BSR/ASHRAE Standard 234P

Public Review Draft

Method of Testing Air Cleaning Devices and Systems with Duct-Mounted Components for Particle and Microorganism Removal or Inactivation Using a Chamber with a Recirculating Duct System

Second Public Review (April 2026)
(Draft Shows Complete Proposed Standard)

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FOREWORD

Many test methods exist for single pass testing of HVAC mounted devices that remove contaminants in the unit. There are also tests (e.g., AHAM, ASHRAE) for many in-room air cleaners. However, there were no standard test methods for air cleaners that are mounted in a duct or HVAC unit but perform most or all their function in the occupied spaces in a building. To address this issue, ASHRAE convened SPC 234 (previously 185.5) to develop tests for separate bioaerosol and particle challenges in a chamber with recirculating duct test facility as Standard 234 P. At around the same time SSPC 145 formed a subcommittee to write Standard 145.4P to address the same issues for gas-phase challenges.

For each type of challenge in Standard 234P, there are chamber and recirculating duct specifications, temperature and humidity requirements, maximum background levels for the challenge and other possible contaminants, quality assurance tests and requirements, sampling and analyses requirements, data analysis including statistical requirements, and reporting specifications. Most of these specifications are the same across contaminants. The main output of each test is an efficacy measurement in the form of a V_{ACS} for each contaminant. The V_{ACS} is essentially the same as a clean air delivery rate (CADR) (from the AHAM AC tests) and is named using the term used in ASHRAE Standard 241. A test for either MS2 or particles is considered a Standard 234 test; additional organisms are allowed as additions to a standard MS2 test. Reporting includes which challenge(s) was used.

Test specifications are included that are intended to simulate real situations to the extent that a lab test can. Lab tests must be more controlled and repeatable than general in-situ use, which limits these accommodations. The user must determine how to apply the results to their own application. These specifications include locations allowed for devices, residence time in the recirculating duct after the duct-mounted air cleaners and allowed ranges for air change rate and air velocities at the air cleaners. It is intended that users consult manufacturer guidance on these issues.

The reporting requirements include details of the air cleaning system, the test parameters, the data achieved including challenge concentrations over time, byproduct levels, device resistance to airflow, and the values calculated from these data.

For bioaerosols, the standard requires a test with an MS2 challenge with analysis for MS2, formaldehyde, ozone, TVOC and ultrafine particles. Triplicate tests will be required for the bioaerosol tests meaning that there will be three complete natural decay tests and three complete air cleaning system tests performed. This is due to the inherent variability observed in bioaerosol testing. The data for the three sets will be averaged to produce the V_{ACS}. The resulting V_{ACS} is expected to be acceptable for use in meeting Standard 241 requirements and will be useful for determining air cleaning ability for other uses. For other bioaerosols, since we do not specify the solution that the bioaerosol is generated from, it is important for users to know that they should only compare results for the same solution as this will change the level of inactivation and capture for some air cleaners.

For the particle challenge test, the challenge is a KCl aerosol measured over at least 20-300 nm. This test sets required equipment, aerosolization techniques, and sampling techniques to allow comparison of results across test labs. The V_{ACS} for these particles, reported by size range, are intended to meet the need for ultrafine particle removal efficacy.

These tests are intended to apply to the specific device in the specific conditions of test and to allow comparison of air cleaners. The results may be applied to other conditions if used with care.

1. PURPOSE

This standard provides a method of test for evaluating air cleaning devices and systems that contain a duct-mounted component for particle and/or microorganism removal or inactivation in a chamber with a recirculating duct system.

2. SCOPE

2.1 The method of test identifies particle or selected indicator microorganisms to serve as the test challenge(s) for

separate tests.

2.2 This standard defines procedures for generating, sampling, and quantifying the specified test challenge(s) to calculate device or system efficacy, and describes the environmental conditions and chamber characteristics required for the method of test.

2.3 This standard covers HVAC-duct mounted air cleaning devices and air cleaning systems that require a duct-mounted component and require a chamber with a recirculating duct system.

2.4 This standard establishes minimum performance specifications for the equipment required to conduct the tests and establishes a reporting system to be applied to HVAC-duct mounted devices and systems covered herein.

2.5 This standard specifies specific particle and bioaerosol challenges that are tested separately. One challenge type is considered one test.

2.6 This standard does not address the health and safety effects of operating devices and systems covered herein.

3. DEFINITIONS, SYMBOLS, AND ACRONYMS

3.1 Definitions

ACS (air cleaning system) test: test performed with the air cleaning system (ACS) installed and running, when applicable.

aerosol: particles (solid or liquid) suspended in air.

air change rate (ACR): time required in minutes to completely change the air volume in the chamber and recirculating duct.

air changes per hour (ACH): number of times in one hour the chamber and recirculating duct air volume (a closed loop) is changed.

air cleaner: A device or system used to remove or inactivate airborne contaminants.

air cleaning device (ACD): one air cleaner in a single container.

air cleaning system (ACS): one air cleaning device with related controls and power if any.

baseline: concentration of analytes (microorganisms, ions, chemicals, particles) in the chamber air before injection of the test aerosol and with the device off.

bioaerosol: aerosol containing biologically active bacteria, spores, viruses, toxins, or other similar materials.

diffuser-mounted air cleaner: air cleaning device mounted within the supply duct or diffuser, and within five feet of the supply air discharge, that cleans the air in the duct and/or in the test chamber.

in-duct air cleaner: air cleaning device mounted in the duct that cleans the air in the duct and/or in the test chamber.

in-room air cleaner: air cleaning device or system that is placed in a room to clean the air.

microorganism: virus, bacteria, or mold.

natural decay: test performed, either without the ACS installed or with the ACS installed but not running, for cases where the ACS does not change the results of the test (e.g., due to blocking airflow).

net percent reduction: percent reduction in contaminant over time after subtracting the percentage reduction due to natural decay.

particle size distribution: particle counts for an aerosol, separated by particle diameters.

percentage reduction: percent reduction in contaminant over time.

3.2 Acronyms

ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
ATTC	American Type Culture Collective

BMBL	Biosafety in Microbiological and Biomedical Laboratories
BSL	biosafety level
CDC	Centers for Disease Control and Prevention
CFU	colony forming unit
CV	coefficient of variance
DI	deionized
DMAC	diffuser-mounted air cleaner
GLP	good laboratory practice
HEPA	high efficiency particulate air (filter)
ID	internal diameter
IDAC	in-duct air cleaner
IRAC	in-room air cleaner
KCl	potassium chloride
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
OSHA	Occupational Safety and Health Administration
PFU	plaque forming unit
QA/QC	quality assurance/quality control
RH	relative humidity
SOP	standard operating procedure
TVOC	total volatile organic compounds
UFP	ultrafine particles
UV	Ultraviolet
V_{ACS}	Air cleaning system equivalent clean airflow rate

4. EQUIPMENT

4.1 General

4.1.1 The test setup shall include a test chamber and recirculating duct system that is representative of an HVAC system or duct mounted air cleaners located outside a room as described in this section. Figure 4-1 is a schematic of a typical test setup. Figure 4-2 identifies the system components in more detail. They are the test chamber and recirculating duct, composed of a test duct, supply duct, return duct, and a recirculating fan.

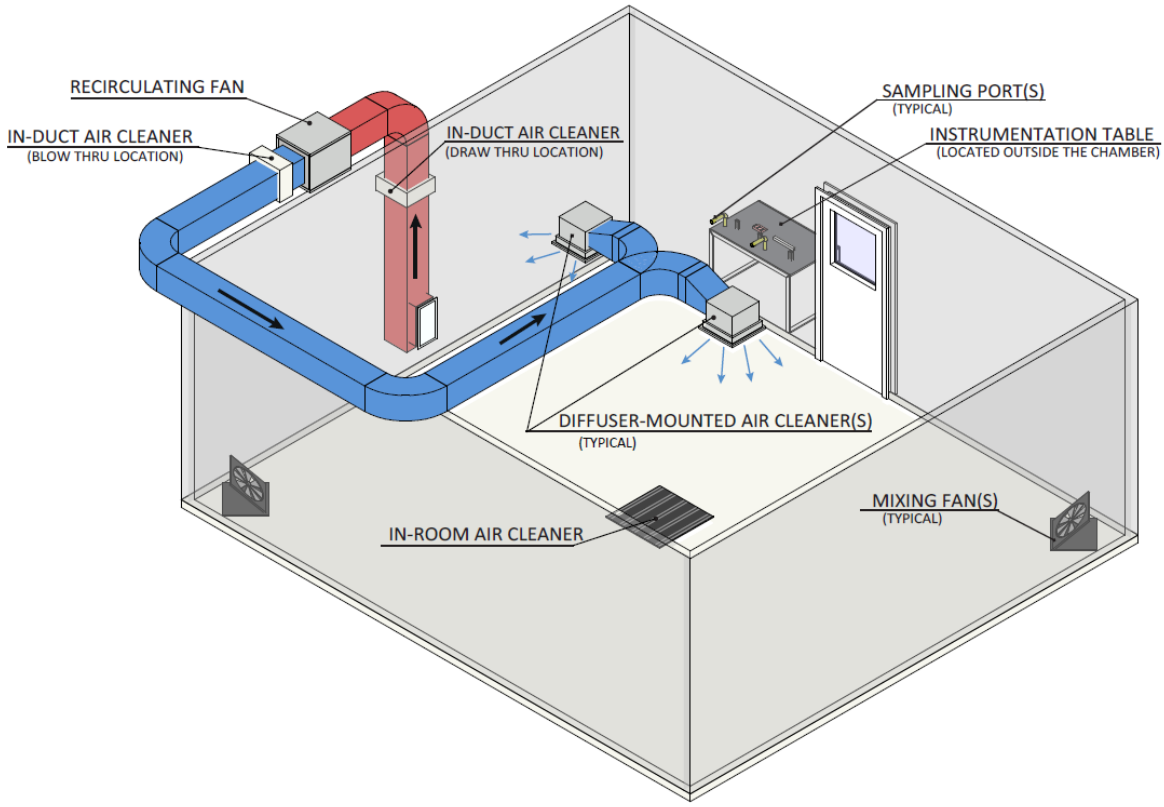

Figure 4-1 Schematic of one possible configuration of the chamber with recirculating duct.

