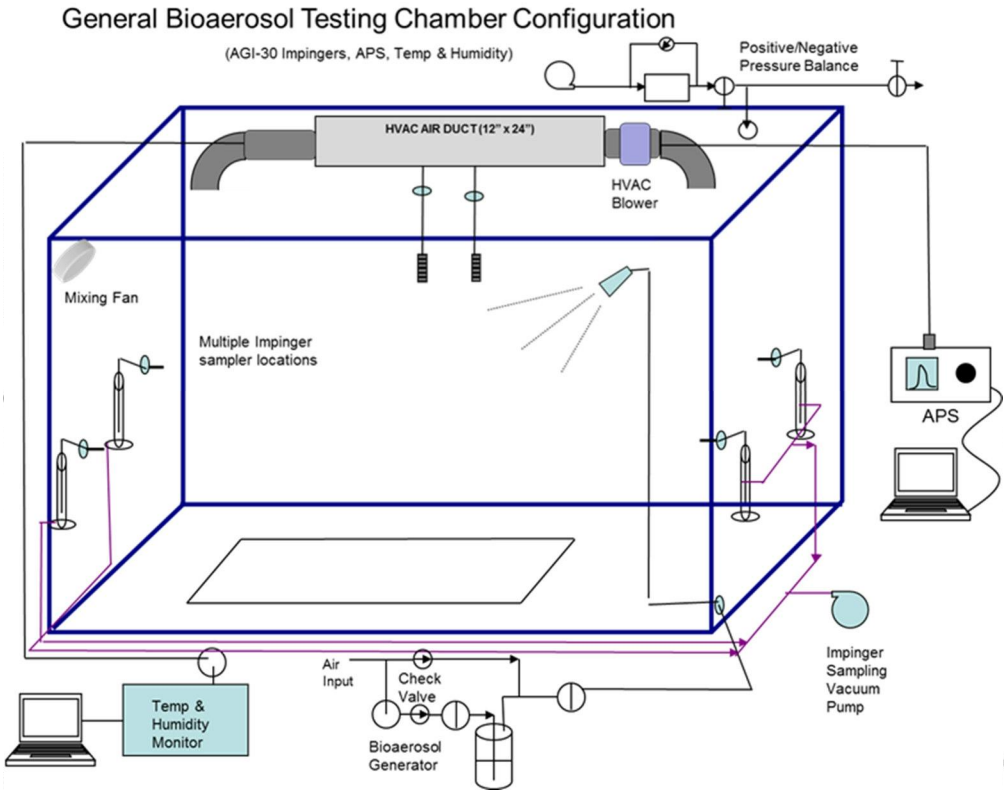

Figure 3: *Bio-Aerosol Test Chamber Flow Diagram.*

Bioaerosol Generation System

Test bioaerosols were disseminated using a Collison 24-jet nebulizer (BGI Inc. Waltham MA) driven by purified filtered house air supply. A pressure regulator allowed for control of disseminated particle size, use rate and sheer force generated within the Collison nebulizer.

Prior to testing, the Collison nebulizer flow rate and use rate were characterized using an air supply pressure of approximately 60 psi, which obtained an output volumetric flow rate of 50-80 lpm with a fluid dissemination rate of approximately 1.25 ml/min. The Collison nebulizer was flow characterized using a calibrated TSI Model 4040 mass flow meter (TSI Inc., St Paul MN).

Bioaerosol Sampling and Monitoring System

Two AGI impingers (Ace Glass Inc. Vineland NJ) were used for bio-aerosol collection of all biological aerosols to determine chamber concentration. The AGI-30 impinger vacuum source was maintained at a negative pressure of 18 inches of Hg during all characterization and test sampling to assure critical flow conditions. The AGI-30 sample impingers were flow characterized using a calibrated TSI Model 4040 mass flow meter.

Aerosol particle size distributions and count concentrations were measured in real-time through the duration of all control and Plasma air trial runs using a Model 3321 Aerodynamic Particle Sizer (APS) (TSI Inc., St Paul, MN). The APS sampled for the entire duration of all trials with 1 minute sampling intervals. A general flow diagram of the aerosol test system is shown above in **Figure 3** above.

Species Selection

Species selection is based on Biological Safety Level 1 (BSL1) surrogates for BSL3 pathogenic organisms. *MS2* is a viral RNA bacteriophage that is commonly used as a surrogate for the influenza virus, and is now being considered as a possible surrogate for other RNA viruses such as SARS-COV-2. This is due to SARS-COV-2s similar size to influenza and RNA genome. The major difference is the enveloping of SARS-COV-2 that influenza does not possess.

