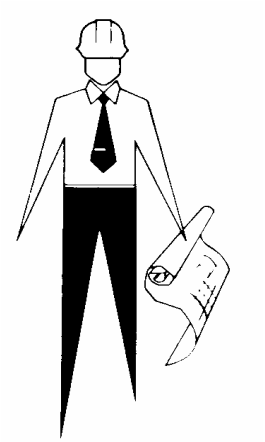
PROCEDURAL STANDARDS FOR CERTIFIED TESTING OF CLEANROOMS



2009 – THIRD EDITION

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PROCEDURAL STANDARDS FOR CERTIFIED TESTING OF CLEANROOMS

FIRST EDITION – OCTOBER 1988
SECOND EDITION – APRIL 1996
THIRD EDITION – OCTOBER 2009

These Procedural Standards were developed using reliable engineering principles and research plus consultation with, and information obtained from, manufacturers, users, testing laboratories and others having specialized experience. They are subject to revision as further experience and investigation may show is necessary or desirable. Cleanroom Performance Testing, which complies with these Procedural Standards, will not necessarily be acceptable, if when examined and tested, it is found to have other features that impair the result intended by these standards. The National Environmental Balancing Bureau assumes no responsibility and has no liability for the application of the principles or techniques contained in these Procedural Standards. Authorities considering adoption of these Procedural Standards should review all Federal, State, local and contract regulations applicable to the specific installation.

FOREWORD

The purpose of the NEBB *Procedural Standards for Certified Testing of Cleanrooms* is to establish a uniform and systematic set of criteria for the performance of cleanroom testing and certification.

Today's buildings provide highly controlled indoor environments. This is especially true when dealing with clean environmental conditions required by today's micro-electronics, bio-medical, and other highly technical industries. These conditions could not exist without sophisticated mechanical systems created by a team of skilled professionals. A key member of this team is the NEBB Certified Cleanroom Performance Testing (CPT) Firm.

This Third Edition represents a departure from past editions. All of the material devoted to Cleanroom Fundamentals, contamination theory and practice, and various testing application data has been intentionally omitted from this edition for two reasons. First, all of this material currently exists in the NEBB Cleanroom Home Study Course and secondly, that type of material is not normally presented in a published standard. This Procedural Standard presents the functional requirements of the NEBB Cleanroom program and the testing and reporting requirements only. This edition is divided into two distinct Parts: S*tandards* and *Procedures*. These CPT procedural standards have been developed using language defined by **"*Shall, Should, and May*"** as it relates to the standards and procedures described in this manual. It is important to note these particular words throughout this manual and how they pertain to the NEBB standards and procedures.

These standards and procedures are intended as the minimum NEBB requirements that a NEBB Certified CPT Firm shall follow when performing Cleanroom Testing and Certification procedures. Contract document requirements or contractual agreements between the Owner and the NEBB Certified CPT Firm may supersede the NEBB requirements. These Procedural Standards have been carefully compiled and reviewed by the NEBB Technical Committees.

Part 1 STANDARDS
Part 1, STANDARDS, covers the requirements for Quality Control and Compliance, Instrumentation Requirements, and CPT Reports. Revised requirements for CPT instruments and reports are identified. The new report requirements allow the NEBB Certified CPT Firm more flexibility in designing their reports by prescribing sets of information that ***"Shall, Should*** and/or ***May"*** be required to complete a CPT Report.

Part 2 PROCEDURES
Part 2, PROCEDURES, covers measurement procedures of the various testing requirements for cleanroom testing and certification.

APPENDICES
The Appendices include a suggested CPT Specification, References, and Engineering Equations.

This Third Edition of the CPT Procedural Standards, when used by NEBB Certified CPT Firms, will assure the building owner or operator that facility systems have been properly tested within design and installation limitations.

Andrew P. Nolfo, PE
NEBB Technical Director

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PART 1 - STANDARDS

SECTION 1 - DEFINITIONS

These procedural standards have been developed using language defined by "Shall, Should, and May" as it relates to the standards and procedures described in this publication. It is important to note these particular words throughout this publication and how they pertain to NEBB standards and procedures.

Acceptance Criteria: The value or range of values which is compared to the measured value that will determine if the results of the test pass or fail.

Accuracy: The *accuracy* of an instrument is the capability of that instrument to indicate the true value of a measured quantity.

Aerosol (Cleanroom Use): A suspension of solid (microspheres) or liquid particles (PAO, DOP, DEHS, etc.) in a gaseous medium used to evaluate HEPA filter integrity and/or efficiency.

Aerosol Challenge: Challenging of a filter or an installed filter system by using a test aerosol.

Airborne particle: Solid or liquid object, viable or non-viable, suspended in air.

Air Change Rate: The calculated number of times the total air volume of a defined space is replaced in a given unit of time. This is ordinarily computed by dividing the total volume of the room supply or exhaust air in cubic meters (cubic feet), per unit of time, by the total volume of the subject space.

As-Built Facility: A cleanroom which is complete and operating, with all services connected and functioning, but has no production equipment or operating personnel within the facility.

As-Found Data: Data found and documented during initial testing prior to modifications of a system.

At-Rest Facility: A cleanroom which is complete with all services functioning and with production equipment installed and capable of being operated or operating, as specified, but without operating personnel within the facility.

Calibration: The act of comparing an instrument of unknown accuracy with a standard of known accuracy to detect, correlate, report, or eliminate by adjustment any variation in the accuracy of the tested instrument.

Certificate of Compliance (Conformance): A written statement, signed by a qualified party, attesting that the items or services are in accordance with specified requirements, and accompanied by additional information to substantiate the statement.

Certification: The process of verifying compliance to meet the established acceptance criteria.

Classification: A specified level of airborne particulate cleanliness applicable to a cleanroom or clean zone, expressed in terms of a cleanliness class, in accordance with a referenced standard.

Cleanroom: A specially constructed room in which the air supply, air distribution, filtration of air supply, materials of construction, and operating procedures are regulated to control airborne particle concentrations to meet appropriate cleanliness levels and other relevant parameters (e.g. temperature, humidity, pressure, etc.) as defined by ISO 14644, or any other regulatory entity.

Cleanroom Installation: Cleanroom or one or more clean zones, together with all associated structures, air-treatment systems, services, and utilities.

Cleanroom Performance Testing (**CPT):** The act of evaluating the performance of a cleanroom by performing a series of defined tests with prescribed procedures and reporting requirements.

Clean Zone: A defined or dedicated space in which the concentration of airborne particles is controlled to specified limits or cleanliness levels and other relevant parameters (e.g. temperature, humidity, pressure,) as defined by ISO 14644, or any other regulatory entity.

Contamination: The presence of any unwanted substance, material or energy which adversely affects a product or procedure in a cleanroom.

Controlled Environment: A work space or room in which limited access or special environmental controls are designed into operational standards.

Counting Efficiency: The ratio of the reported concentration of particles in a given size range to the actual concentration of such particles.

Designated Leak: A leak from a HEPA/ULPA filter or filter bank that should be detectable during scanning of the filter installation with a discrete particle counter or aerosol photometer. When using a discrete particle counter, the designated leak is characterized by a designated number of counts, chosen to establish statistical probabilities related to its detection. When using a photometer a designated leak is normally characterized by a reading that is greater than 0.01% of the upstream challenge.

Differential Pressure (ΔP): The difference between two pressures measured between a sample point and reference point.

Deficiency: Any circumstance that adversely affects the specified performance of a device or system.

Dioctyl Phthalate (DOP): A liquid plasticizer that can be used in an aerosolized form to challenge HEPA filters

Dilution System: A device where a known volume of aerosol is mixed with clean air in a known volumetric ratio to reduce concentration.

Effective Filter Face Area: The total area of active filter face through which air passes.

Filter Face Velocity: Measuring the airflow velocity using an appropriate velocity measuring instrument at a specific distance from the filter face or by dividing the airflow volume by the effective filter face area.

Frequency: As pertains to sound and vibration, the number of vibrations or waves or cycles of any periodic phenomenon per second. In noise control of cleanrooms, interest lies in the audible frequency range of 20 to 20,000 Hz (cycles per second).

HEPA Filter (High Efficiency Particulate Air Filter): An extended media, dry-type filter in a rigid frame having a minimum particle-collection efficiency of 99.97 percent for 0.3 micron particulate at a rated airflow. HEPA filters may be specified by type and grade according to the current edition of IEST-RP-CC001 *HEPA and ULPA Filters*. When the term *HEPA filter* is used in this publication, the term generally will apply to both HEPA and ULPA filters, unless the efficiency is stated and an ULPA filter specifically is required.

Isokinetic Sampling: Any technique for collecting airborne particulate matter in which the collection is so designed that the air stream entering the probe is an airflow velocity that is near to, or equal to, that of the air passing into and around and outside the probe.

Laskin Nozzle: A nozzle used for the generation of a heterogeneous DOP or PAO aerosol by compressed air.

Leak: Penetration of contaminates that exceed an expected value of downstream concentration through defects or lack of integrity.

May: Used to indicate a course of action that is permissible as determined by the NEBB Certified CPT Firm.

Micrometer (Micron): A unit of measurement equal to one-millionth of a meter or approximately 0.00003937 inch. (25 microns are approximately 0.001 inch).

Microspheres (Polystyrene Latex Spheres – PSL): Manufactured highly uniform monodispersed particles in an aqueous solution. These particles are used to generate an aerosol challenge medium for testing cleanroom filters.

Mixed Airflow Cleanroom: A hybrid cleanroom consisting of a combination of unidirectional airflow and non-unidirectional airflow within the same room.

NEBB Certified CPT Firm: A *NEBB Certified (CPT) Firm* is a firm that has met and maintains all the requirements of the National Environmental Balancing Bureau (NEBB) for firm certification in Cleanroom Performance Testing and is currently certified by NEBB. A NEBB Certified CPT Firm shall employ at least one NEBB Certified CPT Professional in a full time management position.

NEBB Certified CPT Report: The data presented in a NEBB Certified CPT Report accurately represents system measurements obtained in accordance with the current edition of the NEBB *Procedural Standards for Certified Testing of Cleanrooms*. Any variances from design, specified or agreed tolerances, are noted in the CPT report project summary.

NEBB Certified CPT Professional: A *NEBB Certified CPT Professional* is a full time employee of the firm in a management position who has successfully passed the professional level written and practical qualification examinations and maintains the Certified CPT Professional re-certification requirements of NEBB.

NEBB Certified CPT Technician: A *NEBB Certified CPT Technician* is a full time employee of the firm who has met the technician level experience requirements of NEBB and has successfully passed the technician level written and practical qualification examinations. A NEBB Certified CPT Technician shall be supervised by a NEBB Certified CPT Professional. (Supervision is not intended to infer constant oversight. A NEBB Certified CPT Technician is capable of performing assigned tasks with periodic supervision.)

Non-Unidirectional Airflow Cleanroom: Air distribution where the supply air entering the clean zone mixes with the internal air by means of induction.

Occupancy State(s): Three conditions of various stages of testing of a cleanroom: As-Built, At-Rest, and Operational.

Operational Facility: A cleanroom which is complete with all services functioning, and with production equipment installed and operating under normal conditions with all operating personnel present.

Particle: A solid or liquid object which, for purposes of classification of air cleanliness, falls within a cumulative distribution that is based upon a threshold (lower limit) size in the range from 0.1 to 5 microns (µm).

Particle Count: Concentration expressed in terms of the number of particles per unit volume of air. Normally associated with the particles in the cleanroom or clean zone.

Particle Counter (Discrete): A light scattering instrument with display or recording means to count and size discrete particles in air.

Particle Size: An expression for the size of solid or liquid particles expressed as the apparent maximum linear dimension or diameter of the particle.

Particle Size Distribution: Cumulative distribution of particle concentration as a function of particle size.

Poly-Alpha Olefin (PAO): A synthetic, non-corrosive, non-mutagenic liquid compound which can be used to generate an aerosol to challenge HEPA filters.

Precision: The ability of an instrument to produce repeatable readings of the same quantity under the same conditions. The precision of an instrument refers to its ability to produce a tightly grouped set of values around the mean value of the measured quantity.

Procedure: The approach to and execution of a sequence of work operations to yield a repeatable and defined result.

Range: The upper and lower limits of an instrument's ability to measure the value of a quantity for which the instrument is calibrated.

Resolution: The smallest change in a measured variable that an instrument can detect.

Room Velocity: The average air velocity in the occupied zone at a specified distance downstream of the entrance zone.

Scanning: A method for disclosing leaks in HEPA or ULPA filter units in which the probe inlet of an aerosol photometer or discrete particle counter is held approximately 25 mm (1 inch) from the filter face and moved in overlapping strokes across the test area at a rate based on the leak penetration to be detected and the upstream challenge concentration.

Shall: The term is used to indicate mandatory requirements to be followed strictly in order to conform to the standards and procedures and from which no deviation is permitted. Note: In the event unique circumstances prevent a required action from being fulfilled, a notation shall be included in the CPT report explaining the exception. For example, such notation could be one of the following: *Not Available, Not Applicable, or Not Accessible.* The simple notation "N/A" without definition is not allowed.

Should: The term is used to indicate that a certain course of action is preferred but not necessarily required.

Standard: A required qualification, action, or result for CPT work.

Testing, Adjusting, and Balancing (TAB): TAB is a systematic process or service applied to heating, ventilating and air-conditioning (HVAC) systems and other environmental systems to achieve and document air and hydronic flow rates.

Testing Intervals:

> **6 Months:** Testing that occurs at an average interval not exceeding 183 days throughout periods of operation use, subject to no interval exceeding 190 days.
>
> **12 Months:** Testing that occurs at an average interval not exceeding 366 days throughout periods of operation use, subject to no interval exceeding 400 days.
>
> **24 Months:** Testing that occurs at an average interval not exceeding 731 days throughout periods of operation use, subject to no interval exceeding 800 days.

Threshold Size: A selected minimum particle size of particle counter measurement capability; the smallest particle size discrimination.

ULPA (Ultra-Low Penetration Air) filters: An extended-medium dry-type filter in a rigid frame having a minimum particle collection efficiency of 99.999% for particles in the size range of 0.1 to 0.2 µm.

Ultra-fine particles: A particle with an equivalent diameter less than 0.1micron (µm).

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Unidirectional Airflow Cleanroom: Controlled airflow through the entire cross-section of a clean zone with a uniform velocity and approximately parallel air stream that is no greater than 14 degrees from plumb.

Unidirectional Flow (Parallel Airflow): Controlled airflow through the entire cross-section of a clean zone with a steady velocity and approximately parallel streamlines. Fluid flow in which particles move in a smooth path substantially parallel to the paths followed by all other particles.

Uniform Airflow: Airflow in which the relative standard deviation of velocities or volumes does not exceed 15 percent.

Upstream Particle Concentration: Number of individual particles per unit volume of air associated with the number of particles upstream of the HEPA filter.

Validation: Establishing documented evidence that a process or system, when operated within established parameters can perform effectively and reproducibly to produce a product meeting its predetermined specifications and quality attributes.

Work Station: An open or enclosed work surface with direct HEPA filtered air supply.

Work Zone: An area within the cleanroom which is designated for clean work and for which CPT is required. The work zone shall be identified by an entrance and exit plane normal to the airflow (where there is unidirectional airflow).

SECTION 2 - NEBB PROGRAM, QUALITY CONTROL AND COMPLIANCE

2.1 NEBB PROGRAMS

The National Environmental Balancing Bureau (NEBB) is a not-for-profit organization founded in 1971 to:

a) develop standards, procedures and programs for the performance of cleanroom certification, testing, adjusting and balancing of environmental systems, measurement of sound and vibration of building systems, commissioning of building systems, retro-commissioning of existing building systems and performance testing of fume hoods,
b) promote advancement of the industry through technical training and development, and
c) operate programs to certify firms and individuals who meet and maintain NEBB standards with integrity.

Additional information on NEBB Programs is available at www.nebb.org.

2.1.1 NEBB DISCIPLINES

NEBB establishes and maintains standards, procedures, and specifications for work in its various disciplines, which include:

a) Cleanroom Performance Testing (CPT)
b) Testing, Adjusting, and Balancing (TAB) of Air and Hydronic Systems
c) Sound (S) Measurement
d) Vibration (V) Measurement
e) Building Systems Commissioning (BSC)
f) Retro-Commissioning (RCx-EB)
g) Fume Hood Testing (FHT)

Each discipline is anchored by a NEBB Procedural Standards manual that provides guidelines for work to be performed. NEBB also has created technical manuals, training materials and programs, and seminars to enhance and support each discipline.

2.1.2 CERTIFICATION OF FIRMS

NEBB certifies firms that meet certain criteria, ensuring strict conformance to its high standards and procedures. Among other requirements, NEBB Certified Firms must document a record of responsible performance, own a complete set of instruments required for the sophisticated techniques and procedures necessary to perform certification tests in the various disciplines and have a NEBB Certified Professional as a full-time employee.

2.1.3 CERTIFICATION OF PROFESSIONALS

NEBB also establishes professional qualifications for the supervision and performance of work in its various disciplines. NEBB Certified Professionals must have extensive experience, and they must pass appropriate, college-level written examinations and demonstrate certain practical working

knowledge, technical decisions and proficiency in the use of instruments required for the various disciplines.

2.1.4 CERTIFICATION OF TECHNICIANS

NEBB also certifies technicians who must possess certain background and experience as well as pass rigorous written and practical examinations. NEBB Certified Technician status is maintained by continued employment with a NEBB Certified Firm.

2.1.5 RECERTIFICATION REQUIREMENTS

Through the recertification procedures, the firm must verify that its NEBB Certified Professional is still on staff and that it continues to own a complete set of instruments that are in current calibration. In addition, the firm's NEBB Certified Professional renews his or her certification annually. Among other requirements, Certified Professionals and Certified Technicians must keep abreast of developments in their discipline by attending and successfully completing continuing education seminars annually.

2.2 QUALITY ASSURANCE PROGRAM - CONFORMANCE CERTIFICATION

The credibility of NEBB is built by maintaining integrity through high standards, quality programs, and demonstrated capabilities of its certified firms. As further assurance, NEBB offers a Quality Assurance Program to guarantee that the work will be accomplished in accordance with its standards. NEBB's Quality Assurance Program applies to each project. It assures that the NEBB Certified Firm will perform specified services in conformity with the current applicable NEBB Procedural Standards.

2.2.1 PROGRAM ADVANTAGES

The NEBB Quality Assurance Program affords building owners, architects, engineers and other agents a reliable basis for specifying work within the various disciplines of NEBB. The program promotes proper execution of projects by ensuring compliance with NEBB standards and procedures.

2.2.2 NEBB QUALITY ASSURANCE PROGRAM CERTIFICATE

The NEBB Quality Assurance Program Conformance Certificate is not required, but is available for any project.

2.3 QUALITY CONTROL AND COMPLIANCE

Building owners are entitled to a professional service by every NEBB Certified Firm on every project, whether the job is NEBB-specified or not. It is the responsibility of the NEBB Certified Firm and its NEBB Certified Professional to establish and maintain procedures and practices that will assure a consistent pattern of high quality work on all projects. This point cannot be overemphasized.

2.3.1 CLEANROOM WORK COMPLIANCE

The scope of work shall be performed as specified in the contract documents, or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. Each relevant or applicable item as identified in the contract documents by description, or by reference, shall be performed and documented in the report. Data presented in a report shall provide an accurate quantitative record of system measurements and information.

References to desired procedures may include statements such as "the work will be performed in accordance to NEBB Standards." When specifications indicate that the work shall be performed in accordance with NEBB standards, the procedures will conform to the current edition of the NEBB

Procedural Standards for Certified Testing of Cleanrooms and the work must be performed by a NEBB Certified CPT Firm.

2.4 CERTIFIED CPT PROFESSIONAL RESPONSIBILITIES

It is the responsibility of the NEBB Certified CPT Professional to control the quality of the work. This means that the NEBB Certified CPT Firm, through its NEBB Certified CPT Professional, shall satisfy the project testing requirements exclusive of acceptance criteria or guaranteeing performance.