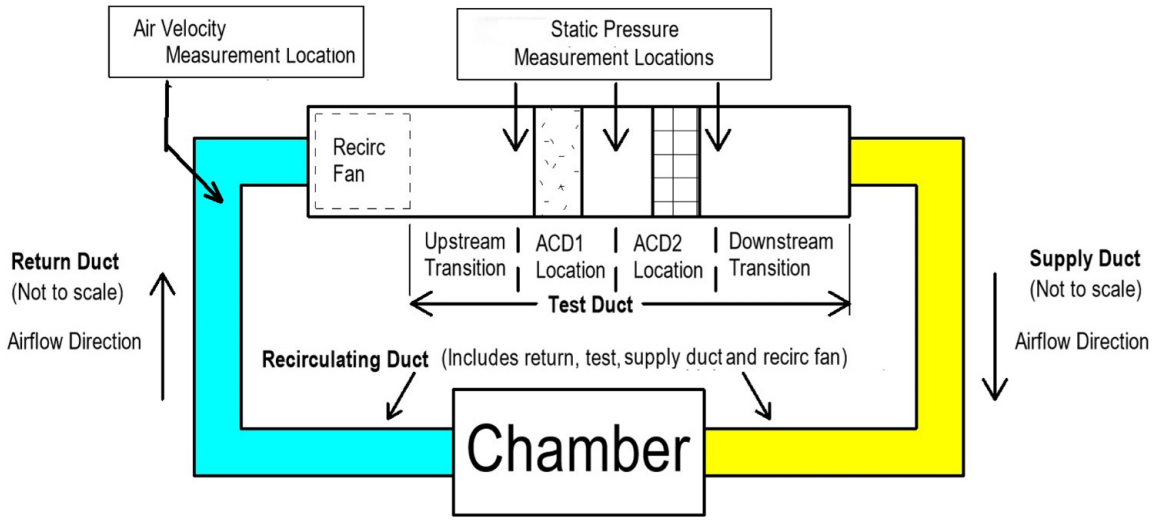

Figure 4-2 Test setup showing recirculating duct with test, supply, return sections and recirculating fan.

4.1.2 The test setup (recirculating duct and chamber [see Section 4.3]) shall be sized to provide a total system air change rate (ACR) of six to ten minutes.

4.2 Recirculating Duct

Recirculating duct shall have return, test, and supply sections, which may be of different sizes and shapes, and the recirculating fan. An example is shown in Figure 4-2.

4.2.1 Duct sections shall be constructed of impervious surfaces, with flex duct permitted only for transitions and

not for main duct runs, and allow for penetrations (e.g., for power lines) that run through the duct wall without air leaks.

4.2.2 The recirculating duct shall include a NIST Traceable hot wire anemometer airflow measuring station with acceptable range and accuracy for the characteristics of the duct and velocities to be measured. The flow measuring device shall be placed in a recirculating duct location with uniform cross section airflow. The airflow measuring device shall be able to record the flow measurements during the ACD/ACS tests.

4.2.3 The recirculating duct fan shall be sized to provide sufficient airflow and static pressure to meet the requirements of the air cleaning system under test, duct pressure loss, and appurtenances. The fan shall be located in the test section or supply/return ducts. If upstream of the test duct, a diffuser perforated plate device or flow straightener device shall be installed downstream of the fan if needed to establish uniform airflow through the air cleaner. Fan output shall be variable, allowing for control of the airflow and pressure to different values.

4.3 Test Duct Section

4.3.1 The test duct section shall contain the air cleaner(s) (ACD/ACS) to be tested in the orientation recommended by the manufacturer's installation and operations manual as represented in Figure 4-2. For diffuser mounted air cleaners (DFMA), the test duct section shall be located at the end of the supply duct.

4.3.2 Duct transitions shall be designed to minimize the effect of non-uniform airflow through the air cleaning device (ACD) being tested

4.3.3 Test section ACD/ACS air velocity shall be between 100 and 600 feet per minute (FPM) [0.51 and 3.05 m/s].

4.3.4 The test duct shall have visual or other means to see if ACS is operating.

4.3.5 The test duct shall allow for measuring the resistance to airflow (pressure drop) across each ACD/ACS location.

4.3.6 The test duct shall allow for measuring the power used by ACS.

4.3.7 If the test duct is to test ultraviolet (UV) emitting ACS, the test duct shall have a UV in duct reflectance of less than 30% at the operational wavelength provided by the manufacturer within 3.3 ft (1 m) of the air cleaner when installed or a longer distance, if specified by the manufacturer.

4.4 Return Duct Section

4.4.1 The minimum size of the return duct section shall be 10-inch (254 mm) round duct or equivalent rectangular duct.

4.4.2 The duct to chamber connection shall be sufficient to meet Chamber mixing conditions.

4.5 Supply Duct Section

4.5.1 The minimum size of the supply duct section shall be 10-inch (254 mm) round duct or equivalent rectangular duct.

4.5.2 If not testing a DFMA, supply duct shall have a 3-second in-duct residence time (minimum) from the ACS to the chamber.

4.5.3 The duct to chamber connection shall be sufficient to meet chamber mixing conditions.

4.5.4 The supply discharge velocity into the chamber shall not exceed 400 FPM (2.03 m/s). All air supply inlets shall be positioned overhead, at a minimum height of 6.5 ft (2 m) above the chamber floor.

4.5.5 A multi-directional supply grill shall be used to achieve acceptable chamber mixing, if needed.

4.6 Test Chamber

4.6.1 The chamber shall, as applicable, comply with government and local agency requirements for handling and testing biological samples, including, but not limited to, OSHA, NIH/CDC, and ANSI/NSF 49.

4.6.2 The chamber shall be constructed of impervious surfaces, such as stainless steel or glass, be electrically well-grounded or bonded as necessary, be sealed with inert materials, and avoid poisoning materials, such as silicone. The sealed chamber condition shall be verified by aerosol surrogate or gas mixing testing (e.g., CO_2) as described in Section 8.

4.6.3 The chamber shall have a viewing port of inert material such as glass or other non-reactive suitable material with limited area.

4.6.4 The chamber shall include a door capable of opening from both the inside and outside and able to be sealed shut during testing. All sealing materials shall be determined not to emit gases during testing of devices relative to no device tests. Sealing procedure shall be consistent across tests and be part of the lab test SOP or equivalent.

4.6.5 The chamber shall be at least 800 ft^3 (22.7 m^3). The height shall be between 8 ft and 10 ft (2.4 m and 3.0 m). The width shall be at least 40% of the length. The chamber shall be sized such that the IRAC airflow results in an ACR ≥ 6 min. Chamber size consideration shall reflect the measurement instruments, methodology of sample collection, and the air cleaning effectiveness of the IRAC.

4.6.6 The chamber shall include mixing fans in the corners of the chamber positioned upward and not pointed at the IRAC (if used) or at the inlet or outlet. These fans shall operate within an airflow range of 50 to 250 CFM (85 to 425 m^3/h) and be sufficient to provide well-mixed conditions in the chamber when the fans and duct are operating.

4.6.7 The chamber shall be equipped with a heating/cooling system to provide an initial chamber temperature of 70.0°F ± 10.0°F (21.1°C ± 5.5°C), and relative humidity of 38% to 52%. This system shall not be a part of the recirculating duct. This system shall continuously monitor the chamber temperature and relative humidity

4.6.8 The chamber shall be equipped to provide nominally AC power for in-chamber devices. When other power levels are used, the value shall be noted in the test reports.

4.6.9 Chamber and duct system shall have an air change rate with the air surrounding the chamber/recirculating duct of less than 0.03 ACH as determined by ASTM E741, *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution* or an equivalent method, and shall allow measurement of pressure difference between inside and outside of duct and chamber system such that pressure change in the system may be measured to within ±1% during natural decay tests.

4.6.10 For bioaerosol tests, the chamber shall include not less than three sampling ports located in positions representative of the airflow dynamics of the chamber (lacking high turbulence or unidirectional velocity). These probes shall be located at a distance of greater than 1 ft (0.3 m) from each wall, and at a sufficient distance from the supply and return openings of the recirculating duct, mixing fan, and air cleaner(s) such that the sample is not influenced. The sampling locations shall be representative of the chamber dynamics and average concentration and located 3.3 to 6 ft (1.0 to 1.8 m) above the chamber floor.

4.6.11 For particle tests, the chamber shall include a sampling location with the inlet inside the chamber located not in the immediate effluent location of an IRAC or the inlet from the recirculating duct but in an area shown to be well mixed. One of the bioaerosol locations is acceptable.

4.6.12 The chamber shall be capable of mounting and installing in-room air cleaning devices including, but not limited to, wall-mounted, tabletop, ceiling-mounted, and floor air cleaners, and shall include air-tight ports for power lines and remote controls.

4.6.13 The chamber shall be equipped with a contaminant injection port that allows the contaminant to be well mixed within the room. Contaminant injection port shall be located so that it does not interfere with any sampling probes and be at least 2 ft (0.7 m) away from the air cleaning system and return air inlet of the duct.

4.6.14 The chamber shall be equipped to allow decontamination and cleaning of the chamber pre-and post-testing without humans entering. Each lab shall have a standard operating procedure (SOP) delineating the decontamination methodology. For chamber/duct systems to be used for particle contamination tests, the cleanup system shall be capable of lowering the air concentration to less than 10 particles/cc per electrical mobility spectrometer size bin.

Informative Note: For example, air may be pulled from the chamber through a cleanup section before being returned to the chamber. A HEPA filter can provide effective removal of particles; carbon/sorbent beds can be used to remove other species from the air and should be designed to remove all other gaseous contaminants and by-products. This cleanup system shall be designed to be shut completely off from influencing the chamber or the recirculating duct during the testing.

4.6.15 The chamber shall be capable of achieving and maintaining all microbial background contaminant concentrations below the limit of detection over multiple sampling periods or a level deemed acceptable

through laboratory standard operating procedures, if the system will be used for bioaerosol testing. Particles, VOC, and aldehyde background levels shall not exceed the levels defined in Table 7-1 and shall be measured using the methods listed in Table 7-1.

4.6.16 The test chamber shall meet the QA/QC requirements in Section 8 before testing is performed.

4.6.17 If the chamber is to test IRAC devices that emit UV into the chamber, the chamber shall have a UV reflectance of less than 30% at the operational wavelength provided by the manufacturer of the ACS under test.

