

# Environmental Technology Verification

## Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems

American Ultraviolet Corporation, DC24-6-120

Prepared by

Research Triangle Institute



Under a Cooperative Agreement with the  
U.S. Environmental Protection Agency



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duct ultraviolet (UV) light systems. This verification statement provides a summary of the test results for the American Ultraviolet Corporation DC24-6-120 Duct Sterilizer.

### **VERIFICATION TEST DESCRIPTION**

All tests were performed in accordance with RTI's "Bioaerosol Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Air Cleaner", a supplement to "Test/Quality Assurance Plan for Biological and Aerosol Testing of General Ventilation Air Cleaners" which was approved by EPA. Testing for biological inactivation was performed using three organisms – two bacteria (*Bacillus atrophaeus* and *Serratia marcescens*) and one bacterial virus (MS2). To model use in a heating, ventilation and air-conditioning (HVAC) system, RTI used a test duct designed for testing filtration and inactivation efficiencies of aerosol, bioaerosol, and chemical challenges.

The testing was conducted in the test duct operated following procedures in the ANSI/ASHRAE (American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*. The air flow rate through the duct during this testing was 0.93 m<sup>3</sup>/sec (1970 cfm). This flow creates a typical air velocity (492 fpm) in the duct, and has been used extensively in prior testing of air cleaning devices in this rig. The air temperature entering the device was approximately 23 °C. Air flow rate and temperature can have an impact on lamp performance, and the values used in this testing are consistent with vendor specifications. Prior to testing the device, the UV lamps were operated for a standard 100-hr "burn-in" period.

There are separate runs for each of the three challenge bioaerosols which were injected upstream of the device. The upstream challenge was ~ 2 x 10<sup>4</sup> CFU or PFU/ft<sup>3</sup>. A no-light test was performed with the UV lights turned off, to determine the microorganism loss that would occur simply as the result of deposition in the test duct, and as the result of kill caused by the physical rigors of flowing through the device. The performance of the device was then reported as the device's efficiency in inactivating the organism with the light on, corrected to account for the loss of organisms observed in the absence of UV light.

Additional secondary measurements included:

- The direct total power consumption by the lamp and ballast, the pressure drop across the device (impacting air handler requirements), and the temperature rise through the unit, if any (impacting cooling coil energy consumption).
- A single measurement of the intensity of 254 nm UV radiation (μW/cm<sup>2</sup>) at a point 161 cm (63 in.) upstream from the lamps, to demonstrate that the lamps were functioning and to provide a test reference value for the laboratory for documentation purposes.

Verification testing of the American Ultraviolet Corporation DC24-6-120 began on July 31, 2007 at the test facilities of RTI and was completed on August 21, 2007.

### **VERIFIED TECHNOLOGY DESCRIPTION**

The American Ultraviolet Company's DC24-6-120 is part of the DC Series of in-line duct sterilizers that are designed to install into air duct sections to position high output UVC (short-wave ultraviolet radiation, in the "C" band - 200 to 280 nanometers) lamp(s) perpendicular to passing airflow for "pass-by" air sterilization purposes as well as surface sterilization. The ballast enclosure mounts directly to the duct exterior with lamp(s) protruding into the duct section through a cutout in the duct wall. Type 304 stainless

## American Ultraviolet Corporation, DC24-6-120 Duct Sterilizer

steel construction is utilized for long life. Outdoor ballast enclosures are available as an option. The SBL415 High Output UVC Lamp is used in the system.

### VERIFICATION RESULTS

The American Ultraviolet Corporation DC24-6-120 achieved the biological inactivation efficiency tests presented in Table 1.

Table 1. Inactivation Efficiency, %

	Spore form of bacteria ( <i>B. atrophaeus</i> )	Vegetative bacteria ( <i>S. marcescens</i> )	Bacterial virus (MS2 bacteriophage)
Inactivation efficiency (UV light on), %	98	≥ 99.5 <sup>a</sup>	99

a – the value 99.5 represents a 95% confidence limit for *S. marcescens*. There were no downstream counts measured.