2.4.1 EXECUTION OF CPT PROCEDURES

The NEBB Certified CPT Professional shall have project responsibility, which includes authority to represent the NEBB Certified CPT Firm. Examples of project responsibility may include labor decisions, negotiating change orders, committing to contract interpretations and implementing changes in job schedules.

The NEBB Certified CPT Professional has the responsibility to assure that the cleanroom performance tests have been completed and reported in accordance with these CPT Procedural Standards and the contract documents to assure the accuracy of all data that is included in the final report. Factors such as technician training, instrument use, coordination, supervision, work instructions, and project communication play a critical role in achieving this requirement.

2.4.2 TECHNICIAN TRAINING

The NEBB Certified CPT Professional has a responsibility to assure that technicians performing the work are properly trained and possess sufficient skills. Areas that should be stressed are CPT procedures, instrument use and maintenance, coordination, supervision, and project communication.

2.4.3 CLEANROOM PROCEDURES TRAINING

NEBB Certified CPT Technicians must be prepared to completely measure and record data in the manner specified in the NEBB *Procedural Standards for Certified Testing of Cleanrooms*. It is mandatory that NEBB Certified CPT Technicians possess the ability to perform the specific tasks and procedures required for each project. An understanding of items such as HVAC system operation, operating characteristics, cleanroom protocol, etc. are important, and technicians should possess rudimentary knowledge of all related systems and procedural considerations. This may require periodic training to promote knowledge and skill development as well as to facilitate the transfer of knowledge and basic skills in the use of new technology.

2.4.4 INSTRUMENT USE AND MAINTENANCE

NEBB Certified CPT Technicians shall possess knowledge and skill in the proper use and care of instruments required to perform the work. This shall include a thorough understanding of the operating principles, the range and accuracy of the instrument requirements as specified in the NEBB *Procedural Standards for Certified Testing of Cleanrooms* and the proper use of equipment and instruments. Considerations for the delicate nature of many of the instruments typically used, as well as the adverse effects of dirt, shock, jarring movements and exceeding rated capacities, shall be addressed along with the proper methods for storing and transporting the instruments.

2.4.5 COORDINATION / SUPERVISION

The NEBB Certified CPT Professional shall be responsible for directing technicians in performing the work. Instructions may delineate items such as the scope of work, location and quantity of measurements, location and quantity of sample locations, leak testing procedures, design, specified

or agreed criteria, etc. so that field personnel may know exactly what to do and what is required of them.

2.4.6 PROJECT COMMUNICATION

The NEBB Certified CPT Professional shall report on progress made toward work completion, when required, as well as report and address problems if encountered. When a problem exists, the NEBB Certified CPT Professional should notify the appropriate project personnel. The NEBB Certified CPT Professional may provide input as to the cause of the problem and recommend possible solutions.

2.4.7 FIELD WORK COMPLETION

The NEBB Certified CPT Professional shall determine when the cleanroom testing work has been completed, and when to submit the final report. The field work is complete when the field testing scope of work as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm is achieved.

2.4.8 COMPILATION AND SUBMISSION OF FINAL CLEANROOM REPORTS

Reports shall include information and data to provide an accurate quantitative record of system measurements and information. Reports also shall include notes and comments, as appropriate, to provide the reviewer with additional details related to the test procedure, system operation and results. Reports shall meet the criteria listed in Section 5 or as agreed between the Buyer / Owner and the NEBB Certified CPT Firm.

The certification page shall bear the stamp of the NEBB Certified CPT Professional. The stamp on the certification page shall be signed as evidence that the NEBB Certified CPT Professional has personally reviewed and accepted the report. *Signature stamps are specifically prohibited.*

2.4.9 PROJECT COMPLETION

The project completion shall be defined by having all field testing and project document deliverables completed and submitted to the Owner / Buyer.

SECTION 3 RESPONSIBILITIES

3.1 INTRODUCTION

Many approaches can be taken to deliver a successful cleanroom project. In order to maximize value and benefits derived from cleanroom testing, it is important to understand that the owner/buyer, design professionals and other construction team members have responsibilities that will affect the outcome of the testing process.

The following outline represents NEBB's recommended practices that may take place on a conventional design/bid or buy/construct delivery project or on a direct procurement project between the Owner / Buyer and the NEBB Certified CPT Firm. While other delivery approaches will exist, the overall concept of the delineation of responsibilities remains. The Owner / Buyer shall be the responsible party that dictates the procedures that are employed.

3.2 OWNER / BUYER AND DESIGN AND CONSTRUCTION TEAM RESPONSIBILITIES

3.2.1 OWNER / BUYER AND DESIGN PROFESSIONAL RESPONSIBILITIES

It is recommended that the Owner / Buyer and / or contract documents shall:

a. Specify the tests to be performed, the parameters to be measured and the acceptable tolerances. NEBB standards and procedures define industry best practices to perform the testing.

b. Define who retains the services of the NEBB Certified CPT Firm and require that the NEBB Certified CPT Firm be retained early in the construction process.

c. Define the applicable standards, cleanliness classification(s), acceptance criteria, etc. prior to submission of project fees; i.e. ISO Class 4 at 0.3 microns (µm).

d. Clearly identify on the architectural, mechanical and electrical plans and in the specifications, the system components required for cleanroom testing; i.e. pressure relationships, cleanroom reflected ceiling plans, cleanroom floor plans, etc.

e. Specify that the building and/or HVAC control system be commissioned and documented per NEBB commissioning standards and procedures before the cleanroom testing work begins.

f. Specify that the air and water systems be Tested, Adjusted and Balanced (TAB) and documented per NEBB *Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems* before the cleanroom testing work begins.

g. Specify that the building control system firm provides access to hardware and software, or onsite technical support required to assist the cleanroom testing effort. The hardware and software or the onsite technical support shall be provided at no cost to the NEBB Certified CPT Firm.

h. Provide adequate access to all equipment and components required by the cleanroom testing process.

i. Completely define validation / commissioning support responsibilities for the NEBB Certified CPT Firm.

3.2.2 OWNER / BUYER AND / OR CONSTRUCTION TEAM RESPONSIBILITIES

It is recommended that the Owner / Buyer and/or construction team shall:

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a. Provide the NEBB Certified CPT Firm with a complete set of conformed contract documents (drawings, specifications, and approved submittals), including all current approved change orders and contract modifications.

b. Develop a project schedule with the input of the NEBB Certified CPT Firm that coordinates the work of other disciplines and provides *adequate* time in the construction process to allow successful completion of the cleanroom testing and certification work.

c. Notify the NEBB Certified CPT Firm of ***all*** schedule changes.

d. Ensure that the cleanroom envelope is complete.

e. Ensure that all necessary mechanical, electrical and HVAC work is complete and is safe to operate. Permanent electrical power shall be complete and all electrical systems shall be properly installed in accordance with all applicable codes to ensure the safety of all construction personnel.

f. Complete the installation, programming (including design parameters and graphics), calibration and startup of all building control systems that affect the cleanroom operation, and verify that the building control system provider has commissioned and documented their work.

g. Require that the building control system firm provide access to hardware and software, or onsite technical support required to assist the cleanroom testing effort. The hardware and software or the onsite technical support shall be provided at no cost to the NEBB Certified CPT Firm.

h. Define the cleanroom entry protocol; i.e. gowning, wipe-down procedures, etc.

i. Complete the TAB work prior to the NEBB Certified CPT Firm performing the necessary cleanroom tests.

j. Provide the NEBB Certified CPT Firm with a HEPA filter layout, and where required, serial number and location of each filter within all cleanrooms.

3.2.3 NEBB CERTIFIED CPT FIRM RESPONSIBILITIES

The NEBB Certified CPT Firm ***SHALL***:

a. Perform the scope of work as specified in the contract documents, or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

b. Follow the current NEBB CPT standards and procedures when performing the cleanroom tests.

c. Communicate on a regular basis through proper channels, items relating to design, installation, or function that prevent the NEBB Certified CPT Firm from achieving completion of the cleanroom tests in accordance with the current edition of the NEBB *Procedural Standards for Certified Testing of Cleanrooms.*

d. Perform the specified validation/commissioning support requirements.

e. Publish a NEBB Certified CPT Report of final conditions that accurately reflect the measurements and conditions of the cleanroom tests performed as specified in the contract documents, or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

SECTION 4 - STANDARDS FOR EQUIPMENT, INSTRUMENTATION AND CALIBRATION

4.1 MINIMUM INSTRUMENTATION

A NEBB Certified CPT Firm will use a variety of instrumentation to perform the specified cleanroom tests on a project. It is the responsibility of the NEBB Certified CPT Firm to use on a project appropriate instrumentation that meets the requirements of TABLE 4-1 and TABLE 4-2. TABLE 4-1 lists the minimum instrumentation that a NEBB Certified CPT Firm ***SHALL*** own and maintain to perform the primary cleanroom tests. TABLE 4-2 lists the minimum instrumentation that a NEBB Certified CPT Firm ***SHOULD*** own and maintain to perform the optional secondary cleanroom tests. Instrumentation used on a NEBB project shall be in proper operating condition and shall be used in accordance with the manufacturer's recommendations.

4.2 RANGE AND ACCURACY

A NEBB Certified CPT Firm shall possess instruments for each function and range listed in Table 4-1. Each instrument shall have been specifically designed to meet the description criteria of the function. This criterion may include such features as range, accuracy, resolution, capacity, etc. Instrumentation with multiple capabilities shall be accepted for more than one function when submitting documentation for a firm's certification, providing that each separate function meets NEBB requirements. Information and data regarding description of all submitted instrumentation for the stated functions shall be available from the manufacturer.

The accuracy and range as reported by the instrument manufacturer shall be verified by a testing laboratory traceable to the National Institute of Standards and Technology (NIST) or equivalent institute in countries other than the United States. Calibration requirements for each function are specified in Table 4-1 and 4-2 and shall be met.

Firms with multiple sets of instrumentation shall comply by calibrating all instrumentation used by the firm on cleanroom projects in accordance with Tables 4-1 and 4-2.

NEBB Certified CPT Professionals must understand the importance of using accurate instrumentation in the field, and shall be prepared to have witnesses verify their work with the NEBB Certified CPT Firm's calibrated instruments. Results of the data verification shall validate the accuracy of the instrumentation used to perform the work.

Instruments shall be used in accordance with manufacturer's recommendations. The most suitable instrument, or combination of instruments, should be employed for a particular measurement or reading.

TABLE 4-1 NEBB MINIMUM INSTRUMENTATION REQUIREMENTS

Test	Equipment/ Instrumentation	Description	Calibration Interval
Airflow Velocity and Uniformity Test (One of the following Shall be provided) (Sections 10.3, 10.5, & 10.6)	Anemometer (Direct Air Velocity Measurement)	A digital anemometer capable of meeting the following requirements: Range: 0.25 – 12.5 m/s (50 - 2500 fpm) Accuracy: ±5% of reading 0.50 m/s (100 fpm) or greater Accuracy: ±10% of reading 0.50 m/s (100 fpm) or less Resolution: 0.005 m/s (1.0 fpm)	12 Months
	Manometer (Indirect Air Velocity Measurement)	A digital manometer capable of meeting the following requirements: Range*: 0.25 – 12.5 m/s (50 - 2500 fpm) Accuracy*: ± 5% of reading Resolution*: 0.1 m/s (20 fpm) (* Based on conversion of velocity pressure to velocity at the local atmospheric conditions)	12 Months
	Tube Array	A tube array with the following: Range: 0.13 – 12.5 m/s (25 to 2500 fpm) Accuracy: ±3% of reading ±0.04 m/s from 0.25 to 40 m/s (± 7 fpm from 50 to 8000 fpm.	Not Required
	Pitot Tube or Single-Point Probe	Range: 0.13 – 12.5 m/s (25 to 2500 fpm) Accuracy: ±3% of reading ±0.04 m/s from 0.25 to 40 m/s (± 7 fpm from 50 to 8000 fpm.	Not Required
Airflow Volume and Uniformity Test (Section 10.4 & 10.8)	Direct Reading Hood	A flow capture hood with an integral analog or digital manometer capable of meeting the following requirements: Range: 50 – 1000 L/s (100 - 2000 cfm) Accuracy: ±5% of reading, ± 2.5 L/s (±5% of reading, ± 5 cfm) Resolution: (Digital): 0.5 L/s (1.0 cfm) (Analog): 2.5 L/s (5.0 cfm)	12 Months
Airflow Volume and Uniformity Test (Section 10.9)	Manometer	A digital manometer capable of meeting the following requirements: Range: 0.25 – 12.5 m/s (50 - 2500 fpm) * Accuracy: ±5% of reading Resolution: 0.1 m/s (20 fpm) (* Based on conversion of velocity pressure to velocity at the local atmospheric conditions)	12 Months
	Pitot Tube or Single-Point Probe	Range: 0.13 – 12.5 m/s (25 to 2500 fpm) Accuracy: ± 3% of reading ± 0.04 m/s from 0.25 to 25 m/s (± 7 fpm from 50 to 5000 fpm).	Not Required

TABLE 4-1 NEBB MINIMUM INSTRUMENTATION REQUIREMENTS (CONT.)

Test	Equipment/ Instrumentation	Description	Calibration Interval
Leak Testing (w/Photometer) (Section 10.11, 10.13 & 11.14)	Aerosol photometer	The instrument shall have a threshold sensitivity of 10^{-3} micrograms per liter of challenge aerosol particles and be capable of measuring concentrations over a range of 10^{5} times the threshold sensitivity. Sample flow rate shall be 28.3 L/min (1 cfm) with a probe inlet sized to provide isokinetic sampling. Readout shall be either linear or logarithmic with an accuracy of 1% of full scale of the selected range.	12 Months
	Aerosol Generator	A device that can aerosolize either a polydispersed or a monodispersed artificial particle medium for filter integrity testing, including Laskin nozzle type, thermal generator, atomizer, etc.	Not Required
	Scanning Probes	Scanning probe (square or rectangular) fitted with a sampling tube whose length does not exceed 8 meters (25 feet).	Not Required
Leak Testing (w/Particle Counter) (Section 10.12, 10.13 & 11.14)	Particle Counter (Scanning)	A light scattering instrument with display or recording means to count and size discrete particles in air, as defined by ASTM F50-69. Instruments of this type shall provide for a minimum sampling flow rate of 28.3 L/min (1.0 cfm) and a threshold size discrimination of a minimum of 0.3 micrometer (microns) in size.	12 Months
	Scanning Probes	Near-Isokinetic (square or rectangular) scanning probe fitted with a sampling tube no longer than 8 meters (25 feet).	Not Required
	Aerosol Generator	A device that can aerosolize either a polydispersed or a monodispersed artificial particle medium for filter integrity testing, including Laskin nozzle type, thermal generator, atomizer, etc.	Not Required
	Diluter	A device used with the scanning particle counter to sample the aerosol challenge upstream of a filter under test. The resulting counts after dilution should not exceed 100,000 particles.	12 Months

TABLE 4-1 NEBB MINIMUM INSTRUMENTATION REQUIREMENTS (CONT.)

Test	Equipment/ Instrumentation	Description	Calibration Interval
Airborne Particle Count Cleanliness Classification Test (Sections 10.14 and 10.15)	Particle Counter	A light scattering instrument with display or recording means to count and size discrete particles in air, as defined by ASTM F50-69. Instruments of this type shall provide for a minimum sampling flow rate of 28.3 L/min (1 cfm) and a threshold size discrimination of a minimum of 0.3 micrometer in size. The unit shall be provided with an isokinetic sampling probe to maintain the probe inlet velocity at the test airflow rate.	12 Months
	Sampling Probes	Sampling probe fitted with a sampling tube no longer than 8 meters (25 feet).	Not Required
Room Pressurization Test (Section 10.16)	Manometer	An analog or digital manometer capable of meeting the following requirements: Range: 0 - 125 Pa (0 – 0.50 in.w.g.) Accuracy: ±2% of reading Resolution: 2.5 Pa ≤ 250 Pa (0.01 in.w.g. ≤1 in.w.g.) 25 Pa > 250 Pa (0.1 in.w.g. >1 in.w.g.)	12 Months

TABLE 4-2 NEBB MINIMUM (*SHOULD*) INSTRUMENTATION REQUIREMENTS

Test	Equipment/ Instrumentation	Description	Calibration Interval
Airflow Parallelism Test (Section 11.2)	Test Medium	A non-contaminating smoke vapor source, streamers, thread or string	Not Required
	Support Stand & Support Stand with Pointer	A device for positioning the test medium at the specified location and height that is aerodynamically designed to yield the least impact to room airflow.	Not Required
	Plumb Bob or Spirit Level	A small mass of heavy material suspended by a line and used to ascertain a vertical line.	Not Required
	Tape Measure	Linear measurement device with a minimum resolution of 1.0 mm or 1/16 in.	Not Required

TABLE 4-2 NEBB MINIMUM (*SHOULD*) INSTRUMENTATION REQUIREMENTS (CONT.)

Test	Equipment/ Instrumentation	Description	Calibration Interval
Recovery Test (Section 11.3)	Aerosol Generator	A device that can aerosolize either a polydispersed or a monodispersed artificial particle medium for filter integrity testing, including Laskin nozzle type, thermal generator , ultrasonic humidifier, atomizer, etc.	12 Months
	Aerosol photometer	The instrument shall have a threshold sensitivity of 10^{-3} micrograms per liter of challenge aerosol particles and be capable of measuring concentrations over a range of 10^{5} times the threshold sensitivity. Sample flow rate shall be 28.3 L/min (1 cfm) with a probe inlet sized to provide isokinetic sampling. Readout shall be either linear or logarithmic with an accuracy of 1% of full scale of the selected range.	12 Months
	Particle Counter	A light scattering instrument with display or recording means to count and size discrete particles in air, as defined by ASTM F50-69. Instruments of this type shall provide for a sampling flow rate of 28.3 L/min (1 scfm) and a threshold size discrimination of a minimum of 0.2 micrometer in size. The unit shall be provided with an isokinetic sampling probe to maintain the probe inlet velocity at the test airflow rate.	12 Months
Lighting Level and Uniformity Test (Section 11.4)	Light Meter	A portable photo-electric illumination meter approved for field measurement in accordance with the Illumination Engineering Society Lighting Handbook (IES).	12 Months

TABLE 4-2 NEBB MINIMUM (*SHOULD*) INSTRUMENTATION REQUIREMENTS (CONT.)

Test	Equipment/ Instrumentation	Description	Calibration Interval
Sound Level Test (performed w/SLM) (Section 11.5)	Sound level meter (SLM)	Sound level meter (SLM) for sound pressure measurements shall meet the Type 1 or Type 2 requirements specified in the most current version of *ANSI S1.4*	12 Months
	Full and Third Octave Filters	Filters for sound pressure measurements shall meet the requirements specified in the most current version of *ANSI S1.11*	12 Months
	Acoustic Calibrators	Calibrators for sound pressure calibration shall meet the requirements specified in the most current version of *ANSI S1.40*	12 Months
Sound Level Test (performed w/Real Time Analyzers) (Section 11.5)	Real Time Analyzer	Real Time Analyzer for sound pressure measurements shall meet the minimum requirements as specified in ANSI S1.4 and S1.11 and, Lines of resolution ≥ 400 Frequency range capability = 0 – 20.0 kHz True dynamic range ≥ 70 dB Sum and exponential averaging Peak hold function Memory for storage of measurements	12 Months
	Full and Third Octave Filters	Full and Third Octave Filters for sound pressure measurements shall meet the requirements specified in the most current version of *ANSI S1.11*	12 Months
	Acoustic Calibrators	Acoustic Calibrators for sound pressure calibration shall meet the requirements specified in the most current version of *ANSI S1.40.*	12 Months

TABLE 4-2 NEBB MINIMUM (*SHOULD*) INSTRUMENTATION REQUIREMENTS (CONT.)