Viral Culture & Preparation

Pure strain viral seed stock and host bacterium were obtained from ATCC. Host bacterium was grown in a similar fashion to the vegetative cells in an appropriate liquid media. The liquid media was infected during the logarithmic growth cycle with the MS2 bacteriophage. After an appropriate incubation time the cells were lysed and the cellular debris separated by centrifugation. MS2 stock yields were greater than 1 x 10^{11} plaque forming units per milliliter (pfu/ml) with a single amplification procedure. This stock MS2 viral solution was then diluted with PBS to approximately 1 x 10^{10} plaque forming units per milliliter (pfu/ml) for use in the Collision nebulizer

Plating and Enumeration

Impinger and stock MS2 bacteriophage cultures were serially diluted and plated in quadruplicate (multiple serial dilutions) using a small drop plaque assay technique onto tryptic soy agar plates. The plated cultures were incubated for 24-48 hours and enumerated and recorded.

Bioaerosol Control Testing

To accurately assess the Plasma air unit, test chamber pilot control trials were performed with MS2 bacteriophage over a 240-minute period without the device in operation to characterize the biological challenge aerosol for particle size distribution, aerosol delivery/collection efficiency, and viable concentration over time.

Control testing was performed to provide baseline comparative data in order to assess the actual reduction from the Plasma air challenge testing and verify that viable bioaerosol concentrations persisted above the required concentrations over the entire pilot control test period.

During control runs, a single low velocity fan located in the corner of the bioaerosol test chamber was turned on for the duration of trial to ensure a homogenous aerosol concentration within the aerosol chamber. The blower on the air duct system containing the device was turned on during the control to simulate the real testing conditions. The mixing fan was used for all control runs and remained on during the Plasma air decontamination trials. The two impingers used for bacteriophage were pooled and mixed prior to plating and enumeration. A complete test matrix for all bioaerosol trials can be found above in **Figure 4**.

Plasma air Testing

For each control and challenge test, the Collison nebulizer was filled with approximately 40 mL of biological stock and operated at 50 psi for a period of 15 minutes (organism dependent). For control and Plasma air trials, the impingers were filled with 20 mL of sterilized PBS (addition of 0.005% v/v Tween 80) for bioaerosol collection. The addition of Tween 80 was shown to increase the impinger collection efficiency and de-agglomeration of all microorganisms.

The chamber mixing fan was turned on during MS2 bacteriophage dissemination to assure a homogeneous bioaerosol concentration in the test chamber prior to taking the first impinger sample

Following bioaerosol generation, baseline MS2 concentrations were established for each pilot control and Plasma air test by sampling simultaneously with two AGI-30 impingers located at opposite corners of the chamber. AGI samples were collected for 2 to 20 minutes at intervals of 60 minutes throughout the entire test period. The mixing fan remained on during the duration of testing to assure the chamber was properly mixed as it was being pulled through the air duct system and pushed back out.

Collected impinger chamber samples were pooled and mixed at each sample interval for each test. Aliquots of impinger samples were collected and then used for plating. Impingers were rinsed 6x with sterile filtered water between each sampling interval, and re-filled with sterile PBS using sterile graduated pipettes for sample collection.

Test Matrix for the PA603

Trial	Run	Device	Organism	Target Monodispersed Particle Size	Trial Time (min)	Sampling Period (min)	Sampling
C1 T1 T2 T3	Control Challenge Challenge Challenge	Plasma Air 603	*MS2 Bacteriophage - RNA Virus*	0.8-1.0um	240	0, 60, 120, 180, 240	AGI Impingers

Figure 4: *Bioaerosol Test Matrices for all trials*

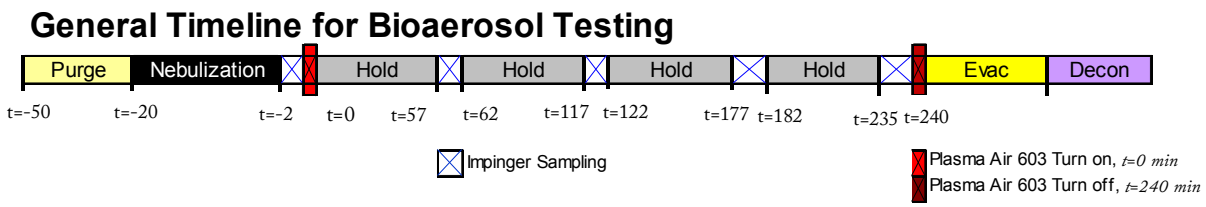

Figure 5: *General Timeline for the Plasma Air 603 Testing*

For Plasma air biological testing, the unit was turned on immediately following a time 0 baseline sample and operated for the entirety of the test (2 hours). Subsequent impinger samples were taken at 0, 60, 120, 180, and 240 minutes and samples enumerated for viable concentration to measure the effective viable MS2 bacteriophage reduction during operation of the Plasma Air device over time. All samples were plated in quadruplicate on tryptic soy agar media over a minimum of a 3 log dilution range. A general timeline for bioaerosol testing can be found in **Figure 5**.