The irradiance was measured as 6290  $\mu\text{W}/\text{cm}^2$  at 161 cm (63 in.) upstream from the lamps with an airflow of 0.93  $\text{m}^3/\text{sec}$  (1970 cfm). The mean dosage was calculated as 23,600  $\mu\text{W}\text{-s}/\text{cm}^2$  with a range of 19,900 – 29,000  $\mu\text{W}\text{-s}/\text{cm}^2$ . The system had six lamps that were burned in for 100 hours prior to measurements. The spore form of the bacteria *B. atrophaeus* is more resistant to being killed by UV light (irradiation) than the vegetative bacteria *S. marcescens*.

The APCT Center's quality manager reviewed the test results and the quality control data and concluded that the data quality objectives given in the approved test/QA plan were attained.

This verification statement addresses the biological inactivation efficiency. Users of this technology may wish to consider other performance parameters such as service life and cost when selecting an in-duct UV system for bioaerosol control.

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# **Environmental Technology Verification**

## **Biological Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Systems**

American Ultraviolet Corporation, DC24-6-120

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## NOTICE

This document was prepared by RTI International\* (RTI) with partial funding from Cooperative Agreement No. CR 831911-01 with the U.S. Environmental Protection Agency (EPA). The document has been subjected to RTI/EPA's peer and administrative reviews and has been approved for publication. Mention of corporation names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products.

## FOREWORD

The Environmental Technology Verification (ETV) Program, established by the U.S. Environmental Protection Agency (EPA), is designed to accelerate the development and commercialization of new or improved technologies through third-party verification and reporting of performance. The goal of the ETV Program is to verify the performance of commercially ready environmental technologies through the evaluation of objective and quality-assured data so that potential purchasers and permittees are provided with an independent and credible assessment of the technology that they are buying or permitting.

The Air Pollution Control Technology Verification Center (APCT Center) is part of the EPA's ETV Program and is operated as a partnership between RTI International (RTI) and EPA. The center verifies the performance of commercially ready air pollution control technologies. Verification tests use approved protocols, and verified performance is reported in verification statements signed by EPA and RTI officials.

## AVAILABILITY OF REPORT

Copies of this verification report are available from

- Research Triangle Institute  
Engineering and Technology Unit  
PO Box 12194  
Research Triangle Park, NC 27709-2194
- U.S. Environmental Protection Agency  
Air Pollution Prevention and Control Division, E343-02  
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Web site: <http://www.epa.gov/etv/verifiedtechnologies.html>

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\* RTI International is a trade name of Research Triangle Institute.

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## ACRONYMS/ABBREVIATIONS

A	amp(s)
ANSI	American National Standards Institute
APCT Center	Air Pollution Control Technology Verification Center
ARTI	Air-Conditioning and Refrigeration Technology Institute, Inc.
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
B	<i>Bacillus</i>
BG	<i>Bacillus atrophaeus</i> (formerly <i>B. subtilis var niger</i> and <i>Bacillus globigii</i> )
C	Celsius
cfm	cubic feet per minute
CFU	colony forming unit(s)
cm	centimeter
CV	coefficient of variance
DQO	data quality objective
E	<i>Escherichia</i>
EPA	U.S. Environmental Protection Agency
ETV	environmental technology verification
F	Fahrenheit
fpm	feet per minute
HEPA	high efficiency particulate air
HVAC	heating, ventilation and air conditioning
in.	inch(es)
J	joule(s)
L	liter(s)
m	meter(s)
mm	millimeter(s)
mL	milliliter(s)
min	minute(s)
$\mu\text{m}$	micrometer(s)
nm	nanometer(s)
QA	quality assurance
QC	quality control
QMP	quality management plan
QSA	quality system audit
Pa	pascal(s)
PFU	plaque forming unit(s)
psig	pounds per square inch gauge
RMS	root mean square
RTI	Research Triangle Institute
S	<i>Serratia</i>
s	second(s)
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program
UV	ultraviolet
UVC	Short-wave ultraviolet radiation, in the "C" band (200 to 280 nanometers)



## ACKNOWLEDGMENTS

The authors acknowledge the support of all of those who helped plan and conduct the verification activities. In particular, we would like to thank Mike Kosusko, EPA's Project Manager, and Paul Groff, EPA's Quality Assurance Manager, both of EPA's National Risk Management Research Laboratory in Research Triangle Park, NC. We would also like to acknowledge the assistance and participation of American Ultraviolet Corporation personnel who supported the test effort.

