

November 29, 2012

Mr. Dan Briggs
Genesis Air
5202 CR 7350, Suite D
Lubbock, TX 79424

Dear Mr. Briggs:

RTI tested the efficacy of microbe inactivation by the in-duct ultraviolet photocatalytic oxidation (UV-PCO) air cleaner and the Model 2008 B3 (serial number B3-1-08-003) air purifier unit on behalf of Genesis Air. This letter report details the results of the tests. The testing program for both units utilized two organisms: one spore, *Bacillus atrophaeus*, and one vegetative bacterium, *Staphylococcus epidermidis*. The UV-PCO unit was installed in RTI's test rig, which is compliant with ASHRAE 52.2 specifications with modifications for biological sampling, and tested at a flow rate of 2000 CFM.

Bacillus atrophaeus (*Bg*) is a spore-forming bacterium with spore size ranging from 0.7-0.8 x 1-1.5µm. The organism is a ubiquitous environmental bacterium, found at high levels in soil and highly associated with indoor dust. *Bg* is generally recognized by the scientific and testing communities as one of the simulants for *B. anthracis* in numerous biowarfare agent testing scenarios. Accordingly, *Bg* has value as a historically used simulant and permits comparison to past testing and studies.

Staphylococcus epidermidis (*S. epidermidis*) is a common gram-positive human shedding organism, but can be a pyogenic (fever-causing and pus-forming) pathogen. It is also closely related to *Staphylococcus aureus*, the species responsible for Methicillin-resistant *Staphylococcus aureus* (MRSA) infections. *S. epidermidis* can be viewed more broadly as a representative of vegetative bacteria which are generally more susceptible to neutralization than bacterial spores.

Single Pass In-duct Test Method

The testing was conducted in the test duct shown schematically in Figure 1. The test section of the duct is 0.61 m by 0.61 m (24 in. by 24 in.). The locations of the major components, including the sampling probes, the device section (where the device is installed), and the aerosol generator (site of bioaerosol injection) are shown. The test duct is operated following procedures in the ANSI/ASHRAE (American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard 52.2-2007, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*.

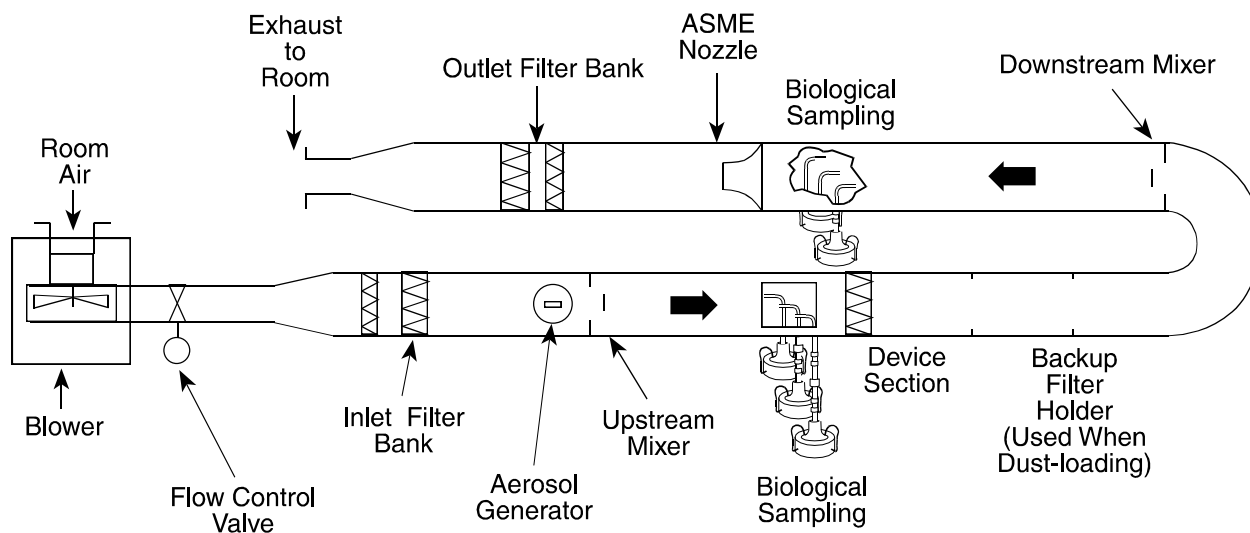


Figure 1. Schematic of Test Duct. UV-PCO device is placed in device section.