Plates were incubated for 24 hours and enumerated for viable plaque forming units (pfu) to calculate aerosol challenge concentrations in the chamber and reduction of viable microorganisms.

Post-Testing Decontamination and Prep

Following each test, the chamber was air flow evacuated/purged for a minimum of twenty minutes between tests and analyzed with the APS for particle concentration decrease to baseline levels between each test. The chamber was decontaminated at the conclusion of the trials after the device was removed with aerosol/vaporous hydrogen peroxide (35%). The Collison nebulizer and impingers were cleaned at the conclusion of each day of testing by soaking in a 5% bleach bath for 20 minutes. The nebulizer and impingers were then submerged in a DI water bath, removed, and spray rinsed 6x with filtered DI water until use.

Bioaerosol Particle Size Data

Aerosol particle size distributions were measured with the APS throughout the trials. The APS has a dynamic measurement range of 0.5 to 20µm and was programmed to take consecutive real time one-minute aerosol samples throughout the duration of each aerosol trial.

Data was logged in real time to an Acer laptop computer, regressed, and plotted. The aerosol particle size distribution for MS2 in the large chamber during the trials is shown in **Figure 6**.

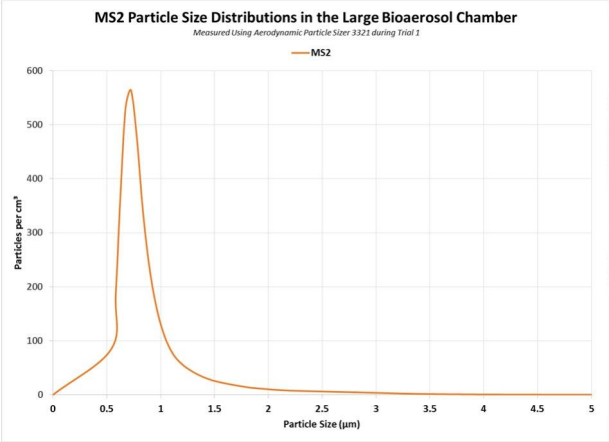

Figure 6: *Viral (MS2) Number Particle Size Distribution in Test Chamber.*

The particle size distribution for MS2 bioaerosols are shown to be within the respirable range for alveolar region tract lung deposition and show a low geometric standard deviation (GSD) indicating a monodispersed aerosol was generated into the test chamber. The key particle size distribution values for MS2 bacteriophage in the chamber can be found in **Figure 7.**

	Number Particle Size
Median (µm)	0.857
Mean (µm)	0.938
Geo. Mean (µm)	0.893
Mode (µm)	0.777
Geo. St. Dev.	1.35
Total Conc.	4.99e+03(#/cm³)

Figure 7: *Key Particle Size Distribution Values for MS2 Bioaerosol in Chamber.*

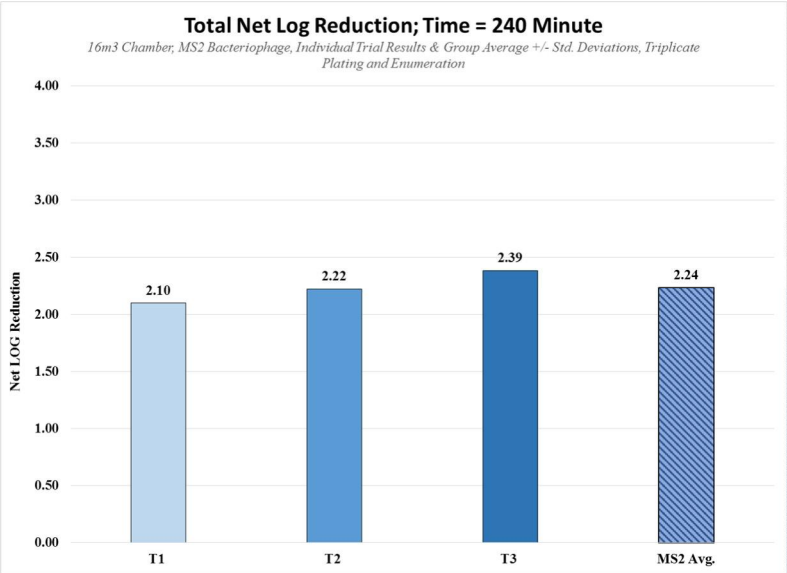

Figure 8: *MS2 Net LOG Reduction at T-240*

Data Analysis

Results from the control trial were graphed and plotted to show natural viability loss over time in the chamber. This control run served as the basis to determine the amount of reduction the Plasma Air 603 produced above natural reduction. The control and trial runs are plotted showing log reduction in viable bioaerosol for each organism.