Test	Equipment/ Instrumentation	Description	Calibration Interval
Vibration Level Tests (performed w/ Vibration Meter) (Section 11.6)	Vibration Meter	Vibration Meter for vibration measurements shall meet the minimum requirements as specified below: Displacement: 0.00254 mm to 2.54 mm (0.1 to 100 mils), Velocity: 0.13 - 2500 mm/s (0.005 to 100 in/sec) Acceleration: 0.098 – 980 m/s² (0.01 to 100 G's) Frequency Range – 1 to 200 Hz (0 to 12,000 CPM) Frequency Resolution Narrowband – 1 Hz	12 Months
	Accelerometers / Transducers	Accelerometers / Transducers for vibration measurements shall have the following minimum specifications: Sensitivity (±10 %) ≥100 mV/G Measurement Range = ±490m/s(50 G) peak Frequency Range = 1 to 1000 Hz at ±5 % Mounted Natural Frequency ≥ 30,000 Hz	12 Months
	Vibration Integrators	Vibration Integrators for SLM for vibration measurements shall meet the minimum requirements as specified below: Displacement: 0.003 - 2.5 mm (0.1 to 100mils) Velocity: 0.13 – 2500 mm/s (0.005 to 100 in/sec) Acceleration: 0.098 – 980 m/s² (0.01 to 100 G's) Frequency Range: 1 to 10,000 Hz Frequency Resolution: 1/3-Octave – 12.5 to 20,000 Hz	12 Months
	Vibration Calibrators	Vibration Calibrators for vibration calibration of SLM shall have the following minimum specifications Operating Frequency = 159.2 Hz Acceleration Output = 1.00 G rms ±3% Distortion (with 0 to 100 gram load) ≤3%	12 Months
General Temperature and moisture Uniformity Test (Section 11.8)	Air Temperature Measurement Instrument	An analog or digital thermometer capable of meeting the following requirements: Range: 4.5°C-38°C (40°F-100°F) Accuracy: ±1% of reading Resolution: 0.1°C (0.2°F)	12 Months
	Humidity Measurement Instrument	An analog or digital hygrometer capable of meeting the following requirements: Range: 10% - 90% RH, Accuracy: ±2% RH, Resolution: 1% RH	12 Months

TABLE 4-2 NEBB MINIMUM (*SHOULD*) INSTRUMENTATION REQUIREMENTS (CONT.)

Test	Equipment/ Instrumentation	Description	Calibration Interval
Comprehensive Temperature and Moisture Uniformity Test (Section 11.9)	Data Recorder - Temperature	Electronic thermometers and temperature sensors with readout devices capable of meeting the following requirements: Range: 4.5°C - 38°C, (40°F - 100°F) Accuracy: ± 0.05°C, (±0.1°F) Resolution: ± 0.05°C. (±0.1°F) Instruments shall be capable of recording temperature and humidity or dew point at specified time intervals and time periods.	12 Months
	Data Recorder - Humidity	Humidity measuring instruments and sensors used with readout devices capable meeting the following requirements: Range: 10% - 90%, Accuracy: ±0.1%, Resolution: ±0.1% Instruments shall be capable of recording temperature and humidity or dew point at specified time intervals and time periods.	12 Months
Electrostatic Tests (Section 11.10)	Electrostatic Voltmeter Electrostatic Field meter	Voltmeter or field meter shall have a range of ± 8.163 kv/cm (±19.99 kv/inch) with an accuracy of ± 5% and a response time of less than 2 seconds for 0 kv to ± 5 kv	12 months
	Ohmmeter	Ohmmeter shall have operating voltages of 10 and 100 volts (DC) under load and current limiting circuitry. It should be capable of measuring from 1 ohm to 10^{14} ohms.	12 months
	Electrodes	Electrodes shall weigh 2.27 kg (5 pounds) and have a flat, circular contact area 64 mm (2.5 inches) in diameter, which shall comprise of a surface of aluminum or tin foil 0.0127 to 0.0254 mm (0.005 inch to 0.001 inches) thick, backed by a layer of rubber 6.4 mm (1/4 inch) thick and measuring 40 and 60 durometer hardness as determined with a Shore Type A durometer (ASTM D2240-68). At least one electrode lead shall have a clip for connecting to ground.	12 months
	Charged Plate Monitor	Device shall have a measuring range of -5 kv to + 5 kv with an error of ± 5% of full scale and a response time of 0.1 seconds. A power supply in the instrument should provide charging to at least ±1000 volts. Timing circuits should be capable of measuring a discharge time from 1000 volts to 100 volts of either polarity.	12 months

TABLE 4-2 NEBB MINIMUM (*SHOULD*) INSTRUMENTATION REQUIREMENTS (CONT.)

Test	Equipment/ Instrumentation	Description	Calibration Interval
Conductivity Tests (Section 11.11)	Ohmmeter	Ohmmeter shall have an open circuit voltage of 500 volts (DC) and a nominal internal resistance of not less than 100,000 ohms.	12 months
	Electrodes	Electrodes shall weigh 2.27 kg (5 pounds) and have a flat, circular contact area 64 mm (2.5 inches) in diameter, which shall be comprised of a surface of aluminum or tin foil 0.0127 to 0.0254 mm (0.005 inch to 0.001 inch) thick, backed by a layer of rubber 6.4 mm (1/4 inch) thick and measuring 40 and 60 durometer hardness as determined with a Shore Type A durometer (ASTM D2240-68).	12 months
Electromagnetic Interference (EMI) Test (Section 11.12)	Magnetic Field Meter	A magnetic field meter with a dynamic range of 0.1 to 4000 milligauss	12 months
	Magnetic Field Sensor	A magnetic field sensor with an external, multi-turn loop.	12 months
Air Change Rate / Hour (ACH) Test (One of the following Shall be provided) (Section 11.13)	Direct Reading Hood	A flow capture hood with an integral analog or digital manometer capable of meeting the following requirements: Range: 50 – 1000 L/s (100 - 2000 cfm) Accuracy: ±5% of reading, ±2.5 L/s (±5% of reading, ±5 cfm) Resolution: (Digital): 0.5 L/s (1.0 cfm) (Analog): 2.5 L/s (5.0 cfm)	12 Months
	Manometer	A digital manometer capable of meeting the following requirements: Range: 0.25 – 12.5 m/s (50 - 2500 fpm) * Accuracy: ±5% of reading Resolution: 0.1 m/s (20 fpm) (* Based on conversion of velocity pressure to velocity at the local atmospheric conditions)	12 Months
	Pitot Tube or Single-Point Probe	Range: 0.13 – 12.5 m/s (25 to 5000 fpm) Accuracy: ±3% of reading ± 0.04 m/s from 0.25 to 25 m/s (±7 fpm from 50 to 5000 fpm.	Not Required
Bench Scan Filter Leak Tests (One of the following Shall be provided) (Section 11.14)	Photometer	Same as Leak Testing w / photometer	12 Months
	Particle Counter	Same as Leak Testing w / particle counter	12 Months

Instrumentation with multiple capabilities shall be accepted for more than one function when submitting documentation for a firm's certification, providing that each separate function meets NEBB requirements.

Calibrations of all instrumentation requiring calibration shall be traceable to current the National Institute of Standards and Technology (NIST) Standards for US firms, or equivalent organizations in other countries.

SECTION 5 – STANDARDS FOR REPORTS AND FORMS

5.1 REPORTS

The NEBB *Procedural Standards for Certified Testing of Cleanrooms* establishes minimum requirements of a NEBB Certified CPT Report. The standards have been developed and written using **"Shall, Should, and May"** language. It is important to note these particular words throughout this document and how they pertain to NEBB Procedural Standards.

NEBB does not require the use of NEBB produced forms. Customized forms are acceptable based on the data acquisition requirements of this section. Where contract document data reporting requirements exceed the minimum requirements of NEBB, the NEBB Certified CPT Firm is responsible to meet the requirements of the contract documents. Where no contract documents exist, the scope of services and reporting shall be as agreed to between the Owner/Buyer and the NEBB Certified CPT Firm.

There may be projects where the reporting requirements may be defined by the owner or a regulatory agency. These reporting requirements may or may not conform to the NEBB reporting requirements. The NEBB CPT Firm shall be allowed to utilize client-specific reporting forms and methods in lieu of the NEBB reporting requirements and sign and stamp the report if allowed or required by the Owner / Buyer.

NEBB requires that all pages in the report shall be identified by a unique page/section number.

NEBB Cleanroom Reports shall include the following information:

A. Report Title

B. Report Certification

C. Table of Contents

D. Standard Operating Procedures (SOP's) References

E. Report Summary / Remarks

F. Test Forms

G. Instrument Calibration Certificates

H. Abbreviations

5.2 REQUIRED FORMS

Listed below are the **requirements** for each NEBB Certified CPT Report in **Shall, Should, and May** language.

5.2.1 REPORT TITLE

Shall Data: The heading: "Certified Cleanroom Test Report"; Project Name / Address; Owner Name/Address, NEBB Certified CPT Firm Name / Address / Certification Number.

May Data: Architect Name; Architect Address / Contact Numbers; Engineer Name; Engineer Address / Contact Numbers; HVAC Contractor Name / HVAC Contractor Address / Contact Numbers, etc.

5.2.2 REPORT CERTIFICATION

The certification page **Shall** bear the stamp of the NEBB Certified CPT Professional. The stamp on the certification page **Shall** be signed as evidence that the NEBB Certified CPT Professional has reviewed and accepted the report. ***Signature stamps are specifically prohibited.***

Shall Data: Project Name; Test Occupancy State(s), Certifying NEBB Certified CPT Professional's Name; Firm Name; Certification Number; Expiration Date; Certifying NEBB Certified CPT Professional's NEBB Stamp (signed & dated); and the following exact verbiage:

"THE DATA PRESENTED IN THIS REPORT IS A RECORD OF CLEANROOM AND SYSTEM PERFORMANCE AND WAS OBTAINED IN ACCORDANCE WITH THE CURRENT EDITION OF THE NEBB *PROCEDURAL STANDARDS FOR CERTIFIED TESTING OF CLEANROOMS,* AND [edit wording to include the appropriate standards that the cleanrooms were tested such as ISO, FS 209, IEST RP etc.] ANY VARIANCES FROM DESIGN, SPECIFIED, OR AGREED TO CRITERIA ARE NOTED IN THE CLEANROOM REPORT PROJECT SUMMARY."

Should Data: Disclaimer statement with the following suggested wording:

"The results shown and information given in this report are certified to be accurate and complete to the extent possible by equipment and procedures used on this date.

(Insert Firm Name) warrants that the equipment or system listed above and / or identified in this report is operating at the specified levels as shown, at and only at this time, and makes no other warranties, stated or implied, concerning the continued performance, operation or safety in use of this equipment past this time.

Note: The Certification Statement and the Disclaimer Statement may be included on the report title page or on a separate certification page.

5.2.3 TABLE OF CONTENTS

The table of contents shall serve as a guide to the organization of the cleanroom report.

Shall Data: Page / Section numbers of tests performed in the report.

5.2.4 STANDARD OPERATING PROCEDURES (SOP's) REFERENCES

This section shall include a reference to all SOP's used during the execution of the work.

5.2.5 REPORT SUMMARY / REMARKS

A NEBB Certified CPT Report shall include a narrative synopsis of each performance test conducted. The Summary section shall also include a description of the test occupancy state and narrative explanation of any exceptions to the test occupancy state.

All tested items included in the NEBB CPT Report shall be clearly identified with a unique designation. The method of identification may use schematic diagrams, mechanical plans where permissible, or a narrative description. Each data form supplied in a NEBB CPT Report shall include the name of the responsible technician / NEBB Certified CPT Professional who reported the information, and the time period the data was collected.

This section also includes a listing of all deficiencies and items that exceed Contract Document tolerances, or as agreed to criteria between the Owner / Buyer and the NEBB Certified CPT Firm, or any other items that require discussion / explanation in the summary.

5.2.6 INSTRUMENT CALIBRATION CERTIFICATES

Report shall contain a summary list of all instrumentation and equipment used on the project accompanied by copies of the current calibration certificates.

Shall Data:

Instrument type
Instrument manufacturer and model number
Instrument serial number
Instrument calibration date

5.2.7 ABBREVIATIONS

This section ***SHALL*** include a listing of all abbreviations and their definitions used in the report. As an alternative, all abbreviations used in the report shall be defined in the body of the report.

5.3 AIRFLOW VELOCITY AND UNIFORMITY TEST – FILTER FACE AIRFLOW VELOCITY – UNIDIRECTIONAL (Section 10.3)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Sample Location Documentation
Room Identification Name / Number
As Left Data: Average airflow velocity
Test Results Data
Report all airflow measurements with corresponding grid locations.
Relative Standard Deviation when 6 or more readings are taken.
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Filter Size Owner defined requirements As Found Data	Test Occupancy State Client Name

5.4 AIRFLOW VELOCITY AND UNIFORMITY TEST – FILTER FACE AIRFLOW VELOCITY – NON-UNIDIRECTIONAL (Volume Method) (Section 10.4)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Standard Operating Procedure
Room Identification Name / Number
As Left Data: Calculated Average airflow velocity
Developed "correction factor"
Test Results Data
Report all airflow measurements with corresponding grid locations.
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Filter Size Owner defined requirements As Found Data	Test Occupancy State Client Name

5.5 AIRFLOW VELOCITY AND UNIFORMITY TEST - FILTER FACE AIRFLOW VELOCITY - NON-UNIDIRECTIONAL (Velocity Method) (Section 10.5)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Sample Location Documentation
Room Identification Name / Number
As Left Data: Average airflow velocity
Test Results Data
Report all airflow measurements with corresponding grid locations.
Relative Standard Deviation
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Filter Size Owner defined requirements As Found Data	Test Occupancy State Client Name

5.6 AIRFLOW VELOCITY AND UNIFORMITY TEST – AVERAGE ROOM AIRFLOW VELOCITY (Section 10.6)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Room Identification Name / Number
Standard Operating Procedure
As Left Data: Minimum airflow velocity
Maximum airflow velocity
Average airflow velocity
Test Results Data
Report all airflow measurements with corresponding grid locations.
Relative Standard Deviation when 6 or more readings are taken.
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Filter Size Owner defined requirements As Found Data	Test Occupancy State Client Name

5.7 AIRFLOW VOLUME AND UNIFORMITY TESTS – FLOWHOOD METHOD (Section 10.8)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Sample Location Documentation
Room Identification Name / Number
As Left Data: Average airflow volume
Test Results Data
Report all airflow measurements with corresponding grid locations.
Relative Standard Deviation when 6 or more readings are taken.
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Filter Size Owner defined requirements As Found Data	Test Occupancy State Client Name

5.8 AIRFLOW VOLUME AND UNIFORMITY TESTS – TRAVERSE METHOD (Section 10.9)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Sample Location Documentation
Room Identification Name / Number
Duct Size and Individual Velocities
As Left Data: Total Airflow Volume
Test Results Data
Report all airflow measurements with corresponding grid locations.
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Filter Size Owner defined requirements As Found Data	Test Occupancy State Client Name

5.9 FILTER INSTALLATION LEAK TESTS – AEROSOL PHOTOMETER TEST METHOD (Section 10.11)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Room Identification Name / Number
Challenge Medium
Upstream Challenge Concentration
Leak: Location
Percent of Penetration
Type (Media, Grid, Gel, Etc.)
Test Results Data
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Should Data:

Repairs (Existing): Number Size Location Total Area	Repairs (New): Number Size Location Total Area	Repairs (Total): Total Percent of Repair Area

May Data:

Owner defined requirements As Found Data Filter Size Scan Rate	Filter Pressure Drop Test Occupancy State Client Name

5.10 FILTER INSTALLATION LEAK TESTS – DISCRETE PARTICLE COUNTER TEST METHOD (Section 10.12)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Room Identification Name / Number
Challenge Medium
Upstream Challenge Concentration / Particle Size
Leak: Location
Percent of Penetration
Type (Media, Grid, Gel, Etc.)
Test Results Data
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Should Data:

Scan Rate Repairs(Existing):Number Size Location Total Area	Repairs (New): Number Size Location Total Area	Repairs (Total): Total Percent of Repair Area

May Data:

Owner Defined Requirements As Found Data Filter Size Filter Pressure Drop	Test Occupancy State Client Name

5.11 FILTER INSTALLATION LEAK TESTS – TOTAL AEROSOL PENETRATION TEST METHOD (Section 10.13)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Challenge Medium Upstream Challenge Concentration Percent of Overall Leak Penetration Test Results Data Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements As Found Data Filter Size Filter Pressure Drop	Test Occupancy State Client Name

5.12 AIRBORNE PARTICLE COUNT CLEANLINESS CLASSIFICATION TEST – ISO STANDARD (NON-UNIDIRECTIONAL AND UNIDIRECTIONAL) (Section 10.14)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Occupancy State Test Results Data Particle Size(s) of Interest Actual Room Classification Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements	Client Name

5.13 AIRBORNE PARTICLE COUNTING TESTS – SEQUENTIAL SAMPLING (Section 10.15)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Standard Operating Procedure Test Occupancy State Test Results Data Particle Size(s) of Interest Actual Room Classification Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements	Client Name

5.14 ROOM PRESSURIZATION TESTS (SECTION 10.16)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Results Data Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements As Found Data Test Occupancy State Client Name Schematic diagram depicting direction of airflow and differential pressure magnitude

5.15 AIRFLOW PARALLELISM TESTS (Section 11.2)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Results Data Test Location Diagram Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements As Found Data Test Occupancy State	Client Name

5.16 RECOVERY TESTS (Section 11.3)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Room Identification Name / Number
Initial Particle Counts at Particle Size(s) of Interest
Challenge Medium
Challenge Concentration
Test Results Data:
- Recovery Time
- Ending Particle Count at Particle Size(s) of Interest

Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements As Found Data Test Occupancy State	Client Name

5.17 LIGHTING LEVEL AND UNIFORMITY TESTS (Section 11.4)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Room Identification Name / Number
Test Location Diagram
Test Results Data
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Lighting Type(s) Detail natural/artificial influences	Test Occupancy State Client Name

5.18 SOUND LEVEL TESTS (Section 11.5)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Location Diagram Test Results Data: Operating Sound Pressure Levels: NC Curve, RC Curve or A-Weighted Value Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State	Client Name

5.19 VIBRATION LEVEL TESTS (Section 11.6)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Location Diagram Test Results Data: (data stated in appropriate units (SI or IP) and reported in terms of displacement, velocity, acceleration and / or frequency based on scope requirements) Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State	Client Name

5.20 GENERAL TEMPERATURE AND HUMIDITY UNIFORMITY TESTS (Section 11.8)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Location Diagram Test Results Data Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State Client Name	Work Height Level

5.21 COMPREHENSIVE TEMPERATURE AND HUMIDITY UNIFORMITY TESTS (Section 11.9)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Room Identification Name / Number
Test Location Diagram
Work Height Level
Test Results Data
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State	Client Name

5.22 ELECTROSTATIC TESTS (Section 11.10)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Room Identification Name / Number
Test Location Diagram
Test Parameters
Test Results Data
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State	Client Name

5.23 CONDUCTIVITY TESTS (Section 11.11)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Location Diagram Test Parameters Test Results Data Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State	Client Name

5.24 ELECTROMAGNETIC INTERFERENCE (EMI) TEST (Section 11.12)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Test Location Diagram Test Parameters Test Results Data Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State	Client Name

5.25 AIR CHANGE RATE (ACH) TEST (Section 11.13)

Shall Data:

Technician Name Test Date(s) Instrument Identification Room Identification Name / Number Sample Location Documentation Test Results Data Identify all performance data that exceeds the acceptance criteria as specified herein or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

May Data:

Owner defined requirements Test Occupancy State	Client Name

5.26 BENCH SCAN FILTER LEAK TESTS (Section 11.14)

Shall Data:

Technician Name
Test Date(s)
Instrument Identification
Challenge Medium
Upstream Challenge Concentration / Particle Size
Leak: Location
Percent of Penetration
Type (Media, Frame, Etc.)
Test Results Data
Identify all performance data that exceeds the acceptance criteria as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Should Data:

Scan Rate	Repairs: Number Size Location Total Area Total Percent of Media Area Repair

May Data:

Owner Defined Requirements Filter Size	Client Name Filter Pressure Drop

PART 2 - PROCEDURES

SECTION 6 - CLEANROOM STANDARD OPERATING PROCEDURES

6.1 INTRODUCTION

The purpose of this Section is to provide an overview of Standard Operating Procedures (SOP's) for the NEBB Certified CPT Firm. The NEBB Certified CPT Professional shall develop these SOP's and shall be responsible for implementing them within the NEBB Certified CPT Firm.