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## 1.0 INTRODUCTION

This report reviews testing performed for bioaerosol inactivation efficiency of the American Ultraviolet Company's DC24-6-120. Environmental Technology Verification (ETV) Program testing of this technology/product was conducted by RTI's Air Pollution Control Technology Verification Center (APCT Center) from July 31 to August 21, 2007. The testing followed the *Bioaerosol Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Air Cleaners*, Supplement to the APCT Center *Test/QA Plan for Biological and Aerosol Testing of General Ventilation Air Cleaners*<sup>1</sup>.

Section 2 presents a description of the American Ultraviolet Company's DC24-6-120. Section 3 documents the procedures and methods used for the test and the conditions over which the test was conducted. Section 4 provides information on the quality assurance (QA) and quality control (QC). The results of the test are summarized and discussed in Section 5 with limits and applications in Section 6. There is a performance summary in Section 7 and references in Section 8.

This report contains summary information and data from the test as well as the verification statement. Complete documentation of the test results is provided in a separate data package and audit of data quality report. These reports include the raw test data from product testing and supplemental testing, equipment calibrations results, and QA/QC activities and results. Complete documentation of QA/QC activities and results, raw test data, and equipment calibrations results are retained in RTI's files for seven years.

This ETV testing focuses on ultraviolet (UV) light systems that are mounted in the heating, ventilation and air conditioning (HVAC) ducting (in-duct UV light systems) and that operate on a "fly-through" basis. That is, they are designed to destroy bioaerosols in the flowing air stream as it passes through the device. This is distinguished from UV devices that are designed to treat specific surfaces within the HVAC system, in particular, the cooling coils and the condensate drain pan, to prevent biological growth on those surfaces. This program tests inactivation of airborne bioaerosols; inactivation of microorganisms on surfaces is not evaluated.

The bioaerosol tests were conducted using three organisms, consisting of two bacteria (spore-form of *Bacillus atrophaeus* and the vegetative bacterium *Serratia marcescens*) and one bacterial virus (MS2) that cover the range of potential interest for indoor air quality applications. These organisms were selected because of their representative sizes and shapes, and susceptibility to UV inactivation. Generally, vegetative bacteria are readily killed and bacterial spores are more difficult. The spore form of the bacteria *Bacillus atrophaeus* (formerly *B. subtilis* var. *niger* and *Bacillus globigii* or BG) was used to represent gram-positive spore-forming bacteria. The BG spore is elliptically shaped with dimensions of 0.7 to 0.8 by 1 to 1.5  $\mu\text{m}$ . *Serratia marcescens* was used to represent rod-shaped gram-negative bacteria. *S. marcescens* is 0.5 to 0.8 by 0.9 to 2.0  $\mu\text{m}$ .

The bacterial virus (bacteriophage) MS2, having approximately the same aerosol characteristics as a human virus, was used as a surrogate for the viruses of similar and larger size and shape. Although the individual virus particles are in the 0.02 – 0.03  $\mu\text{m}$  size range, the test particle size for the virus tests spanned a range of sizes (polydispersed bioaerosol) in the micron range. This test was not designed to study the inactivation efficiencies for individual virus singlets; rather, it was designed to determine the inactivation efficiencies for virus particles as they are commonly found indoors. A representative challenge would be a polydispersed aerosol containing the bacteriophage because:

- The aerosols created from sneezing and coughing vary in size from < 1 to 20  $\mu\text{m}$ , but the largest particles settle out and only the smaller sizes remain in the air for extended periods for potential removal by an air cleaner;<sup>2</sup>

- For some viruses (e.g., Coxsackie virus), low numbers of viruses have been found associated with the smallest particles;<sup>3</sup> and
- Nearly all 1 - 2  $\mu\text{m}$  particles are deposited in the respiratory tract, while larger particles may not be respired.