All data is normalized with time zero (*t=0* minutes) enumerated concentrations. Subsequent samples are normalized and plotted to show the loss of viability over time.

Results

When tested against the *MS2 bacteriophage* the device showed a consistent net log reduction throughout the duration of the trial. The total net log reduction for the four trials averaged 2.24 log. A graphic displaying the net log reduction for each trial as well as an average for all of the trials can be found in **Figure 8.**

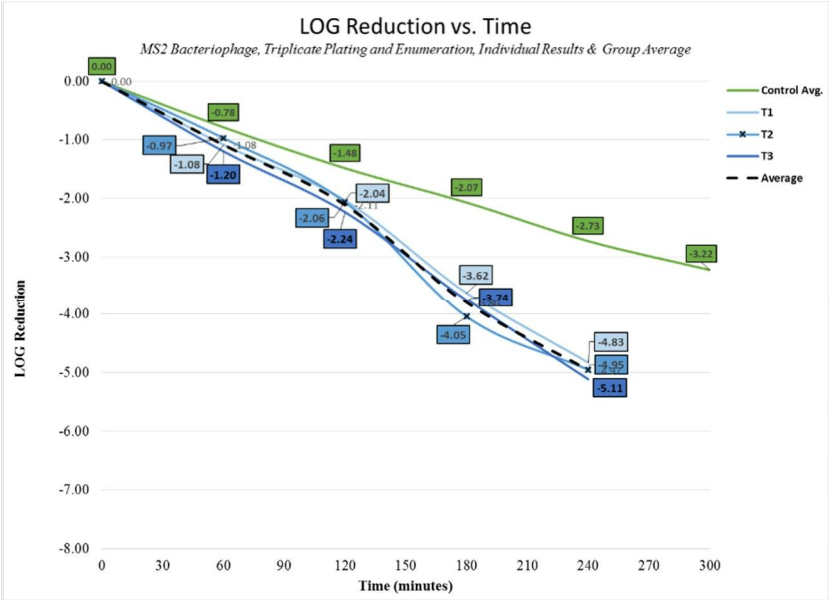

Figure 9: *MS2 LOG Reduction all trials*

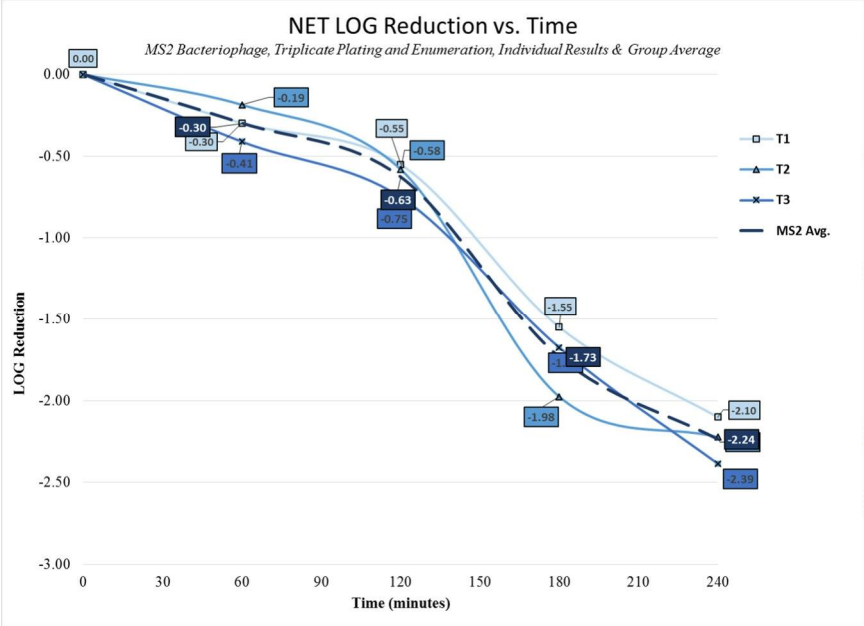

Figure 10: *MS2 Net LOG Reduction all trials*

Summary of Results

When tested against the MS2 bacteriophage, a surrogate traditionally used for influenza and now considered as a possible surrogate for SARS-COV-2, the device showed consistent net log reduction throughout each trial. By the 180-minute time point results showed an average 3.80 LOG reduction which equates to an average 1.73 net LOG reduction. LOG reduction trials as well as the control trial are plotted in **Figure 9**, Net LOG reduction results as well as an average net LOG reduction for the three trials can be found in **Figure 10**.