The NEBB Certified CPT Firm shall have SOP's for the following areas:

a. Safety
b. Instrument Calibration
c. Technician Training
d. Cleanroom Test Procedures
e. Cleanroom Reports
f. Cleanroom Protocol

The NEBB Cleanroom program does not dictate the requirements of each SOP. That is up to each NEBB Certified CPT Firm and NEBB Certified CPT Professional. This section will address the elements that are included in writing and executing SOP's.

6.2 STANDARD OPERATING PROCEDURES

6.2.1 DESCRIPTION

Standard Operating Procedures (SOP's) are documents that describe internal procedures and how to perform various routine operations. They contain step-by-step instructions that technicians consult in order to maintain consistency in their test procedures, repeatability in their results and their reports. SOP's are, in essence, written commitments that describe the performance of routine tasks.

6.2.2 FORMAT

There are many ways to format an SOP. When developing a format, it is important to consider the various categories:

a. Title
b. Purpose
c. Scope
d. Responsibility

e. References
f. Applicable Documents
g. Safety Considerations
h. Procedural Principles
i. Preliminary Operations
j. Procedures
k. Equipment and Instrumentation
l. Tools
m. Calculations
n. Documentation Requirements

6.2.3 TITLE
The Title of an SOP should be direct and brief, describing each procedure in a way that identifies its purpose. The Title should also include any key words useful for locating the procedure in a list of SOP's. Titles should be used to group SOP's by purpose, test method, etc.

6.2.4 PURPOSE
The Purpose of an SOP often restates a well-written SOP title, but can also be used to expand upon the purpose of the procedure.

6.2.5 SCOPE
The Scope describes the application of the SOP. To define the Scope of an SOP, the NEBB Certified CPT Professional should consider to what and to whom the procedure applies, and when it is to be applied.

6.2.6 RESPONSIBILITY
The SOP defines who is responsible for performing the operations cited. For example, it might cite a department or mandate specific training requirements for individuals within a department. SOP's also support routine regulated operations. SOP's should be written by the NEBB Certified CPT Professional in conjunction with the individuals who perform the operations. Although particular individuals in each department may write the majority of the procedures, it is important that everyone in the NEBB Certified CPT Firm be trained to draft and review SOP's.

6.2.7 REFERENCES AND DOCUMENTS
The References and Applicable Documents sections of an SOP are optional. These sections can be used to reference allied SOP's, standards, protocols, or additional information sources, such as vendor manuals and instruction booklets.

6.2.8 SAFETY
Safety considerations appear in all appropriate SOP's. These include physical safety issues (such as hard hats and appropriate eye protection), biological contamination issues (such as masks, gloves and biological safety cabinets) and chemical hazards. It should also include any environmental issues and the appropriate response that should occur during the execution of a procedure.

6.2.9 PROCEDURAL PRINCIPLES
Procedural Principles are provided to help technicians and reviewers understand the fundamental principles of the SOP. This section should also be used to explain why the procedure is required in the context of the facility operations.

6.2.10 PRELIMINARY OPERATIONS

Preliminary Operations are another optional section of an SOP. It may include any operations that should be completed before the actual procedure is initiated. For example, there may be a need to calibrate equipment before the procedure begins. In addition, some facilities require a material checklist section to ensure that all materials required to complete the work are available before the work begins.

6.2.11 PROCEDURES

Procedures should be simple, direct, step-by-step narratives that explain how to perform the tasks in a manner that supports the execution. Any sampling or testing that might occur to support the task should also be cited. The Procedure should include diagrams and drawings in this section when they facilitate understanding of the instructions.

6.2.12 TOOLS

The SOP should contain a listing of all required tools and instrumentation required to perform the required task(s).

6.2.13 CALCULATIONS

Calculations of a final result must also appear in appropriate SOP's. The calculations should include all equations, conversion factors, constants, etc. The SOP Procedure shall detail how to calculate the final results; however, generally it should not dictate acceptance criteria for that result.

6.2.14 DOCUMENTATION REQUIREMENTS

Documentation Requirements for an SOP should address any standard forms to be completed during the procedure. This section should address distribution of results, if applicable. Procedural deviation documentation requirements should also be outlined or referenced in this section.

Each page of an SOP document should contain its abbreviated title, SOP number; edition number and pagination. The company name and some declaration of confidentiality can also appear on each page. As long as each page contains the SOP number and its edition number, only one page—usually the first—needs to contain the document approval signatures and the date of approval.

6.3 ADDITIONAL SOP REQUIREMENTS

6.3.1 LANGUAGE AND DETAIL

The NEBB Certified CPT Professional should write SOP's for the technicians who will use them on a daily basis. Use clear and direct language. Use active verbs for procedural directives. SOP's must be specific enough to be clear and accurate, yet flexible enough to be useful.

When citing the use of an item in a procedure, name the item and its model number. Slang terms for equipment, departments, or procedures may be used, as long as they are explained somewhere in the text to ensure clarity for an outside reviewer. It is good policy for draft SOP's to be reviewed by the technicians who will use them.

6.3.2 REVIEW AND APPROVAL

The review and approval process shall be executed by two distinct individuals: the author and the reviewer. Both individuals shall sign the document. The author should sign first and the reviewer should then second. The reviewer shall be a person who can knowledgeably review and approve the procedure.

6.3.3 DISTRIBUTION AND CONTROL

The distribution of approved SOP's must be controlled. Each department shall maintain a master set of procedures with all distribution(s) documented. There are several ways to document these events such as with log books or forms. Whatever the system, the NEBB Certified CPT Professional and the NEBB Certified CPT Firm shall be able to track the history of creation, change, distribution and use of each document.

6.3.4 MODIFICATIONS

When revised procedures are issued, it shall be documented that the previous versions of the procedure are retrieved and destroyed. The NEBB Certified CPT Professional and the NEBB Certified CPT Firm shall be able to track the history, change, distribution and use of each document.

6.3.5 DATA COLLECTION FORMS / REPORTS

Data collection shall be in accordance with the requirements of Section 5 for all primary and secondary cleanroom performance tests identified in Sections 10 and 11. If unique or non-standard procedures are required for a project, data should be collected and documented in a manner similar to the requirements of this Procedural Standard.

SECTION 7 CLEANROOM SAFETY

7.1 INTRODUCTION

A health and safety program is a definite plan of action designed to prevent accidents and occupational diseases. A health and safety program should include the elements required by the health and safety legislation as a minimum. This section summarizes the general elements of a health and safety program. This should help NEBB Firms to develop programs to deal with their specific needs. Because many small and medium-sized enterprises lack the resources of larger organizations, it is even more vital that small and medium-sized enterprises involve all employees in health and safety activities. The more comprehensive the program is, the more employee involvement can be expected.

The health and safety program discussed in this section is a guideline. The project specific safety program shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Most often the NEBB Certified CPT Firm will be required to follow the client project specific safety program; however in the absence of this project specific safety program, the firm's SOP for cleanroom health and safety program shall be followed. For this reason, the NEBB Certified CPT Firm shall have a Standard Operating Procedures (SOP) for Health and Safety.

7.2 DESIGNING A HEALTH AND SAFETY PROGRAM

7.2.1 DESIGNING A PROGRAM POLICY

A NEBB Certified CPT Firm's health and safety policy is a statement of principles and general rules that serve as guides for action.

The policy should mention:

a. Management's commitment to protect the safety and health of employees
b. The objectives of the program
c. The organization's basic health and safety philosophy
d. Who is accountable for health and safety programs
e. The general responsibilities of all employees
f. That health and safety shall not be sacrificed for expediency
g. That unacceptable performance of health and safety conduct will not be tolerated

The policy should be:

a. Stated in clear, unambiguous, and unequivocal terms
b. Signed by the incumbent chief executive officer
c. Kept up-to-date
d. Communicated to each employee
e. Adhered to in all work activities

7.2.2 DESIGNING A TRAINING PROGRAM

The objective of training is to ease the implementation of health and safety policies into specific job practices and to raise awareness and skill levels of a technician to an acceptable standard.

Occasions when employee training should be required are:

a. Commencement of employment
b. Reassignment or transfer to a new job
c. Introduction of new equipment, processes, or procedures
d. Inadequate performance
e. Customer and job site related chemical or biological hazards, equipment, processes, or procedures

The NEBB Certified CPT Firm should have the following topics included in the safety training:

a. Safety and the Professional
b. Know your accident problems
c. Human relations
d. Maintaining interest in safety
e. Instructing for safety
f. Industrial hygiene
g. Personal protective equipment
h. Industrial housekeeping
i. Material handling and storage
j. Guarding machines and mechanisms
k. Hand and portable power tools
l. Fire protection

7.2.3 ESSENTIALS OF THE HEALTH AND SAFETY PROGRAM

While different NEBB Certified CPT Firms will have different needs and scope for specific elements required in their health and safety program, the following basic items may be considered in each case:

a. Individual responsibility
b. Occupational health and / or safety representative
c. Health and safety rules
d. Correct work procedures
e. Employee orientation
f. Training
g. Workplace inspections
h. Reporting and investigating accidents
i. Emergency procedures
j. Medical and first aid
k. Health and safety incentives
l. Workplace specific items

7.3 RESPONSIBILITIES

7.3.1 INDIVIDUAL HEALTH AND SAFETY RESPONSIBILITIES

Health and safety is the joint responsibility of management and workers. All health and safety activities are based on specific individual responsibilities. Responsibility may be defined as an

individual's obligation to carry out assigned duties. Authority implies the right to make decisions and the power to direct others.

7.3.2 NEBB CERTIFIED CPT PROFESSIONAL RESPONSIBILITIES

To fulfill their responsibilities, the NEBB Certified CPT Professional should:

a. Instruct workers to follow safe work practices
b. Enforce health and safety regulations
c. Correct unsafe acts and unsafe conditions
d. Ensure that only authorized, adequately trained workers operate equipment
e. Report and investigate all accidents / incidents
f. Inspect own area and taking remedial action to minimize or eliminate hazards
g. Ensure that equipment is properly maintained
h. Promote safety awareness in workers
i. Provide a safe and healthful workplace
j. Establish and maintain a health and safety program
k. Ensure that workers are trained or certified, as required
l. Report accidents and cases of occupational disease to the appropriate authority
m. Provide medical and first aid facilities
n. Ensure that personal protective equipment is available
o. Provide workers with health and safety information
p. Evaluate health and safety performance of Cleanroom technicians
q. Advise all employees on health and safety matters
r. Coordinate interdepartmental health and safety activities
s. Provide health and safety training
t. Conduct research on special problems
u. Attend health and safety committee meetings as a resource person

7.3.3 FIELD TECHNICIAN RESPONSIBILITIES

To fulfill their responsibilities, the field technicians should:

a. Use personal protection and safety equipment as required by the Employer
b. Follow safe work procedures
c. Know and comply with all regulations
d. Report any injury or illness immediately
e. Report unsafe acts and unsafe conditions
f. Participate in joint health and safety committees
g. Know what these responsibilities are (communication required)
h. Have sufficient authority to carry them out (organizational issue)
i. Have the required ability and competence (training or certification required)

7.4 ELEMENTS OF THE PROGRAM

The NEBB Certified CPT Professional should address the following elements of the NEBB Certified CPT Firm’s health and safety program:

a. Establish work procedures
b. Analyze project hazards
c. Establish guideline rules
d. Conduct employee safety orientation

e. Establish emergency procedures
f. Establish medical and first aid action plan
g. Perform routine project site safety audits
h. Complete project accident / injury reports
i. Investigate project accidents / injuries
j. Establish and enforce return-to-work policy
k. Promote employee involvement in health and safety programs

7.4.1 PROJECT SPECIFIC ITEMS

Examples of project specific items that should be included in health and safety programs are:

a. Material Safety Data Sheets (MSDS)
b. Lock out procedures
c. Chemical handling rules
d. Biological material handling rules
e. Personal hygiene
f. Vehicle safety rules
g. Working alone guidelines
h. Personal protective equipment requirements

7.4.2 HEALTH AND SAFETY PROGRAM IMPLEMENTATION

A good health and safety program provides a clear set of guidelines for activities that, if followed, will reduce accidents and cases of occupational disease. A NEBB Certified CPT Professional should demonstrate commitment and support the program by:

a. Providing resources such as time, money, and personnel
b. Ensuring that employees receive training or certification as required
c. Making all applicable health and safety information available to all employees entitled to receive it
d. Including health and safety performance as part of employee performances appraisals at all levels
e. Attending health and safety meetings
f. The program must be communicated to all employees, special emphasis should be given to new technicians and newly approved NEBB Certified CPT Professionals.
g. Revisions to policies and procedures should be publicized.
h. The program should be available in a single written document. (However, if separate manuals have been developed for various elements, such as accident investigation procedures, their use should be referenced in the main document).

SECTION 8 CLEANROOM PROTOCOL

8.1 INTRODUCTION

The purpose of this Section is to provide an overview of the cleanroom protocol procedures that should be observed in performing the various cleanroom tests. In general, there are protocols and procedures for cleanroom entry, garment control, tool and equipment entry and gowning procedures. In addition to entry protocols, there are also protocols and behavior requirements while in the cleanroom. The protocols suggested in this section are guidelines and the final procedures shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

The NEBB Certified CPT Firm shall be responsible for creating their own cleanroom protocol and develop it into a Standard Operating Procedure (SOP) for their firm. Most often the NEBB Certified CPT Firm will be required to follow the client project specific protocol. However in the absence of this project specific protocol, the firm's SOP for cleanroom protocol shall be followed. At a minimum, the NEBB Certified CPT Firm's SOP for Cleanroom Protocol should cover: gowning procedures, equipment entrance procedures, and guidelines for employee conduct.

8.2 CLEANROOM PROCEDURES

8.2.1 GOWNING PROCEDURES

The processes and operations that occur in a cleanroom are unique to that particular owner and facility. Therefore the gowning procedures may vary to some degree between each cleanroom and each owner. It is imperative that the Facility / Owner's SOP be reviewed for the specific gowning procedure. When it exists, **the Owner's SOP always takes precedence** and must be followed.

In many cleanroom gowning facilities there are two distinct zones in the gowning area. In some facilities, the two distinct zones may exist in the same room / space defined by some imaginary boundary. The initial area will have gloves, hair bonnets and shoe covers. Since the outside surface of the "cleanroom garments" should be kept as clean as possible, care should be used to avoid touching the outside of the garment with bare hands, hair and street shoes. This is accomplished by donning gloves, bouffant head covers and shoe covers before entering the second phase of the gowning area.

It is important to note that cleanrooms in the electronics industry may be quite different from cleanrooms in the pharmaceutical and bio-technology industries. While gowning remains important, a high emphasis is placed on sterility. Cleaning / washing procedures can be much more rigorous. In some instances, usually associated with bio-containment spaces (i.e. BSL3 and BSL4 labs), street clothes will not be allowed into the room and a complete change of clothing is required.

Upon entering the second area it is important to note that different gowning garments may be used in different facilities. Since gowning materials differ, there is no hard and fast method that can be outlined for actual gowning. Typically, gowning should be done from the head down. Therefore the hood is to be donned first followed by the garment and then the foot covers. Once the garment is obtained, care should be taken to avoid contaminating the exterior surface with the interior of the garment. Proper garment sizing is also required. Once obtained, the garment user should never allow the garment to touch or drag on the floor.

8.2.2 EQUIPMENT ENTRANCE PROCEDURES

Tools, instrumentation and equipment also require special preparation before they can be brought into a cleanroom. As with gowning, each facility will have their own methods and requirements for introducing these items into a cleanroom. It is imperative that the Facility / Owner's SOP be reviewed for material ingress to their cleanroom. When it exists, the Owner's SOP always takes precedence and must be followed.

Typically, there will be a wipe-down station for anything entering the cleanroom. There will also be a wipe-down procedure. Often the procedure will involve wiping down the instruments with non-contaminating wipes moistened with de-ionized water and isopropyl alcohol (IPA) or other sterile solvents. The ingress for equipment may be a separate entrance from the gowning entrance.

8.2.3 CLEANROOM CONDUCT

Examples of personnel rules used by cleanroom operators may be:

a. Clean hands and face before entering clean areas
b. Use lotions and soap containing lanolin to reduce skin flaking
c. Avoid skin contact with solvents
d. Wearing cosmetics and skin medications may not be permitted
e. Jewelry may not be permitted
f. Tobacco use, eating and drinking is not permitted
g. Required gowning, masks, gloves and shoe covers to be worn at all times
h. Equipment, instruments and materials should be cleaned before entry
i. Non-shedding paper and pens should be used. Pencils and erasers are not permitted
j. Work parts are to be handled only with gloved hands, tweezers, or other methods to avoid transfer of skin particles and oils
k. Use containers to transfer and/or store materials

SECTION 9 CLEANROOM TESTS

9.1 INTRODUCTION

This section provides an overview of all cleanroom tests. The procedures required to perform these tests are described in Sections 10 and 11. Certification tests and procedures may vary considerably from project to project. The choice of certification tests may be based on the cleanliness class level, type of cleanroom airflow, occupancy mode and the product produced. The scope of the cleanroom testing services may vary based on the contract document requirements, or based on the agreed scope of services between the Owner / Buyer and the NEBB Certified CPT Firm. Table 9-1, extrapolated from the current version of IEST-RP-CC006, lists recommended tests for initial cleanroom certification.

9.2 CLEANROOM AIRFLOWS

Table 9-1 lists cleanroom certification tests by the type of cleanroom design, *unidirectional airflow*, *non-unidirectional airflow* and *mixed airflow*.

9.2.1 UNIDIRECTIONAL AIRFLOW

In a *unidirectional airflow* system, air is uniformly introduced through HEPA filters from one entire surface of the room, such as the ceiling or a wall. For unidirectional airflow, the filter coverage must be at least 80% coverage. The air flows perpendicularly from this surface at a constant velocity and is removed at the opposite surface (wall or floor). Unidirectional flow provides a direct, predictable path that a sub-micrometer size particle will follow through the cleanroom, with the minimum opportunity for contaminating room components. It also captures the particles constantly generated within the room and introduced into the airstream, thereby reducing the potential for cross-contamination.

9.2.2 NON-UNIDIRECTIONAL AIRFLOW

In a *non-unidirectional airflow* system, air is supplied to the cleanroom conventionally through HEPA filters in a random airflow pattern and mixes with internal air by induction.

9.2.3 MIXED AIRFLOW

A *mixed airflow* system may be used in a cleanroom with two (or more) areas requiring different classifications. Non-unidirectional airflow and unidirectional airflow will sometimes exist in the same space and may be classified independently.

9.3 OCCUPANCY MODE

Cleanroom certification tests are performed after a new cleanroom is built and then periodically as determined by the cleanroom operator or owner. The three occupancy modes are: *As-Built, At-Rest* and *Operational*. These three occupancy modes affect some of the test procedures and are useful in specifying testing and acceptance criteria for cleanrooms.