Informative Note: The lab can use the reflectivity data provided by the manufacturer of the chamber, or a handheld spectroradiometer that is calibrated with a NIST traceable standard.

4.7 In Chamber Air Cleaners (IRAC) (if tested with induct air cleaner)

4.7.1 IRAC air cleaners shall be tested based on their intended use and shall be installed according to the manufacturer's installation and operations manual. Devices shall be installed either within five feet of the chamber supply fan or, if specified in the manufacturer's installation and operations manual, within five feet of the supply diffuser discharge.

4.7.2 If there are no IRAC location instructions, the device shall be placed closest to the middle of the room for in-room devices.

4.7.3 IRAC air cleaners that require power shall have an available means to turn the device on from outside the chamber. Plug-in cords and remotes are acceptable, as are externally mounted switches for in-duct or diffuser-mounted devices.

4.7.4 IRACs shall be installed where they are not in the airflow of the mixing fan. For air cleaners that discharge air in a specific direction, the air discharge shall not be directed toward a sampling port or toward a wall.

4.7.5 For IRACs designed for volumes smaller than the test chamber, multiple IRACs may be located in the chamber during testing. All IRACs used for this purpose shall be identical. Sizing and placement shall be consistent with the manufacturer's specifications and shall be validated by the testing laboratory.

4.7.6 In-duct and diffuser-mounted air cleaners and IRACs may include multiple stages and/or multiple technologies. These shall be tested simultaneously with a standard test. If stages are tested separately, the test report shall be labeled to show that the test was not complete ACS.

5. BIOAEROSOL GENERATION, SAMPLING, AND ANALYSIS

Each bioaerosol test condition shall be performed in triplicate so that three complete natural decay tests (clean chamber air, inject organisms, sample over time) and three complete with ACS tests will be used for the final data analysis and V_{ACS} calculations. Any report with fewer than triplicate tests shall be labeled "Partial Standard 234 Test" or equivalent wording.

5.1 Nebulizers for Bioaerosol Generation

5.1.1 Nebulizers shall be capable of nebulizing microbial suspensions into particles containing no more than one bacterium, fungal spore, or virion.

5.1.2 Compressed air shall be filtered to remove contaminants, including oil, from the air.

5.1.3 The generated aerosol shall be dried down to a stable condition using a drying tower or other dehumidifier, or by allowing sufficient time in the chamber during the required mixing time after the aerosol injection. The lab shall ensure that their nebulizing procedure does not increase the RH in the chamber above acceptable levels.

5.1.4 Collison nebulizers, ultrasonic nebulizers, atomizers or other bioaerosol-generating devices, driven by purified filtered air supply or equivalent shall be chosen to allow correct operation with the organism of a specific test. Given that the organisms are of different sizes, the nebulizer shall allow the organisms to pass through the nozzle. Nebulizers shall be chosen to allow organisms to survive generation.

Informative Note: Neutralization of the aerosol is not required but is allowed.

5.1.5 Biological agents shall be suspended in an appropriate maintenance and delivery solution of salt buffers, artificial sputum, or other buffer solution that maintains viability or infectivity of the biological agent prior to and immediately following nebulization. For MS2 tests, the solution shall be artificial saliva (following

recipe in Heimbuch et al. 2011). For other organisms, the lab shall determine the appropriate suspension buffer based on the test organism and the air cleaning device being tested.

5.2 Bioaerosol Samplers

5.2.1 Air sampling devices shall be placed inside or outside the chamber based on the lab's SOP. Samplers placed outside the chamber shall be connected to the chamber via sampling ports and the appropriate size tubing. The same sampler orientation and tubing configuration shall be used for all tests (natural decay and ACS tests).

5.2.2 Air sampler(s) or sampling port(s) shall be located along the centerline of the room in the lengthwise direction. These probes shall be located at a distance of more than 1 ft (0.3 m) from each wall and at a sufficient distance from the supply and return openings of the recirculating duct, mixing fan, and air cleaner(s) such that the sample is not influenced. The sampling locations shall be representative of the chamber dynamics and average concentration and located 3.3 to 6 ft (1.0 to 1.8 m) above the chamber floor.

5.2.3 Sampling shall be done with impingers, impactors, or other samplers with similar performance. Sampling times and volumes shall be determined to give sufficient and not excessive counts and minimum concentrations in air to obtain statistically valid counts; see Section 10. The same sampling sequence and duration shall be used for all related tests (the natural decay and the ACS and any additional ACS tests that use the same ND k value). Calculated concentrations shall be corrected to account for differing sample times and volumes when they are not the same. When using impactors, the correction hole factor shall be applied before other calculations and shall be required for reporting. When using impingers or gelatin filters, triplicate plates are required for each.

5.2.4 The sampling system shall include a method for rapid change out to allow samples to be taken as quickly as needed for each test.

5.2.5 Samplers shall be confirmed leak free and the associated sampling areas and equipment sanitized following each use to minimize any potential carryover between tests and for personnel safety.

5.2.6 Laboratory SOPs shall include validation of generation and sampling methodologies, including concentrations generated, the efficiency of collection methodologies, and particle size distribution. Sample preparation and analysis shall be based on the specific organism, sampler, and air cleaner.

5.3 Microorganisms

5.3.1 Microorganisms selected for the challenge bioaerosol shall be handled with appropriate primary containment, secondary containment, and following good laboratory practice (GLP) guidelines in accordance with the current version of the CDC/NIH Biosafety in Microbiological and Biomedical Laboratories (BMBL). Where applicable, the lab shall use American Type Culture Collection (ATCC)-traceable microorganisms or ones from other globally recognized culture collections.

5.3.2 Testing for each ACS and set of conditions shall include testing performed with the non-enveloped bacteriophage MS2 (host *Escherichia coli*). Additional organisms such as those listed in Informative Appendix B may be tested in separate runs.

5.4 Background levels for the total of all microorganisms in the chamber air shall be less than the limit of detection. A background sample shall be collected prior to the initiation of each nebulization period to confirm acceptable microorganism background levels during each individual test.

5.4.1 The chamber and recirculating duct system configuration and testing parameters shall meet the minimum ACS testing requirements for any bioaerosols, including requiring a chamber biosafety level (BSL) level of BSL-1, or for bioaerosols requiring BSL-2 and/or BSL-3 settings.

5.4.2 Compliance for all BSL testing to meet the specific biosafety requirements shall be the responsibility of the testing laboratory.

6. PARTICLE (NON-BIO) GENERATION, SAMPLING, AND ANALYSIS

6.1 Submicron Test

This section describes the details that are specific to the submicron particle challenge test. Using the same chamber/duct and other specified equipment above with this challenge generation method, and sampling and

analysis techniques along with the required Std 234 procedures and reporting results in the Standard 234: Ultrafine Particle Test.

6.1.1 Particle Generation

Particles for particle challenge tests shall be generated from a solution of KCl in DI water and have a lognormal distribution with $\mu = 0.12$ µm and $\alpha = 2.5$. Total counts shall be between 8000 and 12000 counts/cc. A charge neutralizer shall be used before the aerosol enters the chamber. If the charge neutralizer generates ions, the generation must allow enough residence time in the generator housing or in the test chamber to allow the excess ions to dissipate before the test begins.

The relative humidity in the chamber shall be verified to be less than 45%, then the generator shall be operated to give the needed concentrations.

Particles shall be dried before the test begins either in the test chamber or a drying tower or equivalent before entering the chamber. After the generator is turned off, the chamber shall be mixed for five minutes or per the duration determined in the particle stability test per Section 8 before sampling for use in the results calculations begins.

6.1.2 Particle Analyzer

The particle analyzer shall be a differential mobility analyzer with real time sampling with counts reported at least every 3 minutes, have a size range of at least 15-350 nm, have an upper count limit at least 5 times the concentration used in the tests, and be able to report particle counts in at least 8 channels across 20-300 nm. Samples for this test shall cover at least 20 to 300 nm. Samples shall be taken at least every five minutes and not more frequently than every minute. Sampling shall continue for one hour or until the counts per reported size range are less than 10 particles/cc.

6.1.3 Particle Background Level

Background counts shall be below 10 particles/cc in each reported size range,

6.2 $PM_{2.5}$ Test

This section describes the details that are specific to the PM2.5 particle challenge test. Using the same chamber/duct and other specified equipment above with this challenge generation method, and sampling and analysis techniques along with the required Std 234 procedures and reporting results in the Standard 234: PM2.5 Test. PM2.5 is generally defined as particulate matter less than 2.5 µm. This test is intended to give a PM2.5 efficacy measurement that can be applied, for example in the Std 62.1 IAQP (subject to acceptance by Standard 62.1).

6.2.1 $PM_{2.5}$ Generation

Particles for the PM2.5 particle challenge test shall be generated from KCl solution in DI water and have a with a mass mean diameter of 0.5 µm and std dev of 1 ±0.7. Total counts shall be between 10000 and 15000 counts/cc. A charge neutralizer that does not generate ions shall be used before the aerosol enters the chamber.

The relative humidity in the chamber shall be verified to be less than 45%, then the generator shall be operated to give the needed concentrations.

Particles shall be dried before the test begins. After the generator is turned off, the chamber shall be mixed for five minutes, or per the duration determined in the particle stability test of Section 8.

6.2.2 PM2.5 Particle Sampling and Analysis

The particle analyzer shall be real time with counts reported at least every 3 minutes, have a size range of at least 0.3-7.0 um, have an upper count limit at least 5 times the concentration used in the tests, and be able to report particle counts in at least 8 channels across the size range. Samples shall be taken at least every three minutes and not more frequently than every minute. Sampling shall continue for one hour or until the counts per reported size range are less than 10% of the original count.

6.2.3 Particle Background Level

Background counts shall be below 10 particles/cc in each reported size range,

7. AIR SAMPLING BEYOND THE CHALLENGE CONTAMINATION

7.1 For the analytes listed in Table 7-1, baseline monitoring shall be conducted before challenge generation for all

tests. It is essential to record and summarize this data in the final test report, ensuring comprehensive documentation of baseline conditions.

7.2 Throughout all testing, the test chamber shall be monitored, either continuously or with samples taken for external analysis at regular intervals for analytes specified in Table 7-1, except for UFP, which shall be monitored continuously. The data logging of analyte concentrations shall occur at intervals not exceeding ten minutes. In cases where data is recorded at intervals shorter than ten minutes, it shall be averaged to ten-minute intervals for consistency. The final report shall present this data, in tabular format with optional graphs, to facilitate clear interpretation and analysis. Non-continuous samples shall be taken at least four times during the test in addition to the background sample.