The unit tested consisted of an ultraviolet photocatalytic oxidation air cleaner with a MERV 13 filter and 4 lamps. The photocatalytic oxidation unit was fabricated by Genesis Air and attached to a hollow frame used for spacing which was pressed against gasketing to ensure a proper seal. The photocatalytic oxidation section had four integrated UV lamps positioned perpendicular to the direction of air flow. The four lamps for the section were connected to a ballast assembly by electrical cords that traversed the side of the test duct through sealed ports. The lamps were warmed up for at least 10 minutes prior to conducting a test and the lamps were visually confirmed to be working at least once during the test.

The challenge bioaerosol suspensions were aerosolized using a Collison modified MRE-type six-jet nebulizer (BGI, Waltham, MA). The output of the nebulizer was mixed with clean, dry air prior to its entry into the test duct to create the dry bioaerosol challenge.

Bioaerosol samples were collected from the air stream with sampling probes positioned within the test duct at both the upstream and downstream sampling sites. Sampling of the *Bg* and *S. epidermidis* was accomplished using Andersen one-stage viable bioaerosol samplers loaded with Petri dishes containing growth media. The one-stage sampler is a multiple-jet impactor. A positive hole correction was used to adjust colony counts from the Andersen multiple-hole impactor for the possibility of collecting multiple colonies through a hole¹. After sampling, the Petri dishes were removed from the sampler and incubated overnight at 37°C. All plates were visually inspected for quality control and colony forming units (CFUs) were enumerated.

For each run, one of the challenge bioaerosols was injected upstream of the device. A “no-device” transmission test was also performed for each organism, to determine the microorganism loss that would occur simply as the result of deposition in the test duct. For investigation of efficacy with respect to microbe culturability, the performance of the device is reported as the device’s efficiency in inactivating the organism, corrected to account for the loss of organisms observed in the absence of the device. For each concentration of each organism, one test was performed with the unit on, and one no device transmission test was performed.

Test Protocol:

The test protocol was as follows:

- 1) Turn on the test duct blower and adjust flow to 2000 CFM.
- 2) Supply power to the ballast assembly and switch lamps on.
- 3) Turn on the Collison nebulizer and drying air and run for at least 8 minutes.
- 4) Collect upstream and downstream bioaerosol samples.
- 5) Turn off collision and UV light ballasts.

For the “no-device” test, the test unit was removed and step 2 was omitted.

Calculations:

The efficiency of the device for inactivating airborne bioaerosols was calculated as:

$$\text{Airborne Inactivation Efficiency (\%)} = 100 (1 - \text{Corrected Survival Rate}) \quad \text{Equation 1}$$

The calculation of the test organism survival rate (culturable transmission) was based on the ratio of the downstream to upstream culturable organism counts. To remove system bias, the Survival Rate was corrected by the results of the no-device transmission test. The no-device transmission rate was calculated in the same manner as the survival rate test, but using the culturable organism counts from the no-device tests.

Single Pass In-duct Test Results

Table 1 presents the efficacy results for the in-duct UV-PCO unit. The inactivation efficiencies were calculated as shown in Eq. 1. The average values presented were calculated using the results from the upstream and downstream measurements for each challenge. These results are also displayed graphically in Figure 2.

Table 1. Inactivation efficiencies for introduced bioaerosols

Inactivation Efficiency (%)			
Test Organism	Flow Rate (CFM)	Mean	Std. Dev.
<i>Bg</i>	2000	65.59	2.05
<i>S. epidermidis</i>	2000	84.63	2.58