For new cleanroom construction projects, testing is normally done in the As-Built occupancy mode. Testing of existing cleanrooms is usually performed with the facility in the At-Rest or Operational occupancy modes. The occupancy mode shall be as specified in the contract documents or as mutually agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

9.3.1 AS-BUILT FACILITY
An As-Built facility is a cleanroom which is complete and operating, with all services connected and functioning, but has no production equipment or operating personnel within the facility.

9.3.2 AT-REST FACILITY
An At-Rest facility is a cleanroom which is complete and has the production equipment installed and operating, but has no personnel within the facility.

9.3.3 OPERATIONAL FACILITY
An Operational facility is a cleanroom in normal operation, including production equipment installed and operating under normal conditions with all operating personnel present.

9.3.4 EXCEPTIONS
In many instances, there will be deviations from these definitions. (Examples: a partial installation of process equipment may have been installed and may or may not be operating; process equipment exhausts may or may not be operating.) These situations should be recognized and noted by the NEBB Certified CPT Firm on any affected test requirements.

9.4 REFERENCE DOCUMENTS

Cleanliness classifications are defined by *ISO Standard 14644, Parts 1, 2 and 3*. The NEBB Certified CPT Professional shall have a thorough knowledge of these ISO Standards.

In addition, procedures for performing for CPT tests are identified in the following *IEST publications: RP-CC006 and RP-CC034*

The NEBB Certified CPT Firm ***Shall*** possess current copies of the above referenced standards and publications in addition to the NEBB *Procedural Standards for Certified Testing of Cleanrooms*.

Other national and international standards also exist which the NEBB Certified CPT Professional may need to access. (See Appendix B)

9.5 PRIMARY TESTS

The primary tests are related to airborne particulate cleanliness classes as required by ISO 14644. In general, the primary tests should be performed in the order that will be most beneficial to the project being certified. By performing these tests, the cleanroom will be correctly classified to the appropriate class level. These tests include:

a. Airflow Velocity and Uniformity Tests
b. Airflow Volume and Uniformity Tests
c. HEPA Filter Installation Leak Tests
d. Airborne Particle Count Cleanliness Classification Tests
e. Room Pressurization Tests

9.6 SECONDARY TESTS

The secondary tests are user optional and relate to particle, air movement and ancillary systems within the cleanroom. These tests include:

a. Airflow Parallelism Tests
b. Recovery Tests
c. Lighting Level and Uniformity Tests
d. Sound Level Tests
e. Vibration Level Tests
f. Temperature and Humidity Uniformity Tests.
g. Electrostatic Tests
h. Conductivity Tests
i. Electromagnetic Interference (EMI) Test
j. Air Change Rate (ACH) Test
k. Bench Scan Filter Leak Tests

9.7 TESTING INTERVALS

Table 9-1 contains *Recommended Tests by Cleanroom Type.* Table 9-2 contains *Recommended Testing Intervals* for each of the various primary and secondary cleanroom performance tests.

TABLE 9-1 Recommended Tests by Cleanroom Type*

NEBB Procedural Standards Section Test	Unidirectional Airflow	Non-Unidirectional Airflow	Mixed	Airflow	IEST Section
10	Airflow volume & uniformity	1,2,3	1,2,3	1,2,3	6.1
10	Airflow velocity & uniformity	1,2,3	1,2,3	1,2,3	6.1
10	Filter leak	1,2	1,2	1,2	6.2
10	Particle count	1,2,3	1,2,3	1,2,3	6.3
10	Pressurization	1,2,3	1,2,3	1,2,3	6.4
11	Parallelism	1,2	Not Applicable	1,2,3	6.5
11	Recovery	1,2	1,2	1,2	6.7
11	Lighting level	1,2,3	1,2,3	1,2,3	6.9
11	Sound level	1,2,3	1,2,3	1,2,3	6.10
11	Temperature and Humidity uniformity	1,2,3	1,2,3	1,2,3	6.11 – 6.13
11	Vibration level	1,2,3	1,2,3	1,2,3	6.14
11	Electrostatic	1,2,3	1,2,3	1,2,3	4
11	Conductivity	1,2,3	1,2,3	1,2,3	4
11	Electromagnetic Interference (EMI)	1,2,3	1,2,3	1,2,3	4
11	Air Change Rate	1,2,3	1,2,3	1,2,3	4
11	Bench Scan	1	1	1	4

The order in which tests are performed is optional, but some sequences are optimal.

1: Test is suited to As-Built occupancy mode
2: Test is suited to At-Rest occupancy mode
3: Test is suited to Operational occupancy mode
4: These tests are not defined in IEST-RP-CC006

*Most material extrapolated from IEST-RP-CC006

TABLE 9-2 Recommended Testing Intervals

NEBB Procedural Standards Section	ISO Reference	Test	NEBB Recommended Test Interval (Months)	IEST Section
10	ISO 14644-3: B.4	Airflow volume & uniformity Airflow velocity & uniformity	12	6.1
10	ISO 14644-3: B.6	Filter leak	12	6.2
10	Annex B, ISO 14644-1	Particle count ≤ ISO Class 5	6	6.3
10	Annex B, ISO 14644-1	Particle count > ISO Class 5	12	6.3
10	ISO 14644-3: B.5	Pressurization	12	6.4
11	ISO 14644-3: B.7	Parallelism	12	6.5
11	ISO 14644-3: B.13	Recovery	24	6.7
11	N/A	Lighting level	24	6.9
11	N/A	Sound level	24	6.10
11	ISO 14644-3: B.9 ISO 14644-3:10	Temperature and Humidity Uniformity	12	6.11 – 6.13
11	N/A	Vibration level	24	6.14
11	ISO 14644-3: B.11	Electrostatic	24	N/A
11	N/A	Conductivity	24	N/A
11	N/A	Electromagnetic Interference (EMI)	24	N/A
11	N/A	Air Change Rate	12	N/A
11	N/A	Bench Scan	N/A	N/A

N/A: Not Applicable

SECTION 10 PRIMARY TESTS

10.1 INTRODUCTION

The primary tests measure attributes that contribute to success of particle control. A thorough operation performance evaluation employing these tests will assist in identifying the current cleanliness classification. In general, the primary tests should be performed in the order that will be most beneficial to the project being certified.

The primary tests include:

a. Airflow Velocity and Uniformity Tests
b. Airflow Volume and Uniformity Tests
c. Filter Installation Leak Tests
d. Airborne Particle Count Cleanliness Classification Tests
e. Room Pressurization Tests

Whenever the term "filter" is used in this section, it is to be implied that the meaning pertains to both HEPA and ULPA filters.

10.2 CLEANROOM / FILTER AIRFLOW VELOCITY AND UNIFORMITY TESTS

These tests are performed to determine the average filter face velocity and uniformity, and / or the average room airflow velocity and uniformity within a cleanroom.

Airflow velocity in meters per second (m/s) or feet per minute (fpm) is a measurement of the speed of the airflow. An average velocity is calculated by dividing the cleanroom / filter area into equal grids and taking the airflow velocity in the center of each of these grids. The average airflow velocity is calculated by dividing the total of the airflow grid velocities by the number of readings taken.

The location of the airflow reading in the work zone shall either be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. For filter face airflow velocity, the tests normally are performed at a specified distance from the filter face: 75 mm, 150 mm, or 300 mm (3", 6", or 12"). For room airflow velocity, the tests are normally performed at the specified work surface elevation. Typically this is 0.91 m (36") above the floor. In order to eliminate confusion of the testing procedures, the tests shall be titled: *Filter Face Airflow Velocity Tests or Room Airflow Velocity Tests.* Although the actual test procedures are basically the same for each test, it is necessary to differentiate between each procedure.

10.3 AIRFLOW VELOCITY AND UNIFORMITY TEST – FILTER FACE AIRFLOW VELOCITY – UNIDIRECTIONAL

The purpose of the filter face airflow velocity test is to document the average airflow velocity and uniformity of the filter face in unidirectional airflow.

10.3.1 INSTRUMENTATION AND EQUIPMENT

An airflow velocity instrument that conforms to the requirements of Table 4-1.

10.3.2 TEST PROCEDURES

10.3.2.1 Measurement readings shall be taken at a distance from the face of the filter system, as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.3.2.2 The measurement area shall be a cross-sectional area of the filter face normal to the airflow. This area shall consist of the net effective filter media area, which is exclusive of the filter frame. For example, a 610 mm x 1220 mm (24 inch x 48 inch) filter does not have a net effective area of 0.74 square meters (8.0 square feet), but is closer to approximately 0.66 square meters (7.1 square feet) with the frame, media glue joints, etc., deducted.

10.3.2.3 When using a single point measurement instrument, such as a hot wire anemometer, divide the net filter face into grids of equal area of not greater than 0.09 square meters (1.0 square foot). When using a multi-point instrument, such as tube array, divide the net filter face into grids of equal area of not greater than 0.37 square meters (4.0 square feet). The grid area shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.3.2.4 Measure and record the airflow velocity at each grid point 150 mm (6 in.) from the filter face or as specified in the contract documents or as agreed to between the Owner and the NEBB Certified CPT Firm. Special care is necessary to keep the sampled area unobstructed during the airflow measurement. The use of a support stand is recommended with single point type measuring instruments. The use of stand off legs of the appropriate length is recommended for a tube array.

10.3.2.5 Take the measurement for a minimum of 5 seconds or the instrument manufacturer's minimum specified time, using the average during that period as the measurement.

10.3.2.6 Calculate the Relative Standard Deviation (RSD). See Appendix C, Section C.6.4.

10.3.3 ACCEPTANCE

10.3.4.1 The average airflow velocity for the filter should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.3.4.2 The Relative Standard Deviation should not exceed 15% unless otherwise specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.3.4 REPORTING

See Section 5.3 for reporting requirements.

10.4 AIRFLOW VELOCITY AND UNIFORMITY TEST – FILTER FACE AIRFLOW VELOCITY – NON-UNIDIRECTIONAL (Volume Method)

For non-unidirectional airflow cleanrooms, the airflow volume measurements are preferable and are more accurate for calculating airflow velocities when readings are taken at a distance greater than 150 mm (6 in.) from the filter face. If filter face airflow velocity measurement readings are performed utilizing a direct reading flowhood, use the testing requirements identified for flowhood volume testing in Section 10.8 and as identified below.

When airflow volumes are being determined using the measured airflow velocities, it is necessary to develop a "correction factor" that accounts for the instrument and filter measurement discrepancies that may exist. See Appendix C, Section C.11.

10.4.1 INSTRUMENTION AND EQUIPMENT
A direct reading flowhood that conforms to the requirements of Table 4-1 in Section 4.

10.4.2 TEST PROCEDURES
10.4.2.1 Flow measuring hoods are preferred for taking airflow volume measurements from each filter. A flowhood with an appropriate flow meter is required.

10.4.2.2 Seat the flow measuring hood firmly to the filter frame to prevent air leakage.

10.4.2.3 The flowhood shall be adequately sized to capture all the air exiting the filter being tested.

10.4.2.4 Measure and record the airflow volumes of each filter in liters per second (L/s) or cubic feet per minute (cfm).

10.4.3 ACCEPTANCE
10.4.3.1 Measure the total airflow for each filter. Determine the average filter face airflow velocity by dividing the measured airflow by the net effective filter area.

10.4.3.2 The average airflow velocity of each filter for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.4.4 REPORTING
See Section 5.4 for reporting requirements.

10.5 AIRFLOW VELOCITY AND UNIFORMITY TEST – FILTER FACE AIRFLOW VELOCITY – NON-UNIDIRECTIONAL (Velocity Method)

The purpose of the filter face airflow velocity test is to document the average airflow velocity and uniformity of the filter face non-unidirectional airflow.

NEBB advises that a volumetric method be used to calculate the filter face velocity in a non-unidirectional cleanroom, however when project specifications require a direct velocity measurement, the following procedure should be used.

10.5.1 INSTRUMENTATION AND EQUIPMENT
An airflow velocity instrument that conforms to the requirements of Table 4-1 in Section 4.

10.5.2 TEST PROCEDURES
10.5.2.1 Measurement readings shall be taken at a distance from the face of the filter system, as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.5.2.2 The measurement area shall be a cross-sectional area of the filter face normal to the airflow. This area shall consist of the net effective filter media area, which is exclusive of the filter frame. For example, a 600 mm x 1200 mm (24 inch x 48 inch) filter does not have a net effective area of 0.74 square meters (8.0 square feet), but is closer to approximately 0.66 square meters (7.1 square feet) with the frame, media glue joints, etc., deducted.

10.5.2.3 When using a single point measurement instrument, such as a hot wire anemometer, divide the net filter face into grids of equal area of not greater than 0.09 square meters (1.0 square foot). When using a multi-point instrument, such as tube array, divide the net filter face into grids of equal area of not greater than 0.37 square meters (4.0 square feet). The grid area shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.5.2.4 Measure and record the airflow velocity at each grid point 150 mm (6 in.) from the filter face or as specified in the contract documents or as agreed to between the Owner and the NEBB Certified CPT Firm. Special care is necessary to keep the sampled area unobstructed during the airflow measurement. The use of a support stand is recommended with single point (hot wire) type measuring instruments. The use of a support stand is recommended with single point type measuring instruments. The use of stand off legs of the appropriate length is recommended for a tube array.

10.5.2.5 Take the measurement for a minimum of 5 seconds or the instrument manufacturer's minimum specified time, using the average during that period as the measurement.

10.5.2.6 Calculate the Relative Standard Deviation (RSD). See Appendix C, Section C.6.4.

10.5.3 ACCEPTANCE

10.5.3.1 The average airflow velocity for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.5.3.2 The relative standard deviation should not exceed 15% unless otherwise specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.5.4 REPORTING

See Section 5.5 for reporting requirements.

10.6 AIRFLOW VELOCITY AND UNIFORMITY TEST – AVERAGE ROOM AIRFLOW VELOCITY

The purpose of this test is to determine the average room airflow velocity and uniformity of that airflow velocity at the specified work surface elevation.

10.6.1 INSTRUMENTS AND EQUIPMENT

An airflow velocity instrument that conforms to the requirements of Table 4-1.

10.6.2 TEST PROCEDURES

10.6.2.1 Measurement readings shall be taken at specified planes and locations in the room as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.6.2.2 The measurement area shall be a cross-sectional area of the room or work area normal to the airflow. This area shall consist of the total work zone or room.

10.6.2.3 Divide the area plane at the measurement point into grids of equal area of not greater than 1.49 square meters (16 square feet), or as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.6.2.4 Measure and record the airflow velocity of each grid point. Special care is necessary to keep the sampled area unobstructed during the airflow measurement. The use of a support stand may be necessary with single point measuring (hot wire) instruments.

10.6.2.4 Take the measurement for a minimum of 5 seconds or the minimum specified time for the meter, using the average during that period as the measurement.

10.6.2.5 Calculate the Relative Standard Deviation (RSD). See Appendix C, Section C.6.4.

10.6.3 ACCEPTANCE
10.6.3.1 The average airflow velocity for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.6.3.2 The average or total airflow volume for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.6.3.3 The relative standard deviation should not exceed 15% unless otherwise specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.6.4 REPORTING
See Section 5.6 for reporting requirements.

10.7 AIRFLOW VOLUME AND UNIFORMITY TEST

The airflow volume in liters per second (L/s) or cubic feet per minute (cfm) is a measurement of the airflow quantity. Airflow volumes may be measured by one of three methods; 1) using a direct reading flowhood, 2) performing a total air traverse of each, or 3) measuring the airflow velocity of each filter and then calculating the air volume of the filter. For accuracy and repeatability, the preferred method of measuring airflow volume is with a direct reading flowhood. The traverse method is the most accurate for normal HVAC TAB work, but this is not necessarily true for cleanrooms due to the duct inlet conditions. Great care must be taken if the air volume is obtained by using the filter airflow velocity because of the exit planes inaccuracies.

For non-unidirectional airflow cleanrooms, the airflow volume measurements are preferable and are more accurate for calculating airflow velocities when the readings are taken at a distance greater than 150 mm (6 in.) from the filter face. As previously stated above, determining volume from filter face velocities should only be done with a great deal of care due to the inaccuracies in calculating the exit plane area. NEBB does NOT recommend determining airflow volumes by using airflow velocities in non-unidirectional cleanrooms. There may be times when it is necessary to determine the filter airflow volume using the filter airflow velocity method (when an obstruction prevents using a flowhood). The procedures as identified in Section 10.3 and the appropriate “correction factor” should be followed to determine the airflow volume. See Appendix C, Section C.11.

10.8 AIRFLOW VOLUME AND UNIFORMITY TEST – FLOWHOOD METHOD

10.8.1 INSTRUMENTION AND EQUIPMENT
A direct reading flowhood that conforms to the requirements of Table 4-1.

10.8.2 TEST PROCEDURES

10.8.2.1 Flow measuring hoods are preferred for taking airflow volume measurements from each filter or supply air diffuser. The flowhood with an appropriate flow meter is required.

10.8.2.2 Seat the flow measuring hood firmly to the filter frame to prevent air leakage.

10.8.2.3 The flowhood shall be adequately sized to capture all the air exiting the filter being tested.

10.8.2.4 Measure and record the airflow volumes of each filter in liters per second (L/s) or cubic feet per minute (cfm).

10.8.2.5 Calculate the Relative Standard Deviation (RSD). See Appendix C for the requirements necessary to calculate the (RSD).

10.8.3 ACCEPTANCE

10.8.3.1 The average airflow volume of each filter for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.8.3.2 The average or total airflow volume for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.8.3.3 The relative standard deviation should not exceed 15% unless otherwise specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.8.4 REPORTING

See Section 5.7 for reporting requirements.

10.9 AIRFLOW VOLUME AND UNIFORMITY TEST – TRAVERSE METHOD

When the airflow volume cannot be measured using a flow hood then a total air traverse should be employed. A suitable length of straight, hard duct is required for an accurate airflow velocity measurement.

10.9.1 INSTRUMENTION AND EQUIPMENT

An airflow velocity instruments that conform to the requirements of Table 4-1.

10.9.2 TEST PROCEDURES

Divide the traverse plane into grids of equal area. Record airflow velocity measurements in accordance with the sample traverse layout. See Appendix C, Section C.5.1.

10.9.3 ACCEPTANCE

10.9.3.1 The average airflow volume of each filter for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.9.3.2 The average or total airflow volume for the cleanroom should be within ±10% of that specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.9.4 REPORTING
See Section 5.8 for reporting requirements.

10.10 FILTER INSTALLATION LEAK TESTS

The purpose of the filter installation integrity test is to ensure and confirm that the filter system is properly installed by verifying the absence of bypass leakage in the installation, and that the filters are free of defects and pinhole leaks.

The test is made by introducing an aerosol challenge upstream of the filters and scanning immediately downstream of the filters and support frame. This procedure detects small pinholes or other damage in the filter medium and frame seal, bypass leaks in the filter frame and gasket seal, and leaks in the filter bank framework. For plenum ceilings, it may be necessary to also scan ceiling penetrations (i.e. sprinkler heads, conduits, pipes, etc.) and ceiling joints.

Two different leak detection techniques are presented, along with recommendations for two different aerosol challenge methods and two different detection instruments; 1) aerosol photometer test method and 2) particle counter test method.

Another test method that is still sometimes referenced is identified as the Filter Installation Leak Tests – Ambient Challenge Test Method. This test is NOT recommended by NEBB. The reason that this test is not recommended by NEBB is due to the low upstream particle concentrations normally found in re-circulated air from cleanrooms. Typical users of this test are unable to locate significant leaks. Scan rates are also quite excessive. See Appendix C, Section C.7.

10.10.1 LEAK TEST METHODS
For the above reasons, three methods of aerosol particle challenge tests are specified and used by NEBB Certified CPT Firms:

a. Filter Installation Leak Tests – Aerosol Photometer Test Method (Section 10.11)
b. Filter Installation Leak Tests – Discrete Particle Counter Test Method (Section 10.12)
c. Filter Installation Leak Tests – Total Aerosol Penetration Test Method (Section 10.13)

10.11 FILTER INSTALLATION LEAK TESTS – AEROSOL PHOTOMETER TEST METHOD

The photometer test method employs either logarithmic or linear mass concentration detection and does not provide discrete quantitative analysis. This test is performed by introducing DOP, PAO or another specified substitute aerosol upstream of filters and verifying the installations integrity by scanning the downstream side of the filters with the photometer and appropriate probe.