7.3 The specific requirements for detection limits of analytes are detailed in Table 7-1, which outlines the minimum detection ranges and resolution for each analyte to ensure accurate and reliable monitoring. For continuous monitors, these specifications apply to the analyzer used during the test; for non-continuous samples, these specifications apply to the combination of sample taken and the analyzer used for later analysis. Analyzers that speciate are allowed for TVOCs; the sum of the compounds from C4 to C10 shall be reported as TVOC. Individual compounds may be reported but are not required for the test.

7.4 In addition to the analytes required for all tests, tests for ACS that state that a specific level of a species is needed in the air for their device to work as expected or well, shall test for that analyte during all tests. These analytes include, but may not be limited to, positive and negative ions and hydrogen peroxide. The detection limit of the analyzer shall be less than 10% of the required or otherwise noted value for the analyte. The sampling for these analytes shall be performed in both the Natural Decay and ACS tests and shall meet the requirements for sampling in Table 7-1. Analyzers shall be located as appropriate, including placing any ion meters inside the chamber.

7.5 All devices used for recording analyte concentrations per Table 8-1 shall be calibrated and operated according to manufacturer specifications. Adherence to these guidelines ensures the reliability and accuracy of the data collected.

7.6 Environmental variables, including but not limited to temperature, barometric pressure, and relative humidity, shall be recorded and reported as described in the Procedure section. All devices used for environmental monitoring shall be calibrated according to manufacturer specifications and should be traceable to NIST standards where applicable.

Table 7-1 Specific Analytes that Require Monitoring for Chamber Baseline and Testing Trials[1]

	Abbreviation	Analyzer Minimum Range	Analyzer Resolution (2)	Analyzer Detection Limit[a]	Analyzer Accuracy	Allowed Bkg Conc.[a]
Formaldehyde	CH_2O	10 – 125 (8 – 100)	1 (1)	5 (4)	5%	8 (6)
Ozone	O_3	0 – 200 (0 – 100)	2 (1)	5 (2.5)	2%	10 (5)
Total Volatile Organic Compounds[b]	TVOC	0 – 2100 (0 – 500)	4 (1)	21 (5)	3%	20 (5)
Ultrafine Particles[c]	UFP	10 - 1000	1	3/cm^3	<30%	100/cm^3 for bio test[d]

a. Units are µg/m^3 (ppb) except for ultrafine particles, which are particle/cm^3

b. MW assumed to be 100 for conversion between units

c. Ultrafine particles, for this test, are defined as those ≤100 nm diameter

d. See Section 6 for particle test requirements

8. QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

Qualification tests shall verify quantitatively that the chamber and recirculating duct system, sampling procedures, and equipment can provide reliable challenge aerosol concentration and air-cleaner drawdown

measurements. Qualification tests shall be performed as required by Table 8-1. System qualifications shall be done before initial testing, after major changes to the test system and on the schedule in Table 8-2.

Table 8-1 Chamber and Duct System and Instrument Qualification Requirements

Section Number	Parameter	Specific to Challenge	Requirement
8.1.1	Background level check	Yes	Meet requirements of Table 7-1
8.1.2	Clean-up system check	No	Meet requirements of Table 7-1
8.2	Chamber and duct air change rate (total allowable leakage)	No	<0.05 ach
8.3.1	Airflow measurement	No	6 to 10 ACR (min)
8.3.2	Air velocity measurements	No	100 to 600 FPM in duct; ≤400 FPM at diffuser
8.4	Chamber mixing and uniformity	No	ASTM D6670 or equivalent (Section 8.4.1)
8.5	Particle stability	Yes	Stability shall be shown
8.6.1	Analyzer response time	Yes	<20% sample line transit
8.6.2	Sample transit time	No	Determine correction factor
8.6.3	Analyzers and sampling systems zeroes	Yes	Below detection limit
8.6.4	Gas sampling pump flow rate check	No	NIST traceable flow device
8.6.5	Gas analyzer calibration	Yes	Use traceable gas standards Shall be done for gas analyzers Curve fit $R^2 \geq 0.95$
8.7	Temperature measuring device	No	Factory calibrated
8.8	RH measuring device	No	Factory calibrated
8.9	Airflow through recirculating duct	No	At least three values

Table 8-2 Qualification Maintenance Items and Schedules (gray shading indicates that the test should be done on this schedule)

Maintenance Item (Subsection Reference)	Each Test	Each Testing Day	Challenge Gas Change	Biannually or After Duct Modification	Other
System Purge (Section 8.1.2)					
Air Change Rate (Total Allowable Leakage) (Section 8.2)					
Airflow and Velocity Measurements (Section 8.3)					
Chamber Mixing and Uniformity (Section 8.4)					
Particle Stability (Section 8.5)					
Analyzer Response Time (Section 8.6.1)					

Table 8-2 Qualification Maintenance Items and Schedules (gray shading indicates that the test should be done on this schedule)

Maintenance Item (Subsection Reference)	Each Test	Each Testing Day	Challenge Gas Change	Biannually or After Duct Modification	Other
Gas Analyzer Calibration Checks at 0%, 10%, 50%, and 100% (Section 8.6)					Within two weeks prior to testing and per manufacturer's instructions
Gas Analyzers Zero and Span (Section 8.6)					
Particle Analyzer Calibration (Section 8.6)					Annually
Sample Transit Time (Section 8.6)					When changing sample lines
Analyzer and Sampling System Zero (Section 8.6)					
Gas Sampling pump flow rate check (Section 8.6)					
Temperature (Section 8.7)					
Relative humidity (Section 8.7)					Every six months
Resistance to airflow across empty test section (Section 8.8)					
Airflow through Recirculating Duct (Section 8.9)					

8.1 Meeting Background Requirements

8.1.1 The test laboratory shall demonstrate and document that the experimental setup can meet the background levels for the challenges and other analytes that will be sampled for as listed in Table 7-1.

8.1.2 The test laboratory shall use a cleanup system to remove all contaminants (particles and gases) to levels below the background concentration limits as shown in Table 7-1.

8.2 Chamber and Duct Air Change Rate Test (Total Allowable Leakage). The test chamber and duct shall be sufficiently airtight during testing (leakage of less than 0.05 ACH) as determined in accordance with ASTM E741, ASTM D6670 (Section 8.2.1), or an equivalent method, with the caveat that the recirculating duct shall be considered part of the single zone with the chamber and shall be operated as usual for tests except that a non-reactive device to add resistance to airflow (e.g., an orifice plate) shall be installed in the recirculating duct during the test. Informative Appendix D is an acceptable method.

8.3 Airflow and Velocity Measurements

8.3.1 The recirculating duct airflow shall be tested to verify that the total airflow is maintained between 6 and 10 minutes, relative to the combined volume of the chamber and the recirculating duct and to verify that the total airflow rate is maintained within 10% of the planned test rate throughout all quality checks and tests.

8.3.2 Air velocities in the recirculating test duct shall be tested to confirm they remain between 100 to 600 FPM (0.51 and 3.05 m/s). Additionally, discharge velocities into the chamber shall be tested to ensure that they do not exceed 400 FPM (2.03 m/s). Air velocities shall remain within 10% of the planned test rate throughout all quality checks and tests

8.4 Chamber Mixing and Uniformity. The chamber shall be evaluated to demonstrate that the challenge gas is well mixed during a test. This evaluation shall be done either using the method ASTM D6670 (Section 8.4.1) modified to include the recirculating duct, or by using one the following procedures using CO_2 as a tracer gas.

8.4.1 For multiple analyzers/samplers, the test shall be performed as described below:

a. Position at least four analyzers (or the inlet ends of the sampling tubes) in the chamber.
b. Turn on recirculating duct fan to typical test airflow.
c. Run cleanup system for required length of time per lab SOP, then turn off.
d. With mixing fans operating as used during testing, generate challenge from standard location, and allow to mix your standard length of time.
e. Take simultaneous samples with all analyzers/samplers. Repeat at least three times.
f. Determine the mean for each point and for the whole data set using at least three data sets.
g. The criterion for a well-mixed chamber and recirculating duct system is that all the sample points' means are within 10% of the overall mean.

Informative Note: If the test does not pass, examine the data for trends indicating that the mixing improved over time. This may indicate that the lab needs to increase their pretest missing time. In this case, later samples may be used to determine acceptable mixing. Adjust the required mixing time by adding the time required to meet the acceptance goal.

8.4.2 For a single analyzer or sampler with multiple sample locations, the test shall be performed as described below:

a. Set up the chamber for sampling.
b. Turn on recirculating duct to typical airflow (the same air flow used in the leakage test).
c. Run cleanup system for required length of time per lab SOP, then turn off.
d. With mixing fans operating as usual, generate challenge from standard location, and allow to mix your standard length of time.
e. Take at least four samples from each point, changing locations between samples. Chamber shall not be opened in between sample.
f. Determine the mean for each point and for the whole data set using at least four data sets.
g. The criterion for a well-mixed chamber and recirculating duct system is that all the sample points' means are within 10% of the overall mean.

Informative Note: This setup may mean that the analyzer can be moved from outside the chamber, that multiple sample lines are set up with the analyzer moved between them outside the chamber or some other means.

8.5 Particle Stability. The particle stability test shall be performed as described below:

a. Use the aerosol required for the Particle Challenge Test
b. Set up the chamber for particle sampling including the sampling probe, sample lines, and analyzer.
c. Seal the chamber as usual.
d. Run the cleanup system per the lab SOP.
e. After turning off the cleanup system, turn on the fans in the chamber as usual for a test. Turn on the duct to an average airflow rate for that chamber/duct system.
f. Turn on the analyzer and take at least two samples to show that the chamber is cleaned of particles.
g. Continue running the analyzer.
h. Generate the KCl aerosol as used for the tests.
i. Monitor the aerosol particle size distribution for at least 20 minutes.
j. Turn of the analyzer.
k. Graph the data to show if the aerosol size distribution became stable and at what point this occurred. Set the time when this occurred plus one minute as the point where a particle challenge test may begin.
l. If the distribution does not stabilize, repeat the test with longer sampling times until the distribution does stabilize.