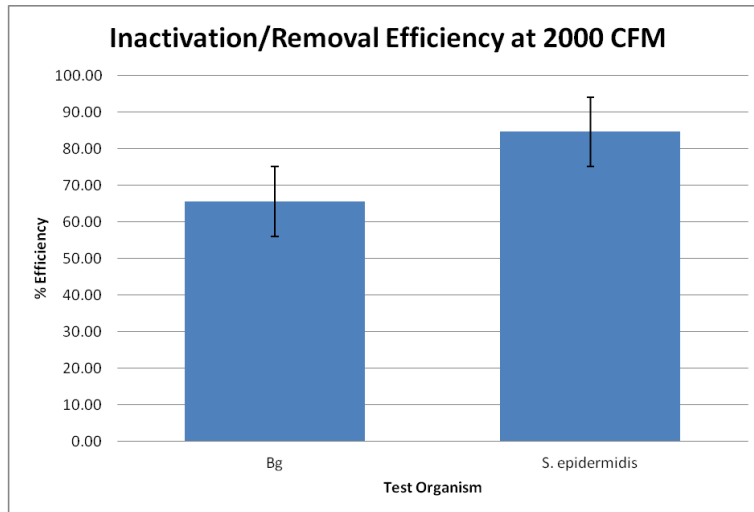


Figure 2. Inactivation/removal efficiency values for single pass efficacy tests

As shown in Table 1 and Figure 2, the efficacy of the unit was dependent upon the challenge organism. The unit was more effective against the *S. epidermidis* than the *Bg* and this observation may be related to the fact that bacterial spores are harder than vegetative structures.

Chamber Air Cleaner Test

The test for each organism included a natural decay measurement and an air cleaner decay measurement. Both measurements are performed after filling the chamber with challenge bioaerosol. The natural decay is defined as the decay of the test bioaerosols in the chamber with the air cleaner off. The air cleaner decay measurement is defined as the decay while the air cleaner is running.

The test method has been described in depth by Foarde et al. (1999). As an overview, the paper describes a test method to determine a Clean Air Delivery Rate (CADR) type measurement for a device when challenged with microbiological aerosols. The method is a modification of the Association of Home Appliance Manufacturers (AHAM) Standard AC-1, “Standard Method for Measuring Performance of Portable Household Electric Cord-Connected Room Aircleaner” which determines the CADR for three different particulate matter challenges (smoke, dust, and pollen). This extension of the AHAM method to microbial aerosols follows the tradition of the AHAM test of using realistic particle challenges and provides a means to compare and evaluate different brands of room air cleaning devices regarding characteristics significant to product use. This is a useful approach for evaluating a wide range of devices.

The Dynamic Microbiological Test Chamber (DMTC) was used for the air cleaner tests. The DMTC is a room-sized environmental chamber contained within the microbiological aerosol test facility, a nominally Class 1,000 cleanroom. The chamber is 2.44 x 2.44 x 3.05 m (18.16 m³ or 640 ft³). The walls and containment ceiling are 10 cm thick prefabricated panels with a stainless steel interior layer. The floor of the chamber was custom constructed of 12-gauge stainless steel with welded seams and insulation underneath between the support members. Floor seams were polished and the coved corners were sealed. The ceiling-mounted mixing fan consists of a two-blade aluminum casting 61 cm in diameter attached to a shaft extending 61 cm from the ceiling into the center of the chamber. To reduce the difficulty of decontaminating the interior features, no electrical outlets were installed inside the chamber. A finished 5 cm penetration in one wall allows extension cord access through rubber stoppers.

Temperature and humidity control were provided by a separate external air handler (AHU). The AHU also controls the steam humidifier which adds water to the chamber air while the HVAC system removes some water and controls the air temperature. Airflow through the system is monitored by an airflow station and controlled by a blower speed controller with the AHU. Air cleaning of the chamber is attained through the use of a HEPA (High Efficiency Particulate Air) filter installed on the discharge side of the AHU. It contains both an ASHRAE 30% prefilter and a HEPA filter.

Figure 3 shows an artist's rendition of the DMTC configured for air cleaner testing. The Model 2008 3 air cleaner was positioned in the center of the chamber.

The challenge bioaerosol suspensions were aerosolized using a Collison modified MRE-type six-jet nebulizer (BGI, Waltham, MA). The Collison nebulizer generated particles or droplets with an approximate mean diameter of 2 μm . These droplets were injected directly into the side of the drying tower and passed through a charge neutralizer before entering the chamber.