## 2.0 TECHNOLOGY DESCRIPTION

The American Ultraviolet Company’s DC24-6-120 is part of the DC Series in-line duct sterilizers that are designed to install into air duct sections to position high output UVC (short-wave ultraviolet radiation, in the "C" band - 200 to 280 nanometers) lamp(s) perpendicular to passing airflow for “pass-by” air sterilization purposes as well as surface sterilization. The ballast enclosure mounts directly to the duct exterior with lamp(s) protruding into the duct section through a cutout in the duct wall. Type 304 stainless steel construction utilized for long life. Outdoor ballast enclosures are available as an option. The SBL415 High Output UVC Lamp is used in the system.

Table 2-1 provides information on the system as supplied by the vendor. Figures 2-1 and 2-2 provide views of the device as tested, installed in accordance with the manufacturer’s specifications.

**Table 2-1. Vendor-Supplied Specifications of the DC24-6-120**

<b>Attribute</b>	<b>Specification</b>
Total power for the lamp (watts)	60 watts per lamp, total of 360 watts
Total UVC power for the lamp (watts)	Estimated 22 UVC watts per lamp
Irradiance (output) of the lamp, give distance and other information (e.g., airflow) ( $\text{W}/\text{cm}^2$ )	1262 $\mu\text{W}/\text{cm}^2$ at 1 meter distance (total) [400 fpm, 7.2 °C (45 °F) airflow]
Dosage ( $\text{J}/\text{cm}^2$ or $\text{W}\text{-s}/\text{cm}^2$ )	N/A
Ballast root mean square (RMS) voltage and current	Available as 120/230/277 VAC 3.45/2.10/1.80 amps total per 6-lamp fixture
Dimensions of the lamp	534mm / 53.4 cm (21.03 in.) arc Length
Dimensions of the ballast box	61 cm (24 in.) long x 15.2 cm (6 in.) wide x 11.6 (4.56 in.) tall
Configuration	six-lamp unit w/ ballasts mounted in enclosure located out of airflow
Other lamp characteristics	N/A



Figure 2-1. Ballast box installed on the outside of the test rig (on right). The device is also visible.



Figure 2-2. Device installed inside the test rig. There are six lamps and three support rods.

### 3.0 TEST DESIGN AND PROCEDURES

#### 3.1 Operation of the Test Duct

The testing was conducted in the test duct shown schematically in Figure 3-1. 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 UV 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 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*.<sup>4</sup>

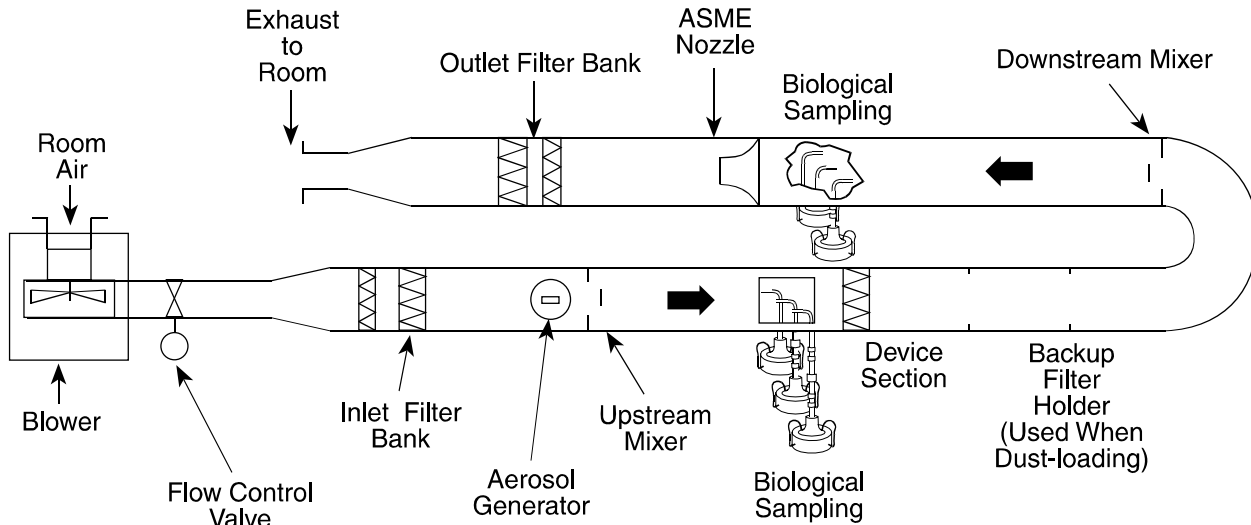


Figure 3-1. Schematic of test duct. UV system is placed in device section.