10.11.1 INSTRUMENTATION AND EQUIPMENT
10.11.1.1 A thermal or laskin nozzle generator that conforms to Table 4-1

10.11.1.2 Photometers that conform to the requirements of Table 4-1.

10.11.1.3 Scanning probe that conforms to the requirements of Table 4-1.

10.11.2 TEST PROCEDURES

10.11.2.1 Verify that the design airflow velocity has been balanced by a NEBB Certified TAB Firm prior to performing the filter installation leak test.

10.11.2.2 Introduce the aerosol into the air supplied to the filters in a manner which will produce a uniform challenge concentration at each of the filters being exposed at the same time. Where several, or all, filters must be exposed simultaneously to the aerosol, it is recommended that the aerosol be introduced at the blower inlet(s) or another location which will produce a uniform mixture over all of the filters.

10.11.2.3 Measure the upstream concentration immediately upstream of the filter being tested. Care must be exercised to assure that a uniform distribution of the challenge aerosol exists.

10.11.2.4 When using a Laskin nozzle aerosol generator set the air supply pressure at a minimum of 138 kPa (20 psi). Determine the amount of airflow volume being challenged. Using Equation 10-1, calculate the quantity of Laskin nozzles required to achieve an upstream concentration level of 10 µg/L or greater, or as specified or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. Place the generator distribution tube in the location as determined in Section 10.11.2.2.

Equation 10-1 (SI): Required Number of Laskin Nozzles

$$N = \frac{C \times Q}{Z}$$

Where:

N = Number of Laskin nozzles required
C = Required upstream challenge concentration (greater than 10 µg/L)
Q = Airflow volume being challenged (L/min)
Z = Constant = 3823 x 100 = 382,300 L/min

Equation 10-1 (IP): Required Number of Laskin Nozzles

$$N = \frac{C \times Q}{Z}$$

Where:

N = Number of Laskin nozzles required
C = Required upstream challenge concentration (greater than 10 µg/L)
Q = Airflow volume being challenged (cfm)
Z = Constant = 135 x 100 = 13,500 cfm

The constant Z is based on one Laskin nozzle producing 100 µg/L of challenge aerosol in 3820 L/min (135 cfm) of airflow.

Note: When using more than one Laskin nozzle, the resulting aerosol generation may not be linear. Caution should be exercised when determining the upstream challenge when using multiple Laskin nozzles. It may be necessary to verify the actual concentration in mg/L with multiple Laskin nozzles based on each aerosol generator. It is the NEBB Certified CPT Firm's responsibility to verify output of their aerosol generator.

10.11.2.5 When using a thermal generator operate per the manufacturer's recommended operating instructions.

10.11.2.6 Measure the upstream aerosol challenge concentration, using either a linear or logarithmic photometer scale.

10.11.2.7 Set the photometer to full scale (100%) and measure the upstream concentration. The concentration should be established using one or more Laskin nozzles adjusted to produce an upstream concentration of 10 to 20 micrograms per liter of aerosol.

10.11.2.8 Once the correct aerosol concentration is established, adjust the photometers gain such that the concentration established represents 100% upstream concentration.

10.11.2.9 Increase the sensitivity of the photometer to a scale where 0.010% of the upstream concentration can be easily read.

10.11.2.10 The filter face and the perimeter of the filter assembly shall be scanned by passing the probe in slightly overlapping strokes so that the entire area of the filter is sampled. The probe shall be held approximately 25 mm (1 inch) from the area to be tested during scanning. Separate passes shall be made around the entire periphery of the filter, along the bond between the filter pack and the frame, and around the seal between the filter and the device, at a scan rate of not more than 0.05 m/s or 5.0 cm/s (10 fpm or 2 inches per second). This assumes an airflow filter face velocity of 0.46 to 0.56 m/s (90 to 110 fpm). If airflow filter face velocities are significantly different, the scan rate shall be calculated using the information found in the current edition of IEST-RP-CC034, HEPA and ULPA Filter Leak Tests.

10.11.3 ACCEPTANCE

10.11.3.1 An unacceptable leak is defined as a sustained reading greater than 0.010% of the measured upstream challenge concentration, or as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.11.4 REPORTING

See Section 5.9 for the reporting requirements.

10.11.5 REPAIRS

10.11.5.1 Filters may be repaired providing:

The size of the repair(s) is not greater than 3% of each filter face area. Additionally, a repair area shall have a minimum dimension which shall not exceed 38 mm (1.5 inches) or as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.11.5.2 Repairs to filter installation leaks may be made by procedures specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.12 FILTER INSTALLATION LEAK TESTS – DISCRETE PARTICLE COUNTER TEST METHOD

The particle counter test method employs discrete particle sizing and quantitative analysis. This test is performed by introducing an artificial aerosol challenge upstream of the filters and verifying the installations integrity by scanning the downstream side of the filters with the particle counter.

The challenge aerosol particle concentration must be greater than 3.53×10^7 (35,300,000) particles per cubic meter, (3×10^6 [3,000,000] particles per cubic foot of air) based on using a probe that is 0.4 inches in the direction of scan and at a scan rate of 2 inches per second. This concentration will allow a

reasonable scan rate that can be manually performed. Particle concentrations of 2.12 x 10^8 (212,000,000) particles per cubic meter, (6 x 10^6 [6,000,000] particles per cubic foot of air) are desirable and will increase the accuracy with which leaks are detected.

NEBB recommends that this test be limited to cleanrooms where the cleanliness classification is ISO Class 6 or cleaner.

10.12.1 INSTRUMENTATION AND EQUIPMENT

10.12.1.1 A particle counter that conforms to the requirements of Table 4-1.

10.12.1.2 A hand held isokinetic sampling probe configured to provide adequate residence time while scanning. Probe shall conform to the requirements of Table 4-1.

10.12.1.3 An aerosol particle generator as described in Table 4-1.

10.12.1.4 A diluter or a reduced flow rate particle counter that conforms to the requirements of Table 4-1.

10.12.2 TEST PROCEDURES

10.12.2.1 Verify that the design airflow velocity has been balanced by a NEBB Certified TAB Firm prior to performing the filter installation leak test.

10.12.2.2 Introduce the aerosol into the air supplied to the filters in a manner which will produce a uniform challenge concentration at each of the filters being exposed at the same time.

10.12.2.3 Measure the upstream particle concentration as the challenge is introduced. Verify that the upstream particle challenge shall be greater than 3.53 x 10^7 (35,300,000) particles per cubic meter, (1 x 10^6 [1,000,000] particles per cubic foot of air). While this concentration will allow a reasonable scan rate, a higher concentration will improve the accuracy and may allow for increased scan rate.

10.12.2.4 The resulting upstream challenge concentration, along with other information specified below is used in Equation 10-2 to calculate the *Acceptable Scan Rate* when utilizing a Discrete Particle Counter Test.

10.12.2.5 Using the resulting scan rate (S_r), scan the filter face and the perimeter of the filter assembly by passing the probe in slightly overlapping strokes so that the entire area of the filter and installation is tested. The probe should be held approximately 25 mm (1 inch) from the area to be tested during scanning. Separate passes should be made around the entire periphery of the filter, along the bond between the filter pack and the frame, and around the seal between the filter and the device.

Equation 10-2

$$S_r = \frac{C_c \times L_s \times F_s \times D_p}{60 \times N_p}$$

Where:

S_r	=	Acceptable Scan Rate—cm/s (in/s)
C_c	=	Upstream challenge concentration—particles/L (particles/ft^3)
L_s	=	Significant leak—percentage of upstream concentration (typically 0.01%)
F_s	=	Sample flow rate of instrument used—L/min (cfm)
D_p	=	Probe dimension parallel to scan direction—cm (inches)
N_p	=	Number of particle counts that indicate the leak (1 through 10)
60	=	Conversion—60 sec/min

NOTE: If a lower value of N_p is used (1), the allowable scan rate will be increased but the probability of finding a leak will be decreased and the probability of false leaks is increased. If a larger N_p is used (3 or greater) the allowable scan rate is decreased but the probability of detecting a leak is increased.

10.12.2.6 When scanning a filter and the supporting assembly installation a particle count detection exceeding N_p will indicate a potential leak. If particles are registered that exceeds N_p, then the particle concentration penetrating the defect shall be determined if a significant leak exists.

10.12.3 ACCEPTANCE

An unacceptable leak is defined as a sustained reading greater than 0.010% of the measured upstream concentration for the particle size of interest, or as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.12.4 REPORTING

See Section 5.10 for the reporting requirements.

10.12.5 REPAIRS

10.12.5.1 Filters may be repaired providing:

10.12.5.2 The size of the repair(s) is not greater than 3% of each filter face area. Additionally, a repair area shall have a minimum dimension which shall not exceed 38 mm (1.5 inches) or as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.12.5.3 Repairs to filter installation leaks may be made by procedures specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.13 FILTER INSTALLATION LEAK TESTS – TOTAL AEROSOL PENETRATION TEST METHOD

The purpose of the total aerosol penetration test method is to verify filter and installation integrity when downstream access to the filter and installation is not accessible. This method is different than the test methods identified in Section 10.11 and 10.12 and therefore a significant leak may be in the range of 0.005% up to 0.030% versus a value of 0.010% when using a photometer or a particle counter methods described above.

This test is performed by introducing challenge aerosol upstream of filters installed in ducts remote to the cleanroom. The filtered air entering the room from the duct is then measured and compared to the upstream concentration to determine the overall penetration of the filter installation.

10.13.1 INSTRUMENTATION AND EQUIPMENT

10.13.1.1 An aerosol particle generator as described in Table 4-1.

10.13.1.2 Photometers shall conform to the requirements of Table 4-1.

10.13.2 TEST PROCEDURES

10.13.2.1 Verify that the design airflow velocity has been balanced by a NEBB Certified TAB Firm prior to performing the filter installation leak test.

10.13.2.2 Introduce a minimum of 10 µg/L of the aerosol challenge upstream of the filters in a manner that will produce a uniform challenge to the filter bank. Using a photometer on its 100% scale, probe the duct and measure the aerosol concentration in the duct directly upstream of the filter(s). Multiple points should be read across a plane closest to the filter in order to determine whether or not a uniform concentration is achieved. A minimum of five evenly spaced readings should be taken and all individual readings should fall within ±5% of the average in order to continue. If any individual reading deviates greater than ±5% of the average, then another location must be found for the introduction of aerosol such that it will meet the uniformity requirements.

10.13.2.3 Locate a place in the ductwork at least ten duct diameters from the filter(s) under test. Using a photometer set to a scale which will measure 0.030% concentration, probe the duct and measure the aerosol concentration penetration. Multiple points should be read across a plane in order to determine whether or not a uniform concentration is achieved. A minimum of five evenly spaced readings should be taken and all individual readings should fall within ±5% of the average in order to continue. If any individual reading is deviates greater than ±5% of the average, then another location must be found for the downstream reading of aerosol penetration such that it will meet the uniformity requirements.

10.13.3 ACCEPTANCE

10.13.3.1 The downstream measured aerosol concentration should not exceed 0.030% of the upstream concentration or as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.13.4 REPORTING

See Section 5.11 for the report requirements.

10.13.5 REPAIRS

10.13.5.1 Repairs are not normally made to filters evaluated by the methodology due to inaccessibility. Most common repair / solution is to replace the filter(s).

10.14 AIRBORNE PARTICLE COUNT CLEANLINESS CLASSIFICATION TEST – ISO STANDARD 14644

The airborne particle count cleanliness classification test is performed to determine the actual particle count level within the facility at the time of the test (As-Built, At-Rest, or Operational). Particle size(s) of interest, the room occupancy mode and the room classification shall be known prior to the beginning of the tests and shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.14.1 INSTRUMENTATION AND EQUIPMENT

A particle counter that meets the requirements of Table 4-1.

10.14.2 TEST PROCEDURES

10.14.2.1 Verification

Verify that all aspects of the cleanroom system which contribute to its operational integrity (air handling, filtration systems, walls, ceilings, floors, etc.) are complete and functioning. The following primary tests shall be completed prior to performing the cleanliness classification tests:

a. Room pressurization tests
b. Airflow tests
c. Filter leak tests

10.14.2.2 Sample Locations
The minimum number of sample locations is one. If only one sample location is employed then a minimum of three single sample volumes shall be taken at that single location. Sampling at more locations than the required minimum will result in greater precision. The minimum number of locations shall be calculated by taking the square root of the room area in square meters round up to the next whole number. This is shown in Equation 10-3.

Equation 10-3

$$SL = \sqrt{\mathrm{RA}}$$

Where: SL = Minimum Number of Sample Locations
RA = Room Area in m²

10.14.2.3 Sample Location Grid
Establish a test point grid pattern at the work surface elevation uniformly distributed throughout the cleanroom, except as limited by equipment.

10.14.2.4 Number of Samples
The minimum number of samples shall be 3. The minimum number of samples at any location is one. More than one sample may be taken at each location.

10.14.2.5 Sample Volume per Location
The single sample volume per location for an ISO classified room shall be per Equation 10-4.

Equation 10-4

$$V_s = \frac{20}{C_{n,m}} \times 1000$$

Where:
V_s = Sample Volume (L)
$C_{n,m}$ = Class Limit (Number of Particles/m³) for the largest considered particle size specified for the relevant class.

Note: The minimum sample volume shall be 2 liters with a minimum sample time of 1 minute.

10.14.2.6 Particle Size
The size of particles to be measured for room class certification shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. Particle counts limits for an ISO classified room shall be per Table 10-1 *Airborne Particulate Cleanliness Classes* ISO 14644.

TABLE 10-1: Airborne Particulate Cleanliness Classes In Accordance With ISO Standard 14644

Class limits are given for each class name. The limits designate specific concentrations (particles per unit volume) of airborne particles with sizes equal to and larger than the particle sizes shown.

Cleanliness Class Number	Class Limits*					
	Particle Size per m^3					
	0.1 µm	0.2 µm	0.3 µm	0.5 µm	1.0 µm	5.0 µm
1	10	2	N/A	N/A	N/A	N/A
2	100	24	10	4	N/A	N/A
3	1,000	237	102	35	8	N/A
4	10,000	2,370	1,020	352	83	NA
5	100,000	23,700	10,200	3,520	832	29
6	1,000,000	237,000	102,000	35,200	8,320	293
7	N/A	N/A	N/A	352,000	83,200	2,930
8	N/A	N/A	N/A	3,520,000	832,000	29,300
9	N/A	N/A	N/A	35,000,000	8,320,000	293,000

N/A = Not Applicable

*Concentration limits for other Cleanliness Classes can be calculated from Equation 10-6.

Equation 10-6

$$\text{Particles/m}^3 = 10^{Cm} (0.1\ \mu m / C_n)^{2.08}$$

Where:
C_n = Particle size in microns
C_m = Cleanliness Classification

10.14.3 ACCEPTANCE

The cleanroom or controlled environment shall have met the acceptance criteria for an airborne particulate cleanliness class (see Table 10-1) when the averages of the particle concentrations measured at each of the locations fall at or below the class limit. Additionally, if the total number of locations sampled is greater than one and less than ten, the mean of these averages must fall at or below the class limit with a 95% UCL. See Appendix C, Section C.5.1.

If the results are non-compliant based on the 95% UCL calculation due to a single “outlier” value, it does not need to be included in a recalculation of the 95% UCL analysis provided that the outlier is due to procedural error or equipment malfunction. Additionally, the calculation is repeated with all remaining sample locations and at least three samples remain in the calculation. Additionally, the cause of the outlier is documented. Deletion of the outlier in the 95% UCL calculation shall be as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Clean work zones within the cleanroom may also be allowed. These clean work zones shall be classified based on the maximum allowable particle count within that clean work zone.

10.14.4 REPORTING
See Section 5.12 for reporting requirements.

10.15 AIRBORNE PARTICLE COUNTING TESTS – SEQUENTIAL SAMPLING

Sequential Sampling Plan For ISO 14644-1
As an alternative method for verifying the compliance of air to the limits of airborne particulate cleanliness ISO Class 4 and cleaner, the sequential sampling plan described in Appendix F of ISO 14644-1 may be used. The advantage of sequential sampling is the potential to reduce significantly the sample volume at each location and, consequently, to reduce sampling times.

10.16 ROOM PRESSURIZATION TESTS

The current ISO 14644 Standards do not address cleanroom pressurization, although a pressure differential of 6 to 25 Pa (0.02 to 0.10 in.w.g.) is generally used, with 12.5 Pa (0.05 in.w.g.) being common increments between rooms, unless otherwise specified.

10.16.1 INSTRUMENTATION AND EQUIPMENT
An airflow pressure instrument that conforms to the requirements of Table 4-1.

10.16.2 TEST PROCEDURES
10.16.2.1 Measure and record the pressure differentials in Pa (in.w.g.) between the inner most cleanroom and adjacent spaces, rooms, or the exterior environment.

10.16.2.2 Measure and record the pressure differential in Pa (in.w.g.) between the next adjacent spaces and other spaces or the exterior environment until all pressure differentials have been obtained and recorded.

10.16.3 ACCEPTANCE
Pressurization levels shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

10.16.4 REPORTING
See Section 5.14 for the reporting requirements.

SECTION 11 SECONDARY TESTS

11.1 INTRODUCTION

The secondary tests are user optional and relate to particle and air movement and other ancillary cleanroom systems:

a. Airflow Parallelism Tests
b. Recovery Tests
c. Lighting Level and Uniformity Tests
d. Sound Level Tests
e. Vibration Level Tests
f. Temperature and Humidity Uniformity Tests
g. Electrostatic Tests
h. Conductivity Tests
i. Electromagnetic Interference (EMI) Test
j. Air Change Rate (ACH) Test
k. Bench Scan Filter Leak Tests

11.2 AIRFLOW PARALLELISM TESTS

The purpose of the airflow parallelism test is to show the actual airflow pattern throughout the uni-directional cleanroom. It can also be used to demonstrate the effects on airflow caused by equipment. This test should be performed after all airflow velocity and uniformity tests and room pressurization tests have been performed. Determining the airflow patterns within a room is performed using various mediums which include the following non contaminating items; vapor source or streamers of thread or string.

11.2.1 INSTRUMENTATION AND EQUIPMENT

1 1.2.1.1 Test Medium (non-contaminating items; carbon dioxide, glycol or other visible vapor source or streamers of thread or string).

11.2.1.2 Support stand which will least affect the airflow in the test location aerodynamically, and will allow the positioning of the test medium at the specified location and height.

11.2.1.3 Plumb bob or spirit level

11.2.1.4 Measuring tape

11.2.1.5 Pointer and stand

11.2.2 TEST PROCEDURES

11.2.2.1 Divide the cleanroom into grids of equal area having dimensions of 3 m x 3 m (10 feet x 10 feet), or as otherwise specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.2.2.2 Secure plumb line, spirit level, or straight edge as required.

11.2.2.3 Mark the plumb line at 305 mm (12 inch) intervals.

11.2.2.4 The distance from the plumb line to the streamer or vapor is determined at a distance of 915 mm and 1520 mm (36 and 60 inches) above the floor. The length of the plumb line should not exceed 1.2m (4 feet)

11.2.2.5 Introduce the aerosol test medium using the support stand at the specified test grid location and height.

11.2.2.6 The angle of deflection is then calculated based on the measured horizontal offset from true vertical. See Appendix C, Section C.8.1

11.2.3 ACCEPTANCE
11.2.3.1 The angle of deflection should not be greater than 14° from center when measured higher than 915 mm (36 inches) above the floor or as otherwise specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.2.4 REPORTING
See Section 5.15 for reporting requirements.