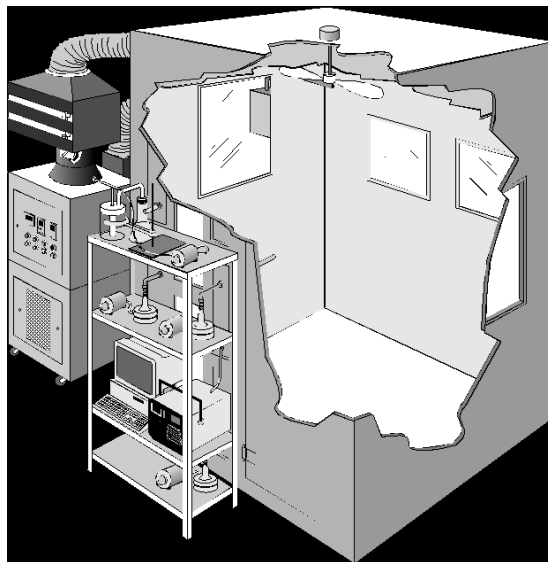


Figure 3: Dynamic Microbiological Test Chamber (DMTC)

Extractive sampling of the bioaerosols was accomplished using ports placed in sampling panels located in one wall of the chamber (see Figure 3). Three sampling ports were used to collect triplicate simultaneous samples. Port A was positioned near the center of the chamber wall, 1.52 m above the floor of the chamber and 1.0 m from the front wall. Port B was 1.52 m above the floor but was 0.25 m from the front wall of the chamber. The third port, C, was directly below Port A, but 0.65 m above the floor of the chamber. Stainless steel 1.27 cm diameter piping extending 0.76 m into the middle of the chamber was used for sample lines. The dimensions of the sample lines were chosen to minimize particle losses during sampling.

Sampling of *B. atrophaeus* and *S. epidermidis* was accomplished using one-stage Andersen viable bioaerosol samplers loaded with Petri dishes containing growth media. The one-stage Andersen sampler is a multiple-jet impactor. After sampling, the Petri dishes were removed from the sampler and incubated overnight at 37°C for both organisms. Colony forming units (CFUs) were then enumerated and their identity confirmed.

Test Protocol: The test protocol for *B. atrophaeus* and *S. epidermidis* was as follows:

- 1) Turn on the chamber AHU and circulating fan.
- 2) Allow the HEPA to clean the chamber air for at least 1 hour.
- 3) Turn off AHU and turn on the unit for 10 minutes to let the UV lamps warm up.
- 4) Turn off the unit and turn on the Collison nebulizer and run for 5 minutes with HEPA-filtered drying air. Turn off Collison nebulizer, and continue to allow the drying air to flow through the drying tower and into the chamber for another 8 minutes.
- 4) One minute prior to the start of collection for the "0 min" sample, turn off the drying air, close the valve between the drying tower and the chamber to prevent backflow, and turn off the circulating fan in the chamber.
- 5) Switch on the air cleaner at the start of collection for the "0 min" sample.
- 6) Collect triplicate bioaerosol measurements at appropriate intervals (usually 0, 4, 8 and 12 minutes, or 0, 5, 10 and 15 minutes).

One modification was used in the natural decay test for *S. epidermidis* and *Bacillus atrophaeus*:
1) Step 5 was omitted.

Calculations:

The performance of the air cleaner was evaluated by determining the Clean Air Rate (Microbial) or CAR_m, calculated as the CADR in the AHAM method. To calculate the CAR_m, the measured decay (k_e) and natural decay (k_n) rates are first calculated using the formula:

$$k = \frac{(\sum t * \ln C_t) - [(\sum t) (\sum \ln C_t)] / n}{(\sum t^2) - (\sum t)^2 / n} \quad \text{Equation 2}$$

where:

C_t = concentration at time, t

n = number of data points used in the regression

k = decay constant (time⁻¹)

t = time (minutes)

Then the CAR(m) was calculated for each measured decay rate, using the formula:

$$CAR_m = V k_e - k_n \quad \text{Equation 3}$$

where:

V = volume of the test chamber (ft³)

k_e = measured decay rate (min⁻¹)

k_n = average natural decay rate (min⁻¹) for an organism.