While Figure 3-1 shows the test duct without recirculation, during testing, the duct may be operated with or without recirculation. The decision for recirculation mode is based on building HVAC considerations. Because of the high efficiency particulate air (HEPA) filters at the beginning and the end of the duct, the recirculation mode does not affect the test data as long as all other criteria are met.

The air flow rate through the duct during this testing was 0.93 m<sup>3</sup>/sec (1970 cfm). This flow creates a typical air velocity (492 fpm) in the duct, and has been used extensively in prior testing of air cleaning devices in this rig. The air temperature entering the device was approximately 23 °C. Air flow rate and temperature can have an impact on lamp performance, and the values used in this testing are consistent with vendor specifications. As explained in the VanOsdell and Foarde (2002)<sup>5</sup> report for the Air-Conditioning and Refrigeration Technology Institute (ARTI), lamps are designed for an optimal temperature, and either higher or lower values may lower the irradiance.

Prior to testing the device, the UV lamps were operated for a standard 100-hr “burn-in” period.

There are separate runs for each of the three challenge bioaerosols which are prepared as described in Section 3.2 and injected upstream of the device. The upstream challenge was ~ 2 x 10<sup>4</sup> CFU or PFU/ft<sup>3</sup>. A no-light test was performed with the UV lights turned off, to determine the microorganism loss that would occur simply as the result of deposition in the test duct, and as the result of kill caused by the physical rigors of flowing through the device. See Section 4.3 for the acceptable range of the penetration for this test. As discussed later, the performance of the device was then reported as the device’s efficiency in inactivating the organism with the light on, corrected to account for the loss of organisms observed in the absence of UV light.

In addition to the measurement of the concentration of culturable organisms upstream and downstream of the device, there were secondary measurements that were not included in the verification statement. These include:

- The direct total power consumption by the lamp and ballast, the pressure drop across the device (impacting air handler requirements), and the temperature rise through the unit, if any (impacting cooling coil energy consumption).
- A single measurement of the intensity of 254 nm UV radiation (μW/cm<sup>2</sup>) at a point 161 cm (63 in.) upstream from the lamps, to demonstrate that the lamps were functioning and to provide a test reference value for the laboratory for documentation purposes.

### **3.2 Preparation and Generation of Bioaerosol Challenges**

The bioaerosol tests were conducted as described in the test/QA plan supplement using three organisms – two bacteria (*Bacillus atrophaeus* and *Serratia marcescens*) and one bacterial virus (MS2). The selection of the bioaerosols was discussed in Section 1.

The microbial challenge suspensions were prepared by inoculating the test organism onto solid or into liquid media, incubating the culture until mature, wiping organisms from the surface of the pure culture (if solid media), and eluting them into sterile fluid to a known concentration to serve as a stock solution. The organism preparation was then diluted into sterile nebulizing fluid. The nebulizing fluid was composed of salts (buffering), peptone, and antifoam (*S. marcescens* only). The composition of the nebulizing fluid should have provided a protective effect similar to organic matter (dirt, debris, etc.) for the *S. marcescens* and possibly the MS2 against the inactivation of the UVC. Based on the VanOsdell and Foarde (2002)<sup>5</sup> report, little or no effect was anticipated for the *B. atrophaeus* as spores were found to be relatively unaffected by protective factors. The nebulizing fluid was quantified on trypticase soy agar to enumerate the bacteria.