11.3 RECOVERY TESTS

The purpose of the recovery test is to determine the amount of time that is necessary for non-unidirectional cleanrooms or clean spaces and their systems to reach a specified steady state cleanliness level after a brief particle generation event within the clean space. It is not recommended for unidirectional airflow clean spaces nor in ISO Class 8 areas. This test must be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Note: There is potential for residue from the aerosol to be deposited on the surfaces within the cleanroom.

11.3.1 INSTRUMENTATION AND EQUIPMENT
11.3.1.1 An aerosol generator that conforms to the requirements of Table 4-2 or airflow visualization generator

11.3.1.2 A discrete particle counter that conforms to the requirements of Table 4-2. An aerosol photometer may be used as an option

11.3.2 TEST PROCEDURES
11.3.2.1 The number of points and the location of the points is to be determined as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.3.2.2 Ensure that the cleanroom HVAC systems are in operation.

11.3.2.3 Set up the particle counter or photometer in accordance with the manufactures instructions.

Note: An aerosol dilutor is recommended when using a particle counter to avoid coincidence loss and contamination of the optics.

11.3.2.4 The sample probe should not be setup directly under the HEPA filter or room air supply. Identify poor airflow areas, turbulent zones, etc. within the test area. The sample probe(s) should be slightly above work surface height or the height of potential product exposure.

11.3.2.5 Up to four sample locations can be measured using one remote instrument. Sample tubing up to 8 m (26 feet) in length can run out of the cleanroom to the particle counter / photometer. Samples will be taken at each location every 15 seconds by sequentially sampling from each tube.

11.3.2.6 Generate a particulate challenge in the cleanroom or clean space to be tested while the air handling units are in operation. Raise the initial particle concentration 1,000 to 10,000 times the target cleanliness level.

11.3.2.7 Stop the aerosol challenge, record the start time, and begin aerosol concentration measurements. Record the aerosol concentration for a 6 second to 12 second sample period for each minute until the particle count is returned to ten times the target cleanliness level. Record and plot the particle concentration versus time for each sample location.

11.3.2.8 The recovery time is the time, in minutes, for the particle concentration to decrease two orders of magnitude, i.e., the time for each location to recover from 1000 times the target concentration to ten times the target. The slowest recovery location in the cleanroom defines the room recovery rate.

11.3.3 ACCEPTANCE

Acceptable recovery times shall then be determined as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.3.4 REPORTING

See Section 5.16 for reporting requirements.

11.4 LIGHTING LEVEL AND UNIFORMITY TESTS

The purpose of the lighting level and uniformity tests is to verify that installed lighting levels and lighting uniformity meet the specified requirements. The measurement procedures are adopted from the Illuminating Engineering Society of North America (IESNA) *Lighting Handbook—Reference Volume.*

While the test procedure to be followed will vary based on the exact layout of the luminaries, there are some common elements that pertain to all of the tests such as: lamp conditioning, measurement conditions, instrumentation and equipment, creating a representative grid pattern for testing locations, etc.

11.4.1 INSTRUMENTATION AND EQUIPMENT

11.4.1.1 A portable photoelectric illumination meter shall meet the requirements of Table 4-2.

11.4.1.2 Other equipment needed for the test are:

a. A reflected ceiling plan or a floor plan and if possible a furniture or equipment layout plan
b. A tape measure
c. Brightly colored dots or another means of marking the test locations of the grid
d. A portable test stand that is the height of the work surface, usually 750 mm (30”) tall, and will allow the instrument and the light sensitive cell to be placed horizontally.

11.4.2 TEST PROCEDURES – GENERAL (APPLIES TO ALL TESTS)

11.4.2.1 Lamp Conditioning:

a. For high intensity, or fluorescent systems, in relatively new lamp installations, at least 100 hours of operation should elapse before measurements are taken

b. With incandescent lamps, seasoning is accomplished in 20 hours or more for common sizes
c. A high intensity discharge or fluorescent system must be illuminated for at least two hours before measurements are taken to be sure that normal operating output and temperature has been attained

11.4.2.2 Measurement Conditions:

a. Luminance measurements should be made under actual working conditions. All lighting in the area including general lighting, task lighting and supplementary lighting should be in normal use
b. Measurements shall be made at work surface elevation and from a specified work point location with the combinations of daylight and electric lighting facilities available
c. Verify that the thermal conditions of the space are stable
d. Care and consideration should be given to identify the influence of natural lighting sources

11.4.3 TEST PROCEDURE – DETERMINATION OF AVERAGE LUMINANCE FROM GENERAL LIGHTING

11.4.3.1 A measurement grid shall be determined and should be positioned to cover a representative area of the working plane. Any obstructions above the working plane, away from columns, tall pieces of equipment, filing cabinets, etc. shall be noted in the report.

11.4.3.2 The use of this method in the types of areas described should result in values of average luminance within 10 percent of the values that would be obtained by dividing the area into 0.6 m (2 foot) squares, taking a reading in each square and averaging.

11.4.3.3 The measuring instrument should be positioned so that when readings are taken, the surface of the light sensitive cell is in a horizontal plane and 760 mm (30 inches) above the floor unless specified in the contract documents or as agreed to between the Owner and the NEBB Certified CPT Firm.

11.4.4 TEST PROCEDURES – SYMMETRICALLY SPACED LUMINARIES IN TWO OR MORE ROWS (SEE FIGURE 11-1)

11.4.4.1 Take readings at stations r-1, r-2, r-3 and r-4 for a typical inner bay. Repeat at stations r-5, r-6, r-7 and r-8 for a typical centrally located bay. Average the 8 readings (R).

11.4.4.2 Take readings at stations q-1, q-2, q-3 and q-4 in two typical half bays on each side of room. Average the 4 readings (Q).

11.4.4.3 Take readings at stations t-1, t-2, t-3 and t-4 in two typical half bays at each end of room. Average the 4 readings (T).

11.4.4.4 Take readings at p-1 and p-2 in two typical corner quarter bays. Average the 2 readings (P).

11.4.4.5 Calculate the average level of luminance using Equation 11-1.

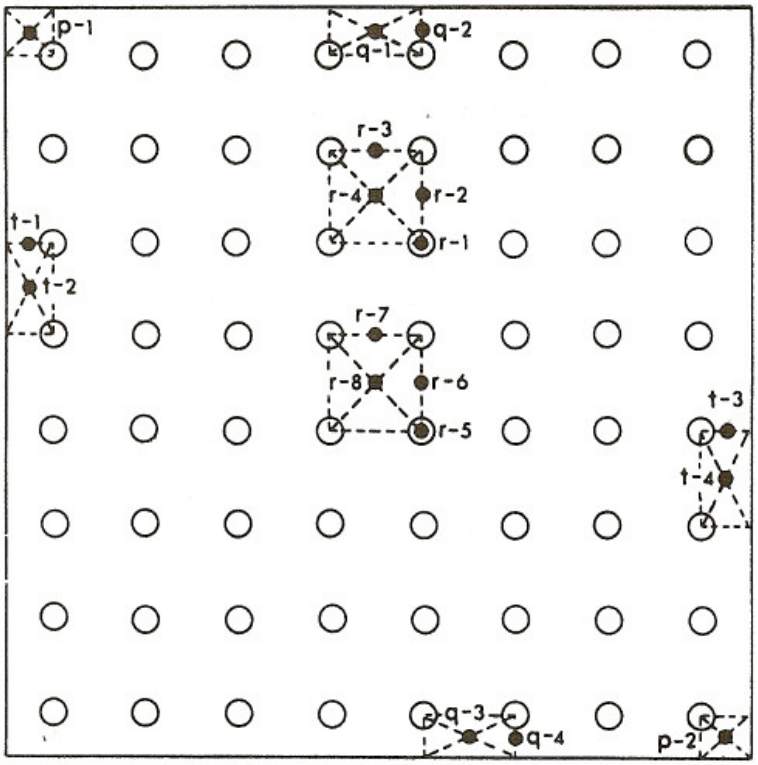

Figure 11-1

Equation 11-1

$$\text{Average luminance} = \frac{R(N-1)(M-1) + Q(N-1) + T(M-1) + P}{NM}$$

Where:

R = "r" average
Q = "q" average
T = "t" average
P = "p" average
N = Number of luminaries per row
M = Number of rows

11.4.5 TEST PROCEDURES – SYMMETRICALLY LOCATED SINGLE LUMINAIRE (SEE FIGURE 11-2)

11.4.5.1 Take readings at stations p-1, p-2, p-3 and p-4 in all 4 quarter bays.

11.4.5.2 Average the 4 readings (P). This average (P) is the average luminance for the area.

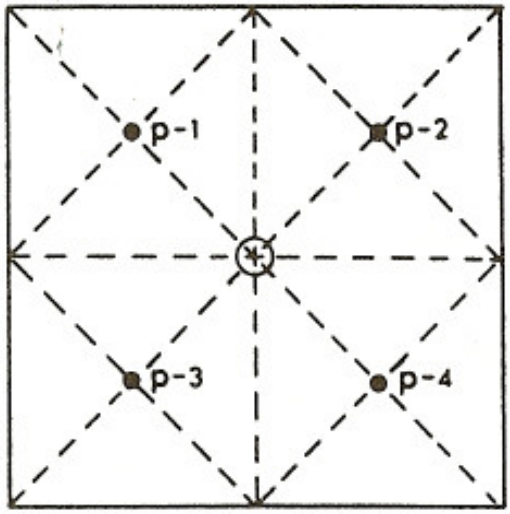

Figure 11-2

11.4.6 TEST PROCEDURES – INDIVIDUAL LUMINARIES IN SINGLE ROW (SEE FIGURE 11-3)

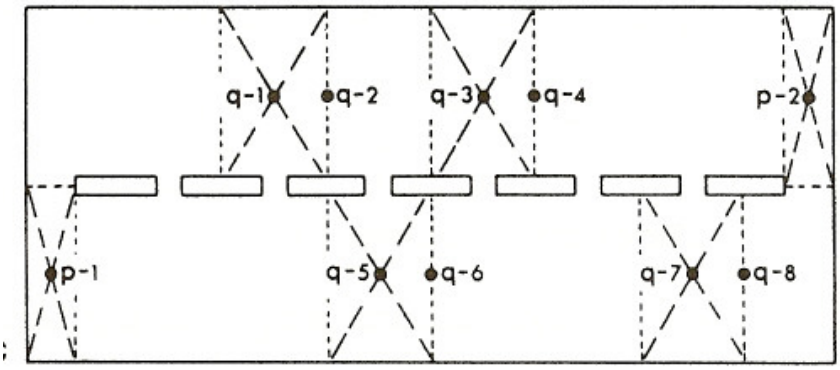

Figure 11-3

11.4.6.1 Take readings at stations q-1 through q-8 in 4 typical half bays located two on each side of the area. Average the 8 readings (Q).

11.4.6.2 Take readings at stations p-1 and p-2 for two typical corner quarter bays. Average the 2 readings (P).

11.4.6.3 Calculate the average level of luminance using Equation 11-2.

Equation 11-2

$$\text{Average luminance} = \frac{Q(N-1)+P}{N}$$

Where:
N = Number of luminaries

11.4.7 TEST PROCEDURES – TWO OR MORE CONTINUOUS ROWS OF LUMINAIRES (SEE FIGURE 11-4)

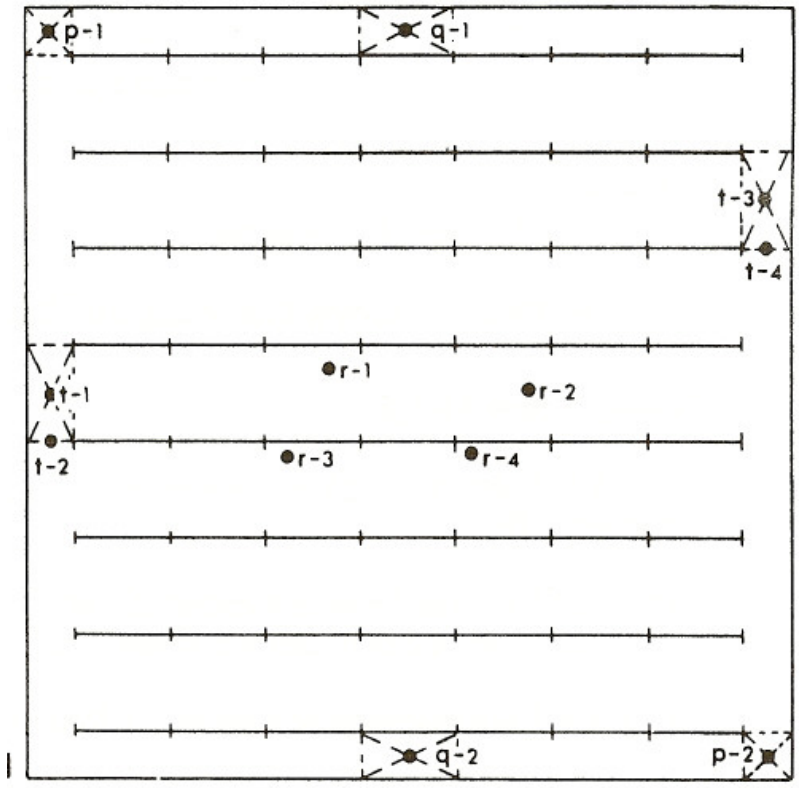

Figure 11-4

11.4.7.1 Take readings at stations r-1 through r-4 located near the center of the area. Average the 4 readings (R).

11.4.7.2 Take readings at stations q-1 and q-2 located at each mid-side of the room and midway of the room and midway between the outside row of luminaires and the wall. Average the 2 readings (Q).

11.4.7.3 Take readings at stations t-1 through t-4 at each end of the room. Average the 4 readings (T).

11.4.7.4 Take readings at stations p-1 and p-2 in two typical corners. Average the 2 readings (P).

11.4.7.5 Calculate the average level of luminance using Equation 11-3.

Equation 11-3

$$\text{Average luminance} = \frac{RN(M-1) + QN + T(M-1) + P}{M(N+1)}$$

Where:

R = "r" average
Q = "q" average
T = "t" average
P = "p" average
N = Number of luminaires per row
M = Number of rows

11.4.8 TEST PROCEDURES - CONTINUOUS LUMINAIRES IN SINGLE ROW (SEE FIGURE 11-5)

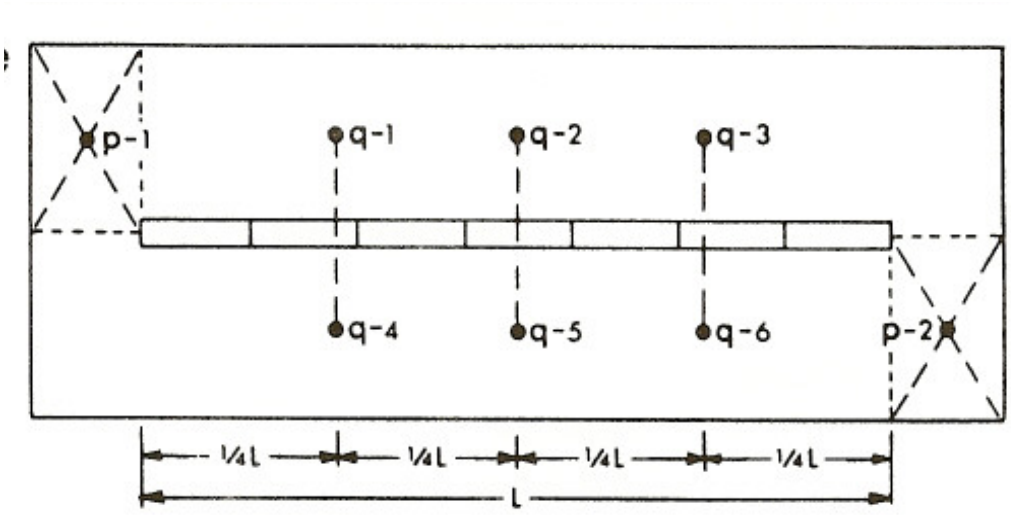

Figure 11-5

11.4.8.1 Take readings at stations q-1 through q-6. Average the 6 readings (Q).

11.4.8.2 Take readings at stations p-1 and p-2 in typical corners. Average the 2 readings (P).

11.4.8.3 Calculate the average level of luminance using Equation 11-4.

Equation 11-4

$$\text{Average luminance} = \frac{QN + P}{N+1}$$

Where:

Q = "q" average
P = "p" average
N = Number of luminaires

11.4.9 TEST PROCEDURES – LUMINOUS OR LOUVER-ALL CEILING (SEE FIGURE 11-6)

11.4.9.1 Take readings at stations r-1 through r-4 located at random in the central portion of the area. Average the 4 readings (R).

11.4.9.2 Take readings at stations q-1 and q-2 located 2 feet (0.6 meter) from the long walls at random lengthwise of the room. Average the 2 readings (Q).

11.4.9.3 Take readings at stations t-1 and t-2 located 2 feet (0.6 meter) from the short walls at random crosswise of the room. Average the 2 readings (T).

11.4.9.4 Take readings at stations p-1 and p-2 located at diagonally opposite corners 2 feet (0.6 meter) from each wall. Average the 2 readings (P).

11.4.9.5 Calculate the average level of luminance using Equation 11-5.

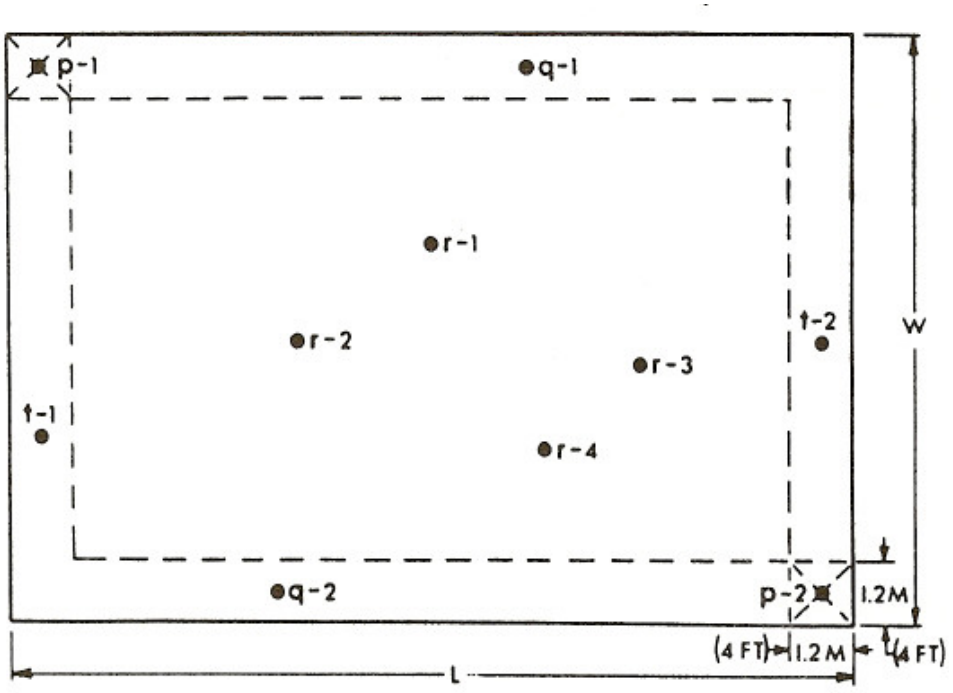

Figure 11-6

Equation 11-5

$$\text{Average luminance} = \frac{R(L-8)(W-8) + 8Q(L-8) + 8T(W-8) + 64P}{WL}$$

Where:

R = "r" average
Q = "q" average
T = "t" average
P = "p" average
W = Width of room
L = Length of room

11.4.10 TEST PROCEDURES – POINT OF WORK MEASUREMENTS

11.4.10.1 With task, general and supplementary lighting in use, the luminance at the point of work should be measured with the worker in a normal working position.