After 60 minutes the device had an average net LOG reduction of 0.30 LOG. After the 120-minute time point there is a continued LOG reduction down to an average of 0.63 net LOG. At the 240-minute time point at the end of the trial the device produced and average net LOG reduction of 2.24. A net LOG reduction of 2.24 is equivalent to a 99.39% reduction in viable MS2 bacteriophage. These results indicate that in theory the Plasma Air device would help prevent the spread of airborne infection. A table showing the results in net log reduction and in percent reduction can be found in **Figure 11** and **Figure 12.**

Average NET LOG Reduction of MS2 By PA603

Bioaerosol Type	Species	Surrogate	Trial ID	60min	120min	180min	240min
Virus	*MS2 bacteriophage (RNA virus)*	*Influenza, other RNA viruses such as SARS*	*T1*	-0.30	-0.55	-1.55	-2.10
Virus	*MS2 bacteriophage (RNA virus)*	*Influenza, other RNA viruses such as SARS*	*T2*	-0.19	-0.58	-1.98	-2.22
Virus	*MS2 bacteriophage (RNA virus)*	*Influenza, other RNA viruses such as SARS*	*T3*	-0.41	-0.75	-1.67	-2.39
Average				**-0.30**	**-0.63**	**-1.73**	**-2.24**
St. Dev.				**0.11**	**0.11**	**0.22**	**0.14**

Figure 11: *Net Log Reduction summary table*

Average NET LOG Reduction of MS2 By PA603

Bioaerosol Type	Species	Surrogate	Trial ID	60min	120min	180min	240min
Virus	*MS2 bacteriophage (RNA virus)*	*Influenza, other RNA viruses such as SARS*	*T1*	49.652%	71.882%	97.176%	99.207%
Virus	*MS2 bacteriophage (RNA virus)*	*Influenza, other RNA viruses such as SARS*	*T2*	34.863%	73.689%	98.941%	99.402%
Virus	*MS2 bacteriophage (RNA virus)*	*Influenza, other RNA viruses such as SARS*	*T3*	61.237%	82.246%	97.882%	99.588%
Average				**48.584%**	**75.939%**	**97.999%**	**99.399%**
St. Dev.				**13.220%**	**5.536%**	**0.888%**	**0.190%**

Figure 12: *Reduction percentage summary table*

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Analytical Testing Facility

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Project

10824.11B

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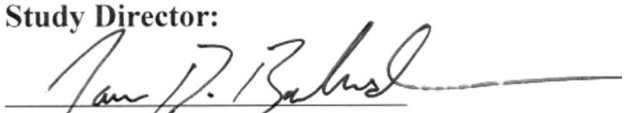
GLP Statement

We, the undersigned, herby certify that the work described herein was conducted by Aerosol Research and Engineering Laboratories in compliance with FDA Good Laboratory Practices (GLP) as defined in 21 CFR, Part 58.

Study Director:



07/08/2020
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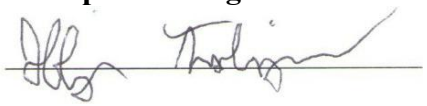

07/08/2020
Date

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Appendix A: Calculations

AGI – 30 impinger or 47mm filter collection calculation:

- Viable aerosol concentration collection (C_a) = cfu or pfu/L of chamber air.
- Viable Impinger concentration collection (C_{Imp}) = cfu or pfu/mL from enumeration of impinger sample or filter sample.
- Impinger sample collection volume (I_{vol}) = 20 mL collection fluid/impinger, or extraction fluid for filter.
- AGI–30 impinger or filter sample flow rate (Q_{imp}) = 12.5 L/min.
- AGI–30 impinger or filter sample time (t) = 5 or 10 minutes, test dependent.

For viable impinger or filter aerosol concentration collection (C_a) = cfu or pfu/L of chamber air:

$$C_a = \frac{C_{Imp} \cdot I_{vol}}{Q_{imp}} t$$

The aerosol system viable delivery efficiency (expressed as %) is:

$$Efficiency = \frac{C_a}{V_p} \cdot 100$$