The bacteriophage challenge was prepared by inoculating a logarithmic phase broth culture of the host

bacteria (*E. coli*) with bacteriophage and allowing it to multiply overnight or until the majority of the host bacteria were lysed (ruptured or broken down). The mixture was processed to collect and concentrate the bacteriophage. Then, the bacteriophage stock was filter sterilized (0.2 µm) to remove the bacteria. The bacteriophage stock was used as the challenge aerosol. The concentration of the bacteriophage stock was approximately  $1 \times 10^9$  or higher plaque forming units (PFU)/mL. The virus assay used a standard double agar layer plaque assay, in which host cell *Escherichia coli* C3000 (ATCC 15597) in the log phase of growth and serial dilutions of the MS2 virus stock (ATCC 15597-B1) were combined and top agar added and then poured onto bottom agar plates.<sup>6</sup> After incubation, at least overnight, at 37 °C, plaques (loci of infection) were counted against an opaque lawn of host cell *E. coli* C3000.

The challenge organism suspensions were aerosolized using a Collison nebulizer (BGI, Waltham, MA) at 15 psi air pressure. The Collison nebulizer generated droplets with an approximate volume mean diameter of 2 µm. The particle diameter after the water evaporated depended on the solids content of the suspension and the size of the suspended particles. Prior experience has shown that the bacterial organism aerosols generated by this procedure are primarily singlets.

### 3.3 Sampling the Bioaerosols

All the bioaerosols were collected in liquid impingers, AGI-4 (Ace Glass Inc., Vineland, NJ). Because exposure to UV radiation is a common environmental hazard, cells have developed a number of repair mechanisms to counteract UV-induced damage that must be considered when experimentally measuring UV effects. Collecting in impinger fluid maximized the collection of damaged organisms. After sampling, the impinger fluid was plated and incubated at appropriate times and temperatures for the test organism being used. To quantify the microbial counts, the plates were incubated at the appropriate temperature and time for the test organism (overnight to a week). Colonies or plaques were counted.

### 3.4 Bioaerosol Control Efficiency Calculation

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

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

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 blank no-light transmission test. The blank no-light transmission rate (light was not turned on in the test duct) was calculated the same as the survival rate test, but using the culturable organism counts from the no-light tests.

### 3.5 Average Dose of UV Delivered by the Device

The equation used to describe the effect of UV on a single species population of airborne microorganisms is:

$$N_t/N_0 = \exp(-k \cdot \text{dose}) \quad (\text{Equation 2})$$

where:

- $N_t$  = the number of microorganisms at time  $t$ ,
- $N_0$  = the number of microorganisms at the start,
- $k$  = a microorganism-dependent rate constant, in  $\text{cm}^2/\mu\text{W}\cdot\text{s}$ . The  $k$  value includes a standard deviation because there is not a single microorganism, but a population.

The fractional inactivation achieved by the device is  $(1 - N_t/N_0)$ , as indicated in Equation 1 and where  $N_t/N_0$  is the survival rate.

We calculate the dose by rearranging Equation 2 to yield

$$\text{Dose} = - \frac{\ln(N_t/N_0)}{k} \quad (\text{Equation 3})$$

Mean dose was computed from Equation 3 using the values of  $N_t$  and  $N_0$  obtained with *B. atrophaeus* and using the organism-specific value of  $k$  for this organism ( $1.6 \times 10^{-4} \pm 0.3 \times 10^{-4} \text{ cm}^2/\mu\text{W}\cdot\text{s}$ ). *B. atrophaeus* was selected for determining dose based on earlier RTI measurements.

The UV dose calculated in this manner is the mean dose to a single organism having an “average” trajectory through the device. It is reported here as a characteristic of the device being tested. Dose is shown as a mean and a range (mean standard deviation), reflecting the natural variation in a population of microorganisms and the spread of the measured values.

## **4.0 QUALITY ASSURANCE/QUALITY CONTROL**

### **4.1 QUALITY ASSURANCE**

Quality assurance/quality control (QA/QC) procedures were performed in accordance with the APCT Center and ETV quality management plans (QMPs) and the test/QA plan for this technology.<sup>(7, 8, 1)</sup>

#### **4.1 Equipment Calibration**

##### **4.1.1 Reference Methods**

As noted in Chapter 1, while reference methods were not available for determining the inactivation efficiency of the device, accepted methods developed and used in related work were used. Test specifications given in the appendices of the approved test/QA plan were derived from the related ASHRAE 52.2 method, with additional specifications and quality control checks relevant to this testing.<sup>(1,4)</sup>

##### **4.1.2 Instrument Checks**

The DC24-6-120 was installed in the test duct, and operated and maintained according to the vendor’s instructions throughout the test. No maintenance was required during the test. The test rig and measurement instruments were checked according to the appendices of the approved test/QA plan and supplement.