8.6 Analyzer and Sampling Systems. To report the time in the chamber when the sample was removed, it is

important to know both the transit times for any sample lines and the analyzer response time for each analyzer. If the airflow through the lines is known (e.g., by calibrated pumps pulling the air), the internal diameter (ID) can be used to calculate the transit time.

8.6.1 **Analyzer Response.** With the analyzer operating per manufacturer's instructions, expose the analyzer to air that meets the clean air requirements in Section 7 long enough to show a steady reading, then turn on a stable concentration of the appropriate gas. Record the time to a stable and correct reading; use this time to correct the time for the sample.

8.6.2 **Sample Line Transit Time.** Set up sample lines as they will be used. Connect to an analyzer with known response time; run clean air through the sample lines and analyzer until a stable reading is obtained. Turn on a stable concentration of the appropriate contaminant. Record the time to a stable and correct reading. Subtract the analyzer response time from the combined time; use this time to correct the time for the sample whenever this sample line is used at the same sample flowrate. Sample line transit time shall be determined when sample lines are changed in length and diameter.

8.6.3 Analyzers and sampling systems zeroes shall be performed per manufacturer's specifications.

8.6.4 **Gas Analyzer Calibration.** Zero, or check zero as appropriate to the analyzer, and calibrate at approximately 10%, 50%, and 100% of 10 times the allowed background level for the analyte. Zero air shall have concentration levels below the reporting limit of the analyte. Use traceable gas standards. Calibrations shall be done for all analyzers, and the curve fit shall have $R^2 \geq 0.95$.

8.6.5 Calibrate particle analyzer per manufacturer's instructions.

8.6.6 **Other Calibrations.** Measuring instruments used to measure air flow, air velocity, and resistance to air flow shall be calibrated per the manufacturer's instructions. Any measuring instrument not specified in another section shall be calculated according to the manufacturer's instructions.

8.7 **Maintaining Temperature and Relative Humidity Levels.** Measuring instruments shall be capable of determining temperature to within ±1.8°F at 70°F (±1°C at 21.1°C) and relative humidity to within ±5% at 50% RH.

8.8 **Empty Duct Resistance to Airflow**. Measure the resistance to airflow across the empty test duct section using the technique to be used in regular testing.

8.9 **Airflow Through the Recirculating Duct.** Using a NIST traceable technique or currently calibrated AHRI (e.g. hot wire anemometer) approved flow measurement system, determining that the airflow in the recirculating duct matches that initial decay test value within 3%. At least three airflow values shall be tested unless the test lab will not use any others.

9. PROCEDURES

Tests with the ACS and natural decay (usually without the air cleaner, but in some cases done with the device installed but OFF as described in Section 9.1.7) shall be performed identically, except for the ACS presence and operation. This is critical so that the natural decay test correctly reflects the change in concentrations due to the ACS itself. The order of the tests is not specified. A natural decay test run with the same batch of microorganisms, recirculating duct airflow, and environmental conditions within three days of, and with the same sampling time points as the ACS test, shall be acceptable as the paired test for more than one ACS test.

9.1 Before Testing–Setup

9.1.1 Take pictures of the ACS, both separately and as mounted for the test, with identifying markings and labels included.

9.1.2 Determine if the ACS identifying markings and labels agree with the manufacturer's information provided by the test requestor.

9.1.3 Measure the lab or chamber barometric pressure sometime during either test or setup.

9.1.4 Make sure that proper decontamination SOP has been followed and completed.

9.1.5 If the chamber has been decontaminated using chemicals, ensure that the air in the chamber has no chemical or other residue from the decontamination process following their SOP.

9.1.6 Determine the coordinated chamber test and sampling plan, including chamber setup, airflows, air velocities, air change rate (ACR), sampling locations, environmental conditions, contamination generation

and needed initial concentration, sample times, lengths of samples, which species/contaminants need to be sampled for, and other relevant details. Point to table 8.2

9.1.7 Prepare for sampling (e.g., plates ready, space in the incubator prepped, instruments that need daily calibration calibrated, data loggers up and running, and other details for running the test).

9.1.8 Set up in-chamber mixing fans, sampling probes, and all needed equipment in the chamber.

9.1.9 Configure the recirculating duct appropriately to maintain required air velocities for main duct, device installation location, branch ducts, diffuser discharge velocity, supply air inlet height, and total duct length.

9.1.10 Installation of the ACS

a. For duct-mounted ACSs, the ACS shall not be installed during the natural decay test unless the device (when off) will not influence the test. For ACS tests, the ACS shall be installed in the duct.

Informative Note: During the natural decay test, a media filter, for example, should not be installed; however, a UV lamp may be installed.

b. In-room ACS components shall be installed in the chamber prior to initiation of the natural decay test.

c. Devices shall be installed according to the manufacturer's installation and operations manual.

d. Devices shall be located either within five feet of the chamber supply fan or, if specified in the manufacturer’s installation and operations manual, within five feet of the supply diffuser discharge.

e. Devices shall be installed so that they can be turned on and off once the chamber/duct system is closed, and in such a manner that the devices do not interfere with each other.

9.1.11 Seal chamber and duct, then turn on the recirculating duct fan to the planned test air velocities, airflow, and air change rate (ACR).

a. The recirculating duct airflow shall be maintained between 6- and 10-minutes air change rate (ACR) using the combined air volume of the chamber and recirculating duct. The recirculating duct airflow shall be maintained within 10% of the planned test rate throughout all quality checks and tests. All results shall be documented to confirm compliance with the specified airflow range.

b. Air velocities in the test section and across the ACD shall be maintained between 100 FPM and 600 FPM. Additionally, discharge velocities into the chamber shall not exceed 400 FPM. Air velocities shall be maintained within 10% of the planned test rate throughout all quality checks and tests.

9.1.12 At least every fifteen minutes, take the measurements required to verify that all velocities and airflows are within specified limits. At a minimum, velocity and airflow shall be measured at the beginning and end of a test.

9.1.13 Operate chamber/duct cleanup system as per lab SOP or established procedure to achieve required background levels. At the start of sampling, the temperature shall be 70.0°F ± 10.0°F (21.1°C ± 5.5°C), and RH shall be between 40% and 60%.

9.1.14 Turn off the equipment and clean up the system before either the ACS or natural decay test.

9.2 Background and Baseline Sample Collection. Each ACS and natural decay test shall include the following.

9.2.1 Begin monitoring temperature (T) and relative humidity (RH), then continue monitoring and recording at least every minute throughout the test. During the test, the temperature shall not exceed 80°F (27°C). For bioaerosol tests, RH shall be maintained between 40% and 60%; for particle tests, RH shall be maintained below 55%.

9.2.2 Turn on the chamber fans.

9.2.3 Turn on all continuous, direct-read analyzers and record the start time for each analyzer. Analyzer instructions shall be followed for needed equilibration times before official test data is collected.

9.2.4 For bioaerosol testing, take all background samples required for all microorganisms, including viruses, bacteria, mold, mildew (as appropriate), and non-biological species, such as ions, relevant gases, and particles as described in Section 8. Record time and sampling rates for the beginning and end of each sample collected.

9.2.5 If the background results exceed the limits specified in Table 7-1, the test shall be considered invalid.

9.2.6 Turn on the recirculating duct fan. While the recirculating duct fan is on, measure the resistance to airflow across the location where the ACS device(s) will be installed for the ACS test. Turn off the fan after the measurements are taken.

9.2.7 At least every five minutes, take required measurements to verify that all velocities and airflows are maintained within specified limits.

9.2.8 Immediately begin an ACS or natural decay test.

9.3 ACS or Natural Decay Test

9.3.1 Begin contaminant generation per Section 5 for bioaerosol generation, or Section 6 or 7 for particle generation using only one challenge per test Continue operation until the desired concentration is achieved, then stop the generation.

9.3.2 Mix the room air to ensure generated contaminants are uniformly distributed and have had time to dry down to a stable size distribution (if not dry when generated) before the test samples are taken. The duration of initial mixing after generation is stopped, shall be at least five minutes with the results of the mixing test (see Section 8) used to determine the actual length. As soon as the initial mixing is done, the recirculating duct shall be turned on and run for two minutes before moving to Section 9.3.3.

9.3.3 Take the time zero samples. All samples taken during the ACS test and the paired natural decay test shall be the same airflow rate, length, and at the same times.

9.3.4 As soon as the initial sample is completed, for the ACS test, turn the device on. Record the time on. For the Natural Decay test, leave the Device Off.

9.3.5 At least every five minutes, take measurements required to verify that velocities, airflows, chamber temperature and humidity are maintained within specified limits. Take ACS readings for resistance to airflow and power consumption.

9.3.6 For bioaerosol challenge tests, take bioaerosol samples during at least five time points over a period of up to three hours. These samples shall include enough quantity/volume to result in acceptable counts to meet the statistical requirements in Section 6.

9.3.7 For particle-only tests, sample for at least five minutes after the mixing period and before the start of the test (this is the ACS ON point for the ACS test). Sample particles at least every five minutes during the test period of 1 hour or until the counts per size bin are less than 10 particles/cc, whichever is sooner.

9.3.8 Take samples and/or record data for all other required species at least three times during the test, where required species include both direct and indirect measure of the ACS active agent (e.g., ions, hydrogen peroxide, by-products, etc.).

9.3.9 Turn off the ACS, if it was ON.

9.3.10 Turn off the airflow in the recirculating duct.

9.3.11 Operate the cleanup system per lab SOP or established procedure to achieve needed background levels. If personnel enter the chamber, appropriate PPE shall be worn.

9.3.12 Repeat the procedure from the beginning of Section 9.2, continuing into the test section for the remaining test(s) to complete at least 3 natural decay and 3 ACS tests for bioaerosol tests and 1 natural day and 1 ACS test for any non-bioaerosol tests.

9.3.13 Once all tests are done, clean out the chamber with the ventilation system. After this, follow the lab procedure to decontaminate the lab, if needed.

10. CALCULATIONS AND GRAPHING REQUIREMENTS

10.1 Challenge Contaminant Sample Calculations

10.1.1 Determining Contaminant Concentration for Each Sample

10.1.1.1 For impactors, the hole correction procedure shall be performed first (see Macher, JM. 1989). For any other samples, any required adjustments to the data shall be performed. If the samplers were overloaded or underloaded, the test shall be repeated.