Chamber Air Cleaner Test Results

The Model 2008 B3 Air Purifier was tested as instructed by Genesis. Figures 4 and 5 show the decay curves for *B. atrophaeus* and *S. epidermidis*. The numbers of CFUs per cubic foot in the chamber are plotted on the y-axis with the time in minutes on the x-axis. The data points for each time represent the average results from the three sampling locations. The natural decay curves are labeled “Device OFF”, while the air cleaner decay curves (with the air cleaner running) are labeled “Device ON.”

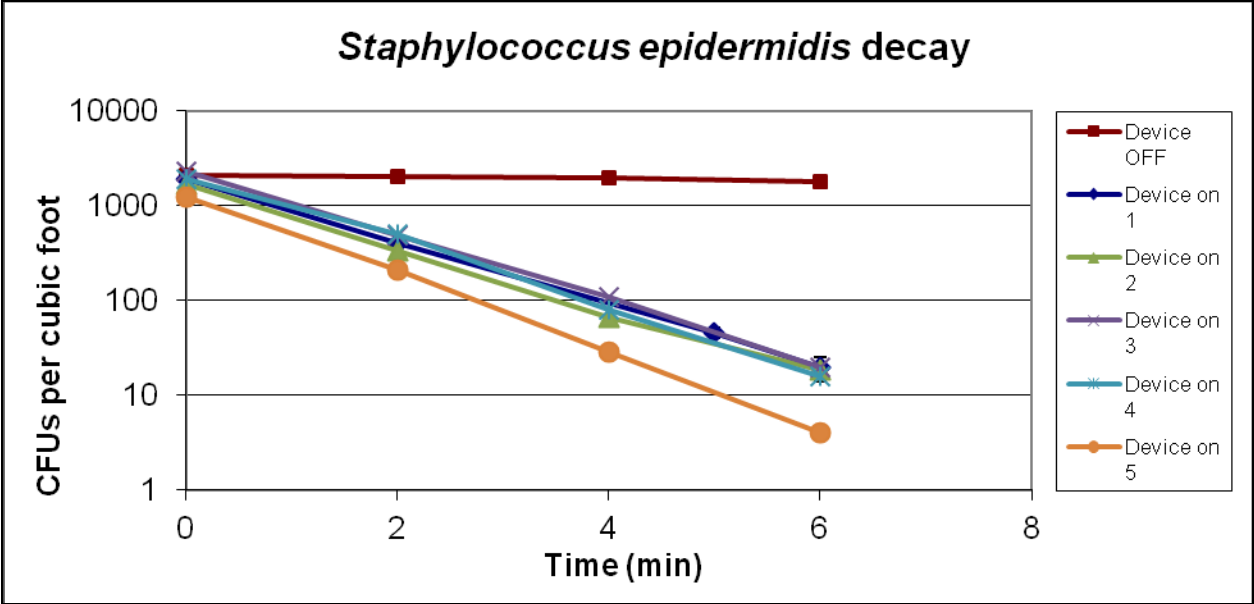


Figure 4. Decay curves for *S. epidermidis*

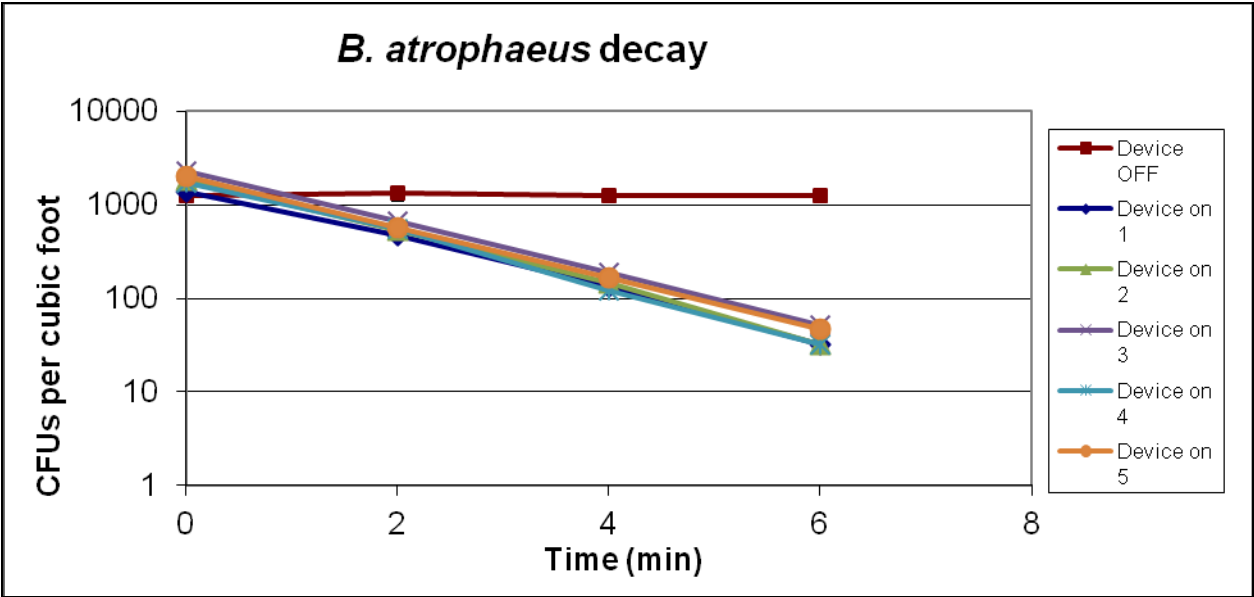


Figure 5. Decay curves for *B. atrophaeus*

In each case, the impact of the Model 2008 B3 is readily visible in the graph. The decay rates with the “device on” are significantly and reproducibly higher than the decay rates with the “device off” over the time periods observed. The actual natural decay (k_n) and measured decay (k_e) rates for each organism calculated according to Equations 2 and 3 for each sample collection are shown in Table 2.

Table 2. Decay rates measured for introduced bioaerosols

Sample Collection	<i>B. atrophaeus</i>	<i>S. epidermidis</i>
Natural Decay		
Kn1	0.00	-0.03
Measured Decay		
Ke1	-0.30	-0.38
Ke2	-0.32	-0.36
Ke3	-0.30	-0.38
Ke4	-0.32	-0.39
Ke5	-0.30	-0.46

Table 3 presents the average CARm results and standard deviations. The CARm was calculated as shown in Eq. 3, and is a comparison of the two decay rates (natural and air cleaner) as a function of the volume of the test chamber (640 ft³).

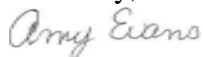
Table 3. CARm values calculated from mean decay rates

Chamber Position	<i>B. atrophaeus</i>	<i>S. epidermidis</i>
Average CARm	196.06	234.74