### **4.2 Audits**

#### **4.2.1 Performance Evaluation Audit**

No performance evaluation audits were performed during this test.

#### 4.2.2 Technical Systems Audit (TSA)

No internal or EPA audit was performed during this APCT testing although one is planned for the next product to be tested. During RTI's Technology Testing and Evaluation Program (TTEP) which evaluated similar UV light systems, both Gene Tatsch<sup>9</sup>, then APCT Center quality manager, and Shirley Wasson<sup>10</sup>, then EPA quality manager, performed combined quality system audits (QSAs)/TSAs of RTI's filter test facility. No significant findings were noted in those assessments that might have impacted the quality of the TTEP results. Minor recommendations were made and were implemented. The current test is being performed using the same equipment and the same methods as during the TTEP testing.

#### 4.2.3 Data Quality Audit

At least 10% of the data acquired during the verification testing of the device was audited by Gene Tatsch as a representative of the APCT Center quality manager, Cary Eaton. Gene traced the data from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

#### 4.3 QA/QC Reporting

Each assessment and audit was documented in accordance with the test/QA plan.<sup>(1)</sup> Once the assessment report was prepared, the RTI task manager ensured that a response was provided as appropriate. For this technology evaluation, no significant findings were noted in any assessment or audit, and no follow-up corrective action was necessary. The testing followed quality assurance and quality control requirements as given in the test/QA plan. The APCT Center quality manager reviewed the test results and the quality control data and concluded that the data quality objectives as shown in Table 4-1 were attained.

**Table 4-1. DQOs for Biological Aerosols**

Parameter	Frequency and description	Control Limits								
Minimum upstream counts for samplers	Each efficiency test.	Minimum of 10 CFU <sup>a</sup> /plate or PFU <sup>b</sup> /plate								
Maximum counts for samplers	Each efficiency test.	Maximum of 500 CFU/plate or 800 PFU/plate								
100% Penetration (no light) (correlation test)	Performed at least once per test sequence per organism.	<table border="1"> <thead> <tr> <th>Test Organism</th> <th>Acceptable Penetration Range</th> </tr> </thead> <tbody> <tr> <td><i>B. atrophaeus</i></td> <td>0.85 to 1.15</td> </tr> <tr> <td><i>S. marcescens</i></td> <td>0.80 to 1.20</td> </tr> <tr> <td>MS2</td> <td>0.75 to 1.25</td> </tr> </tbody> </table>	Test Organism	Acceptable Penetration Range	<i>B. atrophaeus</i>	0.85 to 1.15	<i>S. marcescens</i>	0.80 to 1.20	MS2	0.75 to 1.25
Test Organism	Acceptable Penetration Range									
<i>B. atrophaeus</i>	0.85 to 1.15									
<i>S. marcescens</i>	0.80 to 1.20									
MS2	0.75 to 1.25									
Upstream CFUs	Each test. Statistical check of data quality.	CV <sup>c</sup> ≤ 0.25								
Upstream PFUs	Each test. Statistical check of data quality.	CV ≤ 0.35								

<sup>a</sup> CFU = colony forming units

<sup>b</sup> PFU = plaque forming unit

<sup>c</sup> CV = coefficient of variance



Data quality objectives (DQOs) are qualitative and quantitative statements designed to ensure that the type, quality, and quantity of data used are appropriate for the intended application. In addition, the minimum and maximum upstream counts help to ensure that the challenge concentration of each organism entering the UV device remains at an acceptably steady value that is sufficiently low such that device performance should be independent of the concentration at the test conditions used in this study.

## 5.0 TEST RESULTS

The bioaerosol inactivation efficiency results, derived using Equation 1, are given in Table 5-1. Table 5-2 provides other information about the UV system.