10.1.1.2 For samples with counted plates, convert counts to concentrations. Only plates with counts from 25-300 shall be considered valid. The exact equation will depend on the sampling device and dilutions (if used). The basis form of the equation is as shown in Equation 10-1.

$$\text{Concentration} = \text{Counts/Sample Volume} \quad (10\text{-}1)$$

10.1.1.3 For samples reporting particle mass, the concentration based on mass shall be determined using Equation 10-2 if the analyzer allows reporting by mass. For analyzers reporting particle volume, convert to mass using a specific gravity of 1.4. To convert from particle counts, assume the particles are spherical and use the geometric mean of the size channel as the diameter to determine volume.

$$\text{Concentration} = \text{Mass/Sample Volume} \quad (10\text{-}2)$$

For the PM2.5 Test, sum the masses across all the sizes up to the channel including 2.5 um. Use these total mass values to determine the V_{ACS} as described below.

10.1.1.4 For samples reporting particle counts, the concentration for each size range for each sample (including background), and adjustment of test samples for background levels, shall be determined using Equations 10-3 and 10-4.

$$\text{Concentration} = \text{Counts/Sample Volume} \quad (10\text{-}3)$$

$$\text{Concentration} = C_t - C_b \quad (10\text{-}4)$$

where

C_t = concentration at time point (t)

C_b = concentration of background sample

10.1.2 For non-continuous sampling, calculate the average and coefficient of variance (CV) for each time point. If the CV of any point exceeds 25%, repeat the test or discard that time point's data.

10.1.3 Net percent reduction over time (only required for bio test) shall be calculated using Equations 10-5 and 10-6. The calculation shall be performed for both ACS and natural decay data.

$$\%\ \text{Reduction} = 100 \times (1 - (C_t/C_0) \quad (10\text{-}5)$$

where

C_t = concentration at time point (t)

C_0 = average concentration at time zero

$$\text{Net \% Reduction} = \%\ \text{Reduction}_{ACS} - \%\ \text{Reduction}_{\text{natural decay}} \quad (10\text{-}6)$$

All valid time points shall be reported. Data at a given time point for both ACS and natural decay are required for the time point to be considered valid.

10.1.4 For bioaerosols, data for time points above or below appropriate concentration levels for the sample shall be excluded. Samples that are below the limit of detection (l.d.) shall either be assigned the value for that l.d. or excluded from the calculations. All concentration data values for each of the remaining time intervals (at least five, including C_t) shall be used. Average the bioaerosol concentrations at each sampling time point from the three or more natural decay test decay rates and, separately, average the time-matched bioaerosol concentrations from the three or more ACS test decay rates Calculate the natural logarithm of each averaged concentration value.

For particles, all particles samples above three times the background level or greater than or equal to five counts per sample (whichever is greater) shall be used.

10.1.4.1 Decay Rates

10.1.4.1.1 Calculate the slope of the linear fit to ln(concentration) vs. time relationship for both the ACS and natural decay tests. This gives the decay rate for each test.

10.1.4.1.2 Determine the R^2 value for each fitted line. If $R^2 < 0.85$, either repeat the test or consider removing higher CV time periods and check the R^2. At least five remaining good time sample sets are required for the test to be considered valid.

Informative Note: It is not required to use the C_0 in the V_{ACS} calculation.

10.1.4.2 Calculate V_{ACS} per Equation 10-7.

$$V_{ACS} = (k_{ACS} - k_{natural\ decay}) \times V \quad (10\text{-}7)$$

where

V_{ACS} = clean air delivery rate for microorganisms inactivated or particles removed during the test, CFM (m^3/h)

V = volume of the chamber, ft^3 (m^3)

k_{ACS} = ACS test decay rate, particles/h (particles/minute)

$k_{natural\ decay}$ = natural decay test rate, particles/h (particles/minute)

10.2 For other analytes, calculate the concentrations at the time intervals of each microbiological sample or at least every 10 minutes for continuous samples. It is acceptable to calculate concentrations for each time value, if desired. Subtract the background concentration of the same analyte and tabulate the results.

11. REPORTING RESULTS

The following information shall be included in the test report:

a. Name and location of testing laboratory
b. Test date
c. Laboratory test operators' names
d. Lab Barometric pressure
e. Air cleaner manufacturer's name, the company submitting the air cleaner for testing, how the air cleaner was obtained, and who requested the test.
f. Description of the air cleaner tested, including the following:
    1. Brand and model number (or description of a prototype)
    2. Physical description of the air cleaner including technology-specific details
    3. State whether air cleaner components comply with the manufacturer's specifications
    4. If the air cleaner has options, those used in the test shall be specified. These may include output settings, fan speed, filters, or shielding
    5. For IRAC(s), measured airflow rate and stated airflow as determined by the manufacturer
    6. Photos or drawings of the air cleaner as positioned or located during the test
    7. Number of air cleaners in the test chamber and recirculating duct
    8. Location of air cleaner(s) in the test chamber/recirculating duct, as well as the type of air cleaner: in-duct air cleaner, diffuser-mounted air cleaner, or in-room air cleaner
g. Operation information as stated by the manufacturer, including recommended installation location and orientation. List procedures that were followed to conduct testing that came from the manufacturer's installation and operation instructions.
h. Operating conditions for reporting purposes during the test: measured recirculating duct airflow rate in m^3/s (cfm), the temperature in degrees Celsius (degrees Fahrenheit), relative humidity, static pressure relative to space external to the chamber.
i. Chamber/equipment description (as required by Section 4)
    1. Actual chamber dimensions, volume in m^3 (ft^3), type of test chamber (e.g., BSL-1, BSL-2, BSL-3).
    2. Mixing fans (airflow, make/model, rotation speed, location)
    3. Description of the duct system, specifying the total length of the recirculating duct and measurements of each respective duct section, including the distance between the chamber floor and the supply air inlets, the distance between the supply fan and supply air inlets, airflow rate, air velocity in the main duct, branch ducts, diffuser discharge velocity, velocity across the ACD, attachment points to the chamber, and the air change rate (ACR) during both the natural decay and ACS tests
    4. Ultraviolet (UV) reflectance (if required by Section 4.1.2)

5. Temperature/relative humidity control system
6. Air and/or surface cleanup method(s) used
7. Generator used and operating conditions
8. Sampler/sampling description(s) and location(s)
9. Analysis methods used
10. Detection limits of test methods for each analyte
11. For microorganisms, cite source, aerosolization media, and quantification of sampling/assay uncertainty

j. Test Data

1. Diagram of sampling points, mixing fan location(s), and temperature/RH control device
2. Test air temperature and relative humidity (average and range)
3. Lab barometric pressure, ACD/ACS resistance to airflow, face velocity, and device power consumption
4. For baseline ACS and natural decay test(s)
   i. Challenge organism(s) and suspension used, or particle challenge description
   ii. Duration of each test
   iii. For bioaerosol tests, organism test data expressed in CFU/ft^3 or PFU/ft^3 (CFU/m^3 or PFU/m^3), both tables and graphs, with respect to time. Report the k values and V_{ACS} (including the time range used in the calculation).
   iv. For small particle tests, report the concentrations or particle counts per channel for all samples in tabulated formats. Graph the data for at least the largest and smallest channels. Report the k values and V_{ACS} for each size channel. Graphs including trend lines shall include axes names, equations, and R-values.
   v. For PM2.5 particle tests, report the mass per channel and the total mass for all samples in tabulated formats. Report the k values and V_{ACS} for each size channel. Graph the mass vs time data and include trend lines, axes names, equations, and R-values. The report for PM2.5 Tests shall include "PM2.5 Challenge" in the title.
   vi. All analyte testing results, including tabulated and graphed concentrations
5. Required disclaimer on the cover or Page 1 of the report:

   The data presented in this report represent conditions existing in this test chamber. Caution shall be exercised in drawing conclusions from the data contained in this report as to the efficacy of the air cleaner under different circumstances. If changes are made to any aspect of the design that may change or alter the performance of the system, the system will need to be retested. This includes electronics, reflectors, sources or delivery methods, wavelength, mechanical designs, materials, and design configurations as examples.

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INFORMATIVE APPENDIX A—BIBLIOGRAPHY

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5. Haratian, S. et al "An integration approach to quantifying equivalent clean airflow rates of indoor air cleaning devices from pollutant injection and decay test", Building and Environment Volume 285, Part B, 1 November 2025, 113632

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INFORMATIVE APPENDIX B—POSSIBLE ADDITIONAL ORGANISMS

This test currently only requires one organism for a standard test. However, there are many organisms that are found in the air and manufacturers and users may wish to have specific data for them. This section shows some examples of organisms that would be appropriate for this test. These are low Biosafety Level organisms that are used as surrogates for organisms that are more likely to infect humans. Other organisms are acceptable, including higher level ones with the caveat that the laboratory is responsible for using appropriate safety measures and equipment for the organisms they use.

ANSI/ASHRAE Standard 185.3 requires four types of organisms per complete test. Table B-1, reproduced from ANSI/ASHRAE Standard 185.3-2024, Table A-1, shows examples for each of these four categories.

For the purposes of this standard, a complete test requires that one organism of each type be tested, with the option to do additional organisms.

Different types of organisms have different levels of resistance to different killing mechanisms. Testing organisms of different types should give a realistic expectation of how a device works and allows reasonable comparisons across devices. If an organism other than MS2 is tested with the same procedures, the test report should be labeled “modified” and the organism clearly indicated on the cover, summary results, and first page if there is no cover.

All pathogens used in testing should have an ATCC or BEI number, and ideally, a Certificate of Authenticity (COA).

The rationale for using different organisms is supported by two figures showing relative resistance for organisms from Favero and Bond, 2001 (Figure B-1) and from McDonnell and Russell, 1999 (Figure B-2).