s.d.	7.50	24.08

In the ideal case where the air cleaner provides a well-mixed chamber, the CARm is equivalent to the product of the air cleaner's flow rate and its inactivation/filtration efficiency for the challenge bioaerosol. In a chamber test, however, the test chamber is only "well-mixed" to the extent that the device itself provides this mixing by the air motions generated by its fan. Thus, the CARm combines the effects of the efficiency of the air cleaner and the effectiveness of the air cleaner to draw the test chamber's air through it. Generally, the CARm should not exceed the air cleaner flow rate. Thus, for the organisms tested, the Model 2008 B3 Air Purifier achieved very near the maximum performance that could be expected from a device operating at the designated air flow.

If you have any additional questions, please feel free to call Amy Evans at 919-316-3963 or email at aevans@rti.org.

Sincerely,



Amy Evans

Microbiologist 3

Center for Microbial Community Systems and Health Research

REFERECES

1. Macher, J.M. 1989. Positive Hole Correction of Multiple-jet Impactors for Collecting Viable Microorganisms, *American Industrial Hygiene Association Journal*. 50: 561-568.
2. VanOsdell, D.W., Foarde, K.K., and Chang, J.C.S., "Design and Operation of a Dynamic Test Chamber for the Measurement of Biocontaminant Pollutant Emission and Control", *Characterizing Sources of Indoor Air Pollution and Related Sink Effects, ASTM STP 1287*. Bruce A. Tichenor, Ed., American Society for Testing and Materials, 1996, pp. 44-57.
3. Foarde, K.K., Myers, Eric A., Hanley, James T., Ensor, David S., and Roessler, Peter F, 1999. "Methodology to Perform Clean Air Delivery Rate Type Determinations with Microbiological Aerosols", *Aerosol Science and Technology*, 30:235-245.