**Table 5-1. Inactivation Efficiency, %**

	Spore form of bacteria ( <i>B. atrophaeus</i> )	Vegetative bacteria ( <i>S. marcescens</i> )	Bacterial virus (MS2 bacteriophage)
Inactivation efficiency (UV light on), %	98	≥ 99.5 <sup>a</sup>	99

a – the value 99.5 represents a 95% confidence limit for *S. marcescens*. There were no downstream counts measured.

**Table 5-2. Other Information for the DC24-6-120**

Attribute	Measured or Calculated Values
<b>Test duct operating conditions</b>	
Air flow rate	0.93 m <sup>3</sup> /sec (1970 cfm)
Inlet and outlet temperature	Upstream 23.1 °C <sup>a</sup> (73.6°F) , Downstream 23.8 °C <sup>a</sup> (74.8 °F)
<b>UV exposure conditions provided by device</b>	
Mean dosage calculated from Equation 3 and range resulting from standard deviation of the k value	23,600 (19,900 – 29,000) μW-s/cm <sup>2</sup>
A single irradiance measurement at 254 nm	6290 μW/cm <sup>2</sup> at 161 cm (63 in.) upstream from the lamps at 0.93 m <sup>3</sup> /sec (1970 cfm)
<b>Measures of energy consumption by the unit</b>	
Power consumed by the lamps/ballasts and by any ancillary equipment required by the vendor	488 W
Pressure drop across the device	< 27.9 Pa (0.112 in. H <sub>2</sub> O)
Air temperature rise through the device	0.7 °C (1.2 °F)

## 6.0 LIMITATIONS AND APPLICATIONS

This verification report addresses the inactivation efficiency performance (Table 5-1) for the American Ultraviolet Corporation DC24-6-120 ultra-violet light system that operates in an HVAC system. Other measures are given in Table 5-2. Users may wish to consider other performance parameters such as service life and cost when selecting a UV light system for their application.

## 7.0 REFERENCES

1. RTI. 2007. *Test/QA Plan for Biological and Aerosol Testing of General Ventilation Air Cleaners, and Supplement Bioaerosol Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Air Cleaners*. Research Triangle Institute, Research Triangle Park, NC.
2. Knight, V. 1973. *Viral and Mycoplasmal Infections of the Respiratory Tract*, Lea & Febiger, Philadelphia, PA.
3. Buckland, F.E., and Tyrell, D.A.S. 1962. Loss of Infectivity on Drying Various Viruses, *Nature* 195: 1063-1064.
4. ANSI/ASHRAE (American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers). 1999. ANSI/ASHRAE Standard 52.2-1999, *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*, Section 5.16.2, Atlanta, GA.
5. VanOsdell, D. and K. Foarde. 2002. Final Report ARTI-21CR/610-40030-01 Project – Defining the Effectiveness of UV Lamps Installed in Circulating Air Ductwork, Air-Conditioning and Refrigeration Technology Institute, 4100 N. Fairfax Drive, Suite 200, Arlington, Virginia 22203. <http://www.arti-21cr.org/research/completed/finalreports/40030-final.pdf>
6. Adams, M.G. (1959). *Bacteriophages*. Interscience, New York.
7. RTI. 2005. Quality Management Plan for Verification Testing of Air Pollution Control Technology, Revision 2.2, Research Triangle Park, NC. [http://www.epa.gov/etv/pubs/APCT\\_QMP\\_0205.pdf](http://www.epa.gov/etv/pubs/APCT_QMP_0205.pdf)
8. U.S. EPA. 2002. Environmental Technology Verification Program Quality Management Plan, EPA/600/R-03/021, U.S. EPA, Cincinnati, OH, 2002. [http://www.epa.gov/etv/pubs/ETV\\_02\\_QMP.pdf](http://www.epa.gov/etv/pubs/ETV_02_QMP.pdf)
9. Tatsch, C. Eugene. 2005. Assessment of RTI's TTEP Project, Research Triangle Institute, Research Triangle Park, NC.
10. Wasson, Shirley. 2005. Quality and Technical Systems Audits for Technology Testing and Evaluation Program Bioaerosol Inactivation Efficiency by HVAC In-Duct Ultraviolet Light Air Cleaners, US EPA, Research Triangle Park, NC. Laura Nessley and David Proffitt from Arcadis G&M participated in the audit with Ms. Wasson.