Table B-1 Possible Test Organisms for An ASHRAE Standard 234 Test

	Organism(s)	ATCC Category #	Biosafety Level	Comment(s)
Gram Positive Bacteria	*Staphylococcus aureus*	ATCC 6538	2	Organisms found on BEI, but not exact strain
	Staphylococcus epidermidis	ATCC 12228	1	
	Bacillus atrophaeus	ATCC 9372	1	BEI NR-687
	Bacillus subtilis (vegetative & endospores)	ATCC 6633	1	BEI NR-604
Gram Negative Bacteria	*Escherichia coli*	ATCC 8739	1	Organisms found on BEI, but not exact strain
	Klebsiella pneumoniae	ATCC 4352	2	
	Pseudomonas aeruginosa	ATCC 9027	2	
	Serratia marcescens	ATCC 14756		Only available on ATCC
Bacteriophages	Phi X174	ATCC 13706-B1	1	Only available on ATCC
	MS2	ATCC 15597-B1	1	
	Phi 6	ATCC 21781-B1		Unable to find on ATCC
Fungi	*Penicillium citrinum*	ATCC 9849	1	Only available on ATCC
	Aspergillus fumigatus	ATCC 204305	2	

Table B-1 Possible Test Organisms for An ASHRAE Standard 234 Test

	Organism(s)	ATCC Category #	Biosafety Level	Comment(s)
	Penicillium chrysogenum	ATCC 10106	1	
	Penicillium rubens	ATCC 11709	1	
	Stachybotrys chartarum	ATCC 16026	1	
	Aspergillus brasiliensis	ATCC 16404	1	

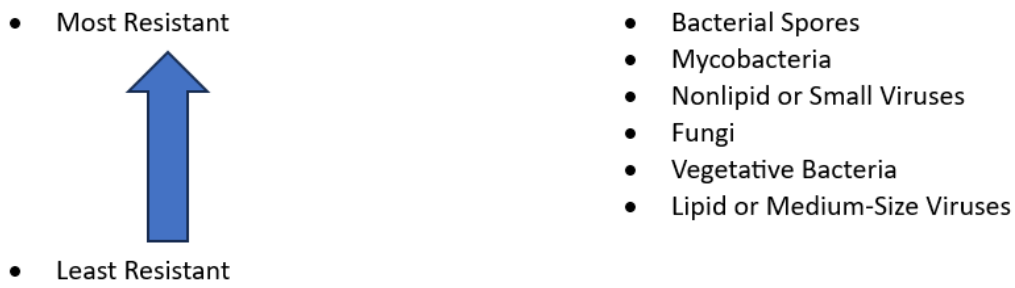

Figure B-1 Relative Resistance to Inactivation

Source: Modified from Favero, M.S. and W.W. Bond. 2001. Chemical Disinfection of Medical and surgical materials. In: Disinfection, Sterilization, and Preservation, 5th Ed., Phila: Lippincott, Williams, & Wilkins, pp. 881-917.

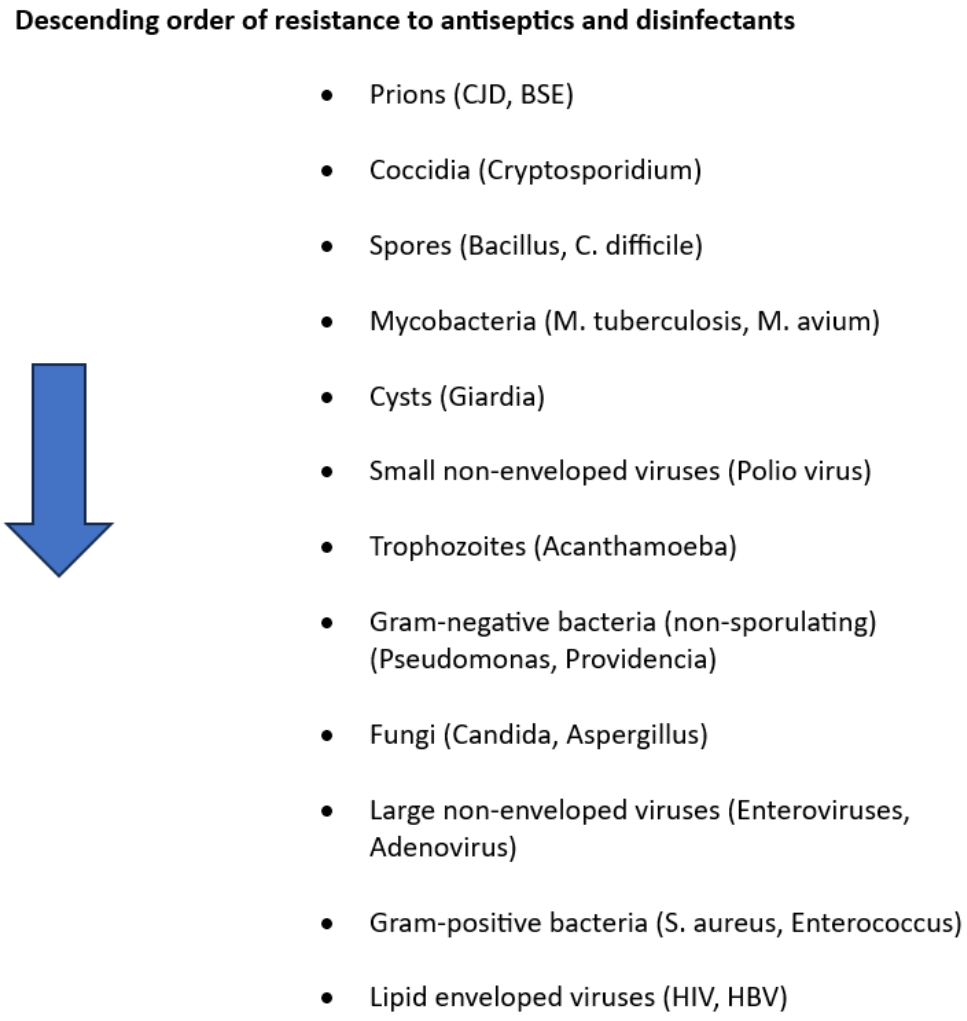

Figure B-2 Descending order of resistance to antiseptics and disinfectants
Source: Modified from McDonnell, Gerald and A. Denver Russell. 1999. Clin. Microbio., doi: 10.1128/CMR. 12.1.147.

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INFORMATIVE APPENDIX C—EXAMPLE V_{ACS} CALCULATIONS

In the examples below, a 1000 ft^3 (28.3 m^3) chamber with 100 ft^3 (2.8 m^3) recirculating duct is used for a test starting at 10000 particles/cm^3. Note that the example works the same if the concentration is in other units. The important units are the time and chamber volume. If (for example) m^3/h were to be used, the answer could be converted from cfm to m^3/h, or units of m^3 and h could be used to make the data table and do the calculations.

The natural decay test concentration decreases slowly, while the ACS test concentration decreases more rapidly. Once the data is tabulated, a simple linear graph is recommended for review to ensure that the data is rational. The curves should either stable at or near the initial value or should decrease over time. It is unlikely that the ACS concentration will be higher than the natural decay concentration at the end of the test. If this occurs and the initial concentrations are similar, check the data for errors. Even if the device doesn't work at all, less decrease than the natural decay may indicate an unnoticed leak in the natural decay test that was plugged for the ACS test, or a similar issue. Zigzags in the data are not usual; some variability is likely.

Preparing a log linear chart should show essentially linear data, although for some devices, this may not be true. If there is a distinct change in slope and the early portion of the test has enough data points, the V_{ECA} may be reported based only on this data. Calculate the natural logarithm (ln) of the concentration, then calculate the slope and R2 of the ln(Conc) vs. time relationship. If the R2 is acceptable, the slope will be the k value.

Perform these steps for both the natural decay and the ACS tests. Then calculate the V_{ACS} from the total volume of the chamber and recirculating duct multiplied by the difference between the two k-values. Note that if the concentrations decreased faster during the ACS than during the natural decay, the V_{ACS} value will be a positive number.

The rationality plot is recommended just to show that the data makes sense but is not required in the test report. Large differences at any time point should be examined. Averages that go up over the test or appear random should also cause enough concern to suggest double-checking the data.

Plotting as ln (Conc) by time (a ln-linear plot) should show linear relationships. The ACS should not have a lower slope than the natural decay. If the device functions properly, the lines should differ significantly. It is not expected that the slopes of a particle test of different sizes and a microorganism test would match.

C1. Particle Test Example

Use one sample every five minutes

Chamber size: 1000 ft^3 (28.3 m^3) with recirculating duct of 100 ft^3 (2.8 m^3)

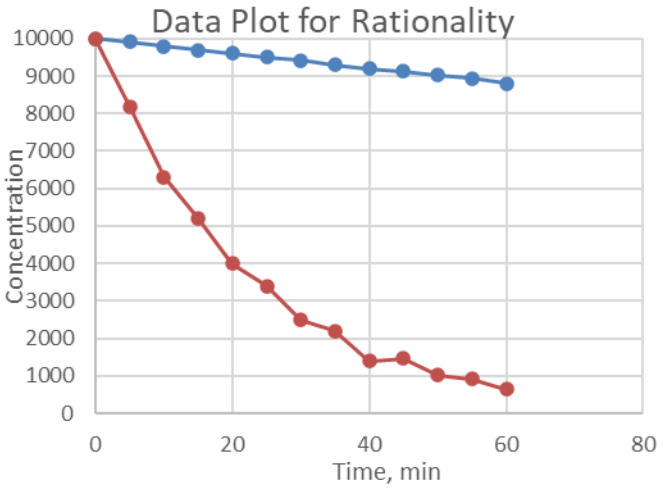
This is modeled on a device that is approximately 85% for a 90 CFM (153 m^3/h) airflow on a single pass.

Particle size (nm)	=	200
Chamber volume (ft^3)	=	1000
Recirculating duct volume (ft^3)	=	100
Total volume (ft^3)	=	1100
V_{ACS} (CFM)	=	47.2

Natural Decay

Time (min)	Concentration	ln(concentration)
0	10000	9.21
5	9910	9.20
10	9799	9.19
15	9700	9.18
20	9600	9.17
25	9500	9.16
30	9420	9.15
35	9300	9.14
40	9200	9.13
45	9130	9.12
50	9020	9.11
55	8945	9.10
60	8805	9.08

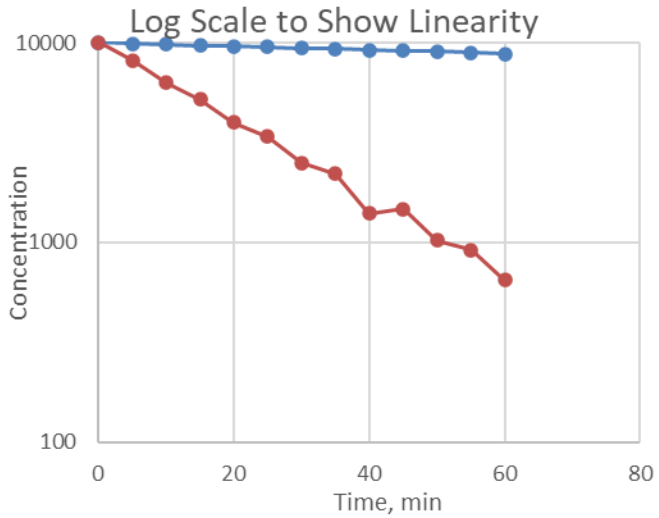
k = 0.0021
R^2 = 0.999



Natural Decay

Time (min)	Concentration	ln(concentration)
0	10000	9.21
5	8180	9.01
10	6311	8.75
15	5200	8.56
20	4000	8.29
25	3400	8.13
30	2500	7.82
35	2200	7.70
40	1400	7.24
45	1470	7.29
50	1021	6.93
55	920	6.82
60	650	6.48

k = 0.0450
R^2 = 0.994



C2. Micro Test Example

This example shows triplicate samples at each time point and includes CV checks and R^2 checks. The intent of this example is to demonstrate a good data set and to provide values for math checks. These are only examples of time intervals; many other time intervals could also be valid.

Chamber volume (ft^3)	=	1000
Recirculating duct volume (ft^3)	=	100
Total volume (ft^3)	=	1100
V_{ACS} (CFM)	=	15.3

Natural Decay

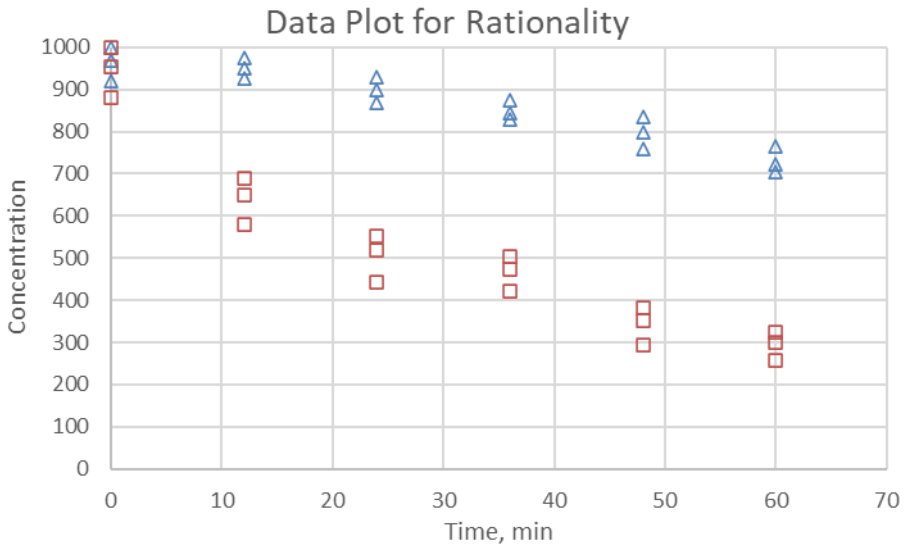
Time (min)	Concentration	CV	ln(concentration)
0	1000	0.042	6.91
0	920		6.82
0	970		6.88
12	975	0.026	6.88
12	950		6.86
12	925		6.83
24	870	0.033	6.77
24	900		6.80
24	930		6.84
36	875	0.027	6.77
36	845		6.74
36	830		6.72
48	800	0.048	6.68
48	835		6.73
48	758		6.63
60	705	0.042	6.56
60	722		6.58
60	765		6.64

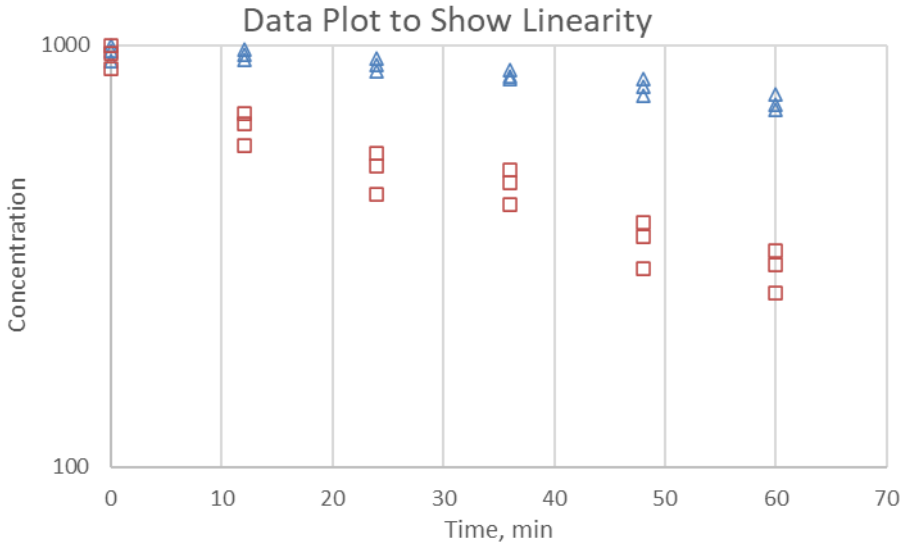
$k = 0.0047$
$R^2 = 0.877$

ACS

Time (min)	Concentration	CV	ln(concentration)
0	1000	0.064	6.91
0	880		6.78
0	955		6.86
12	690	0.087	6.54
12	650		6.48
12	580		6.36
24	443	0.111	6.09
24	518		6.25
24	553		6.32
36	505	0.092	6.22
36	472		6.16
36	420		6.04
48	351	0.128	5.86
48	381		5.94
48	295		5.69
60	258	0.115	5.55
60	301		5.71
60	325		5.78

k = 0.0186
R^2 = 0.924





Example for an "out of specification" particle test showing a low R^2

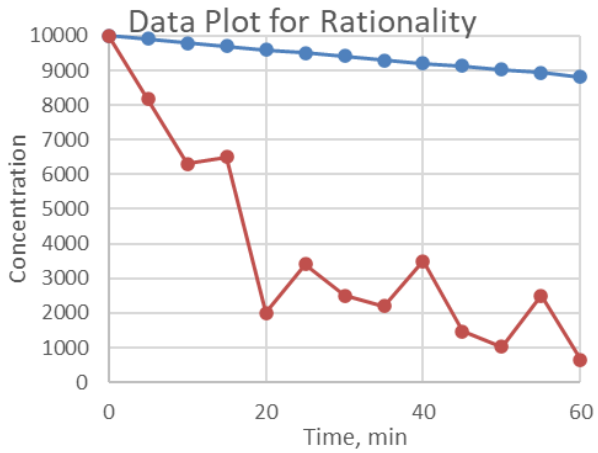
This example shows what a data set that does not meet the test requirements could look like.

Particle size (nm)	=	300
Chamber volume (ft^3)	=	1000
Recirculating duct volume (ft^3)	=	100
Total volume (ft^3)	=	1100
V_{ACS} (CFM)	=	38.1

Natural Decay

Time (min)	Concentration	ln(concentration)
0	10000	9.21
5	9910	9.20
10	9799	9.19
15	9700	9.18
20	9600	9.17
25	9500	9.16
30	9420	9.15
35	9300	9.14
40	9200	9.13
45	9130	9.12
50	9020	9.11
55	8945	9.10
60	8805	9.08

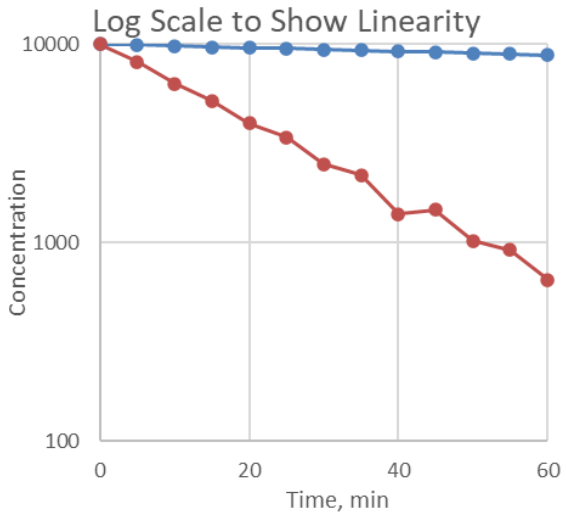
k = 0.0021
R^2 = 0.999


Data Plot for Rationality
Concentration
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
Time, min

ACS

Time (min)	Concentration	ln(concentration)
0	10000	9.21
5	8180	9.01
10	6311	8.75
15	6500	8.78
20	2000	7.60
25	3400	8.13
30	2500	7.82
35	2200	7.70
40	3500	8.16
45	1470	7.29
50	1021	6.93
55	2500	7.82
60	650	6.48

k = 0.0367
R^2 = 0.769



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INFORMATIVE APPENDIX D—EQUIVALENT AIR CHANGE RATE TEST (TOTAL ALLOWABLE LEAKAGE)

Since the goal of the QA check is simply to make sure the chamber and recirculating duct do not have excessive leaks, the specific leak rate is not required as long as the QA check gives and equal or higher value. For any ACS test data analysis, the k-value from the no device test will be used. So, one simple and essentially equivalent option to do the air change rate test is detailed below:

a. Choose easy to work with contaminants that you have a continuous or frequent monitor for (a VOC with PID or 0.5 µm particles are good choices)
b. Place an air cleaner surrogate with a resistance to airflow of ≥1.0 in H_2O (use a value equal to or higher than the highest expected resistance to airflow for actual tests). This can be an orifice plate, a media filter or similar device with airflow resistance.
c. Close up the chamber as you would during the test.
d. Turn on the airflow through the recirculating duct to a typical value.
e. Run the cleanup system as you would before a test.
f. Measure contaminant background levels in the space surrounding the chamber.
g. Measure chamber backgrounds.
h. Generate contaminant (even a small spritz of liquid VOC can suffice)
i. Run mixing fans as you would during an actual test
j. Wait until the value stabilizes (is not fluctuating, indicating lack of mixing or contaminant still evaporating). If it is too high for your normal test needs, you can run the cleanup system to reduce the level. Then make sure the value stabilized.
k. Monitor for one hour
l. Calculate k value or equivalent clean air entering the chamber system
m. If high, re-gasket, seal openings, make sure the cleanup system is sealed off, etc.
n. Repeat.
o. Learn what level is usual for your chamber for ease is noticing that a leak has occurred.
p. If an air mixing test is done after this that results in changes to the chamber, repeat this test.