11.4.10.2 The measuring instrument should be located so that when readings are taken, the surface of the light sensitive cell is in the plane of the work or of that portion of the work on which the critical visual task is performed—horizontal, vertical or inclined.

11.4.10.3 Readings may be recorded in a table.

11.4.11 ACCEPTANCE

Acceptable illumination levels shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.4.12 REPORTING

See Section 5.17 for reporting requirements.
Report any obstructions above the working plane, away from columns, tall pieces of equipment, filing cabinets, etc. shall be noted in the report.

11.5 SOUND LEVEL TESTS

The purpose of performing sound pressure measurements will vary based on the occupancy state of the cleanroom. While the purpose may vary, the procedures are identical. The scope of services for sound level testing shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. The measurement procedures and reporting requirements are based on the requirements from the current NEBB *Procedural Standards for Measurement of Sound and Vibration*. If sound pressure measurements are required, they shall be performed by a NEBB Certified S&V Professional.

11.5.1 INSTRUMENTION AND EQUIPMENT

11.5.1.1 A Sound Level Meter (SLM) meeting the requirements of Table 4-2 shall be utilized to perform all sound level testing.

11.5.1.2 Provide required filters, wind screen, calibrators, etc. that meet the requirement of Table 4-2.

11.5.2 PRELIMINARY TEST PROCEDURES

11.5.2.1 Contract Document Review and Examination
For sound measurements to be meaningful and the data to be reported accurately, advance preparations must be completed. The NEBB Certified CPT Professional shall examine the contract documents, which consist of the contract drawings, the specifications, and the approved submittals, to become familiar with the project requirements and conditions that may preclude proper sound level testing of systems and equipment. The contract documents shall be examined for any information deemed necessary to perform the sound measurements.

The sound criteria established for a project shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. This information may be found in the Project Specifications, the Contract Drawings or some other part of the Contract Documents. The Contract Documents shall be examined for the following items:

a. NC, RC, dB(A), and any other sound criteria.

b. List of any rooms or spaces noted in the specifications that require low noise levels.
c. Schedule of equipment to be isolated.

11.5.2.2 Test Readiness Conditions

a. All construction activities must be completed prior to sound level testing. The cleanroom shall be in an occupancy state that is as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm prior to performing sound level testing. The sound level testing can be performed in any of the 3 occupancy states (As-Built, At-Rest, or Operating).

b. From a construction standpoint, verify that the cleanroom envelope is complete.

c. When the sound testing is performed for an As-Built occupancy state, the NEBB Certified CPT Professional shall verify that all building mechanical/electrical systems have been started, are operational and completely under functional control. All testing, adjusting and balancing activities shall be performed prior to sound level testing. The NEBB Certified CPT Professional shall also verify that all primary cleanroom tests have been completed.

d. When the sound testing is performed for an At-Rest occupancy state, the NEBB Certified CPT Professional shall verify that all of the requirements of Section 11.5.2.2.c are met. Additionally, the NEBB Certified CPT Professional shall also verify that the appropriate process equipment within the cleanroom is operational and completely under functional control and is operating in a manner that is consistent with the normal intended use of the cleanroom. The process equipment that should be operating during the sound pressure testing shall be as specified in the contract documents or as mutually agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

e. When the sound testing is performed for an Operational occupancy state, the NEBB Certified CPT Professional shall verify that all of the requirements of Section 11.5.2.2.d are met. Additionally, the NEBB Certified CPT Professional shall also verify that all personnel are stationed at their normal working environment and that process equipment within the cleanroom is functioning in a manner that is consistent with the everyday active use of the cleanroom. The process equipment that should be operating during the sound pressure testing shall be as specified in the contract documents or as mutually agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.5.3 TEST PROCEDURES

11.5.3.1 As stated above, the usual purpose of performing sound measurements is to determine the actual sound level pressures of the cleanroom. In order to accurately determine the sound pressure levels of the cleanroom, it will be necessary to perform sound measurements when other building systems/conditions and exterior sound sources are at a minimum level and will not influence measurements of equipment being tested.

11.5.3.2 Prior to making any sound level measurements a field calibration shall be performed in accordance with the manufacturer's recommendations both before and after sound making level measurements.

11.5.3.3 Based on the occupancy state, take sound measurements when the appropriate systems, equipment, personnel, etc. are in place.

11.5.3.4 Instrument Placement
Position sound level instrument to achieve a direct line-of-sight between the sound source and the sound-level meter. Unless specified or agreed to between the Owner / Buyer and the NEBB Certified CPT Firm, take sound measurements at a height approximately 1200 mm (48 inches) above the floor and at least 900 mm (36 inches) from a wall, column, or any other large surface capable of altering the measurements.

11.5.3.5 Data measurements
Sound levels measurements are typically reported in terms of dB (Flat or Linear); dB(A), Noise Criteria (NC) or Room (RC). Sound level measurements of the cleanroom shall be reported in either Noise Criteria (NC) or Room Criteria (RC). Sound level measurements shall be recorded and reported in one or both of the following two methods: 1) overall sound levels or 2) in octave bands as follows:

a. Overall dB (Flat or Linear)
b. The sound level meter shall be set to the Slow time constant
c. In each 1/1(Full) octave band, from 31.5 to 8,000 Hz.

11.5 3.6 Locations
The actual scope of work detailing measurement locations shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. If actual locations are not identified on the contract documents, a grid shall be prepared so that the minimum locations meet the following requirements: Minimum of 2 measurements per cleanroom or clean zone space and at least 1 measurement per 36 m^2 (400 ft^2).

11.5.4 ACCEPTANCE
Acceptable sound level criteria shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.5.5 REPORTING
See Section 5.18 for reporting requirements.

11.6 VIBRATION LEVEL TESTS

The purpose of vibration level testing is to measure the actual vibration levels of the cleanroom and to report those measurements. The scope of services for vibration measurements shall as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. The measurement procedures and reporting requirements are based on the requirements from the current NEBB *Procedural Standards for Measurement of Sound and Vibration*. If vibration measurements are required, they shall be performed by a NEBB Certified S&V Professional.

11.6.1 INSTRUMENTION AND EQUIPMENT
11.6.1.1 A vibration meter (minimum 400 line FFT real time analyzer) that meets the requirements of Table 4-2.

11.6.1.2 Provide associated required accelerometers, calibrators, etc. that conform to the requirements of Table 4-2.

11.6.2 PRELIMINARY TEST PROCEDURES

11.6.2.1 Contract Document Review and Examination

For vibration measurements to be meaningful and the data to be reported accurately, advance preparations must be completed. The NEBB Certified CPT Professional shall examine the contract documents, which consist of the contract drawings, the specifications, and the approved submittals, to become familiar with the project requirements and conditions that may preclude proper vibration measurement testing of systems and equipment. The contract documents shall be examined for any information deemed necessary to perform the vibration measurements.

The vibration criteria established for a project shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. This information may be found in the Project Specifications, the Contract Drawings or some other part of the Contract Documents. The Contract Documents shall be examined for the following items:

11.6.2.2 Vibration reporting requirements in terms of displacement, velocity and / or acceleration.

a. List of any equipment, rooms or spaces noted in the specifications that require low vibration levels
b. Schedule of equipment and/ or areas to be vibration isolated
c. Examine submittals for vibration isolators, machinery bases and all other vibration control equipment to verify whether the equipment furnished to the job is in accordance with the manufacturer's submittals.

11.6.2.3 Test Readiness Conditions:

a. All construction activities must be completed prior to vibration level testing. The cleanroom shall be in an occupancy state that is as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm prior to performing vibration measurements. The vibration measurements can be performed in any of the 3 occupancy states (As-Built, At-Rest, or Operating).

b. From a construction standpoint, verify that the building cleanroom envelope is complete.

c. When the vibration measurements are performed for an As-Built occupancy state, the NEBB Certified CPT Professional shall verify that all building mechanical/electrical systems have been started, are operational and completely under functional control. All testing, adjusting and balancing activities shall be performed prior to vibration measurements testing. The NEBB Certified CPT Professional shall also verify that all primary cleanroom tests shall be completed.

d. When the vibration measurements are performed for an At-Rest occupancy state, the NEBB Certified CPT Professional shall verify that all of the requirements of Section 11.6.2.3.c are met. Additionally, the NEBB Certified CPT Professional shall also verify that the appropriate process equipment within the cleanroom is operational and completely under functional control and is operating in a manner that is consistent with the normal intended use of the cleanroom. The process equipment that should be operating during the vibration level testing shall be as specified in the contract documents or as mutually agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

e. When the vibration measurements are performed for an Operational occupancy state, the NEBB Certified CPT Professional shall verify that all of the requirement of Section 11.6.2.3.d are met.

Additionally, the NEBB Certified CPT Professional shall also verify that all personnel are stationed at their normal working environment and that process equipment within the cleanroom is functioning in a manner that is consistent with the everyday active use of the cleanroom. The process equipment that should be operating during the vibration level testing shall be as specified in the contract documents or as mutually agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.6.2.4 Test Readiness Report
Prepare a report identifying all issues that would preclude proper vibration measurements of the cleanroom.

11.6.3 TEST PROCEDURES
11.6.3.1 As stated above, perform vibration measurements when building systems/conditions and exterior vibration sources are at normal or maximum level and may influence measurements. In order to obtain vibration sources, the following should be implemented:

a. Turn on equipment in the building that may be vibration sources
b. Normal human activity should be allowed because it may affect accuracy of vibration measurements
c. Vibration measurements should be performed when actual cleanroom vibration sources will be encountered. This may include such items as: exterior vibration sources, trains, roadway traffic, adjacent construction activities, etc. can be minimized.

11.6.3.2 Based on the occupancy state, take vibration measurements when the appropriate systems, equipment, personnel, etc. are in place.

11.6.3.3 When attempting to isolate a vibration source, it may be necessary to systematically shutdown rotating equipment within the cleanroom. In all situations, the NEBB Certified CPT Professional shall contact the appropriate personnel before shutting down any cleanroom systems or operating equipment.

11.6.3.4 Location and attachment of accelerometer (transducer):

a. The method of attaching an accelerometer can seriously affect its performance. Accelerometers should be attached to vibrating surfaces according to the accelerometer manufacturer's instructions. The accelerometer shall be mounted to surfaces that are flat and clean. If vibration measurements must be made on vibrating machinery which appears to have exceptionally large vibration amplitudes, it may be necessary to attach the accelerometer to the machine by means of threaded metal studs.

b. Heavy accelerometers may affect the accuracy of vibration levels obtained from small or lightweight systems or equipment. Accelerometer weight shall be no more than 10% of the equipment to be tested.

c. It is recommended that the same mounting method be used for all measurements made on any individual piece of equipment and similar pieces of equipment.

d. The hierarchy of mounting an accelerometer, based on accuracy of repeatable results is: stud mount, adhesive mount, magnetic base, bees wax, and hand-held probe. The magnetic base is the most common method of attachment.

11.6.3.5 Measurement Locations
Measure and record vibration levels at all required equipment bases, equipment and on building structure adjacent to the equipment. The vibration measurements should be taken in the vertical, horizontal and axial planes when the measurements can be performed safely. Measure and record acceleration, velocity, and/or displacement readings. Vibration measurement location shall be based on the following:

Equipment Bases	Location
Support pedestals and structural components	Within 150 mm (6 in.) of the top of the support pedestal
Vibration sensitive equipment	Within 150 mm (6 in.) of each isolator or within 150 mm (6 in.) of the equipment

Equipment and Building Structure	Floor Location
Vibration sensitive equipment	Within 150 mm (6 in.) of equipment

11.6.3.6 Data Measurements
Vibration measurements shall be recorded and reported as follows:

Discrete vibration levels: from 1 to 101 Hz in 0.25 Hz increments.

11.6.3.7 Locations
The actual scope of work shall be as specified in the contract documents or as agreed to between the Owner/Buyer and the NEBB Certified CPT Firm.

11.6.4 ACCEPTANCE
Acceptable vibration level criteria shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.6.5 REPORTING
See Section 5.19 for reporting requirements.

11.7 TEMPERATURE AND HUMIDITY UNIFORMITY TESTS

The purpose of the temperature and humidity tests is to document the temperature and humidity levels in the cleanroom or clean space.

Two levels of temperature and humidity tests are used. The first, *general temperature and humidity uniformity tests*, is suited for normal environmental requirements and will be presented in Section 11.8 the second, *comprehensive temperature and humidity uniformity tests*, will be presented in Section 11.9 and is for areas requiring stricter control.

The general level test is used to demonstrate that the cleanroom HVAC systems will maintain the specified levels of temperature and humidity required primarily for occupant comfort. The comprehensive level test is used to demonstrate that the cleanroom HVAC systems will maintain the specified levels of temperature and humidity required for both occupant comfort and process temperature control.

The scope of services for temperature and moisture uniformity testing shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.8 GENERAL TEMPERATURE AND HUMIDITY UNIFORMITY TESTS

11.8.1. INSTRUMENTATION AND EQUIPMENT

11.8.1.1 Temperature measuring devices such as standard thermometers and electronic thermometers shall conform to the requirements of Table 4-2.

11.8.1.2 Temperature sensing devices such as thermocouples, thermostats, or other temperature sensors used with readout devices shall conform to the requirements of Table 4-2.

11.8.1.3 Humidity measuring devices including sling psychrometers, electronic thermo-hygrometers and dew point or humidity sensors shall conform to the requirements of Table 4-2.

11.8.2 TEST PROCEDURES – TEMPERATURE

11.8.2.1 Verify completion of HVAC system testing, adjusting and balancing (TAB) work prior to performing these tests.

11.8.2.2 Allow the HVAC system to operate under automatic control for 24 hours prior to tests.

11.8.2.3 Measure the temperature at a minimum of one location for each temperature control zone. Place each thermometer or each sensor at the designated location at work level height. Allow time for the sensor to stabilize sufficiently for accurate readings.

11.8.2.4 Record the time and temperature reading at each location for each temperature control work zone.

11.8.3 TEST PROCEDURES—HUMIDITY

11.8.3.1 Verify completion of HVAC system testing, adjusting and balancing (TAB) work prior to performing these tests.

11.8.3.2 Allow the HVAC system to operate under automatic control for 24 hours prior to tests.

11.8.3.3 The relative humidity is to be measured at a minimum of one location for each humidity (temperature) control zone. Place the humidity device or sensor at the designated location and height, allowing the sensor to stabilize.

11.8.3.4 Measure and record the humidity readings simultaneously with temperature readings.

11.8.4 ACCEPTANCE

Acceptable criteria for temperature and humidity levels and requirements shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.8.5 REPORTING

See Section 5.20 for reporting requirements.

11.9 COMPREHENSIVE TEMPERATURE AND HUMIDITY UNIFORMITY TESTS

11.9.1 INSTRUMENTATION AND EQUIPMENT

11.9.1.1 Electronic thermometers and temperature sensors that conform to the requirements of Table 4-2.

11.9.1.2 Humidity measuring instruments and sensors that conform to the requirements of Table 4-2.

11.9.1.3 A data logging device with printable or downloadable data output that conforms to the requirements of Table 4-2.

11.9.2 PROCEDURES – TEMPERATURE AND HUMIDITY

11.9.2.1 Designate a minimum of one temperature and relative humidity measurement location in each temperature control zone.

11.9.2.2 Multiple locations in each zone may be located as specified.

11.9.2.3 The presence of heat sources should be noted in relation to the test sample location.

11.9.2.4 Verify completion of HVAC system testing, adjusting and balancing (TAB) work prior to performing these tests.

11.9.2.5 Verify that the airflow uniformity tests have been completed and accepted.

11.9.2.6 Allow the HVAC system to operate under automatic control for 24 hours prior to tests.

11.9.2.7 Place each temperature and humidity sensor at each designated work level sampling location and allow stabilization.

11.9.2.8 Measure and record each temperature and humidity measurement simultaneously at each location at a minimum of every 6 minutes for a minimum period of 2 hours. It is typical to measure each area for 22 hours to assure temporal uniformity.

11.9.3 ACCEPTANCE

Acceptable criteria for temperature and humidity levels and requirements shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.9.4 REPORTING

See Section 5.21 for reporting requirements.

11.10 ELECTROSTATIC TESTS

The purpose of the electrostatic test is to benchmark the levels of electrostatic charge, the resistance properties of surfaces, and the effectiveness of the ionizer charge neutralizing systems.

This test consists of four parts: Measurement of Static Charge Level, Surface Resistance Test, Ionizer Discharge Time Test and Measurement of Ionizer Offset Voltage.

While it is possible to measure static charge directly by placing objects in a Faraday Cup, this is often impractical. The Measurement of Static Charge Level establishes the levels of static charge that are generated on materials within the test area. It does this by measuring the surface voltage (using an electrostatic voltmeter for conductors) or charge-generated electric field (using an electrostatic field meter for insulators or conductors). The Surface Resistance Test determines whether a material may dissipate a static charge effectively when it is connected to ground. It also determines whether or not it is connected to ground. By measuring the surface resistance and the resistance to ground on surfaces, the static-dissipative property can be evaluated.

The Ionizer Discharge Time Test and Measurement of Ionizer Offset Voltage tests relate to the performance of ionizers used to neutralize charge on surfaces that cannot be grounded or are insulators. These tests are performed by measuring the discharge time of an initially charged isolated plate, and by determining the offset voltage (balance) of the ionizer with an initially uncharged isolated plate. The results of each measurement indicate the efficiency of neutralizing static charges and the imbalance between the amount of generated positive and negative ions.

The scope of services for these electrostatic tests shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.10.1 INSTRUMENTATION AND EQUIPMENT

11.10.1.1 An electrostatic voltmeter or field meter which meets the requirements of Table 4-2.

11.10.1.2 A charged plate monitor (CPM) which meets the requirements of Table 4-2.

11.10.1.3 An ohmmeter and electrodes which meet the requirements of Table 4-2.

11.10.2 TEST PROCEDURES – MEASUREMENT OF SURFACE CHARGE LEVEL

11.10.2.1 The measuring point(s) or the object to be measured should be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. The choice of test instrument will depend on whether the object(s) to be measured are insulators or conductors and their physical size. Consult instrument manufacturer's instructions for additional information.

11.10.2.2 Hold the instrument probe at the manufacturer's specified distance from a grounded metal plate and adjust the reading of the electrostatic voltmeter or field meter to zero.

11.10.2.3 Hold the probe parallel to the plate and at a distance that is in accordance with the manufacturer's recommendations.

11.10.2.4 The metal plate should have a surface area large enough for the required probe aperture and be large enough for the probe to surface spacing ratio. Refer to manufacturer's instructions

11.10.2.5 According to the manufacturer's instructions, place the probe near the surface of an object which may be charged and measure the surface voltage (of a conductor with an electrostatic voltmeter), or electric field (of an insulator or conductor with an electrostatic field meter). Record the measurements at each specified measurement point.

11.10.3 TEST PROCEDURES – SURFACE RESISTANCE TESTS

11.10.3.1 Specific test conditions should be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.10.3.2 The two electrodes should be set at the correct distance on the surface in accordance with the manufacturer's recommendations. The surface resistance (point to point) can now be measured with an ohmmeter providing the appropriate output voltage. (Note that standard ohmmeters use too low a voltage for this purpose. The ohmmeter must have the capability of making measurements at 10 volts and 100 volts.) Record the measurements at each specified measurement point.

11.10.3.3 One electrode is connected to ground and the other electrode should be placed on the surface in accordance with the manufacturer's recommendations. The surface resistance to ground can now be measured with an ohmmeter providing the appropriate output voltage. Record the measurements at each specified measurement point.

11.10.4 TEST PROCEDURES – ION GENERATOR TEST

Ionizer performance is evaluated by measuring the discharge time (time to neutralize a known charge) and the offset voltage. The imbalance of positive and negative ions that are in the ionized airflow are determined by the offset voltage measurements. The efficiency of eliminating static charges using ionizers is determined by measuring the discharge time.

11.10.4.1 The measuring point(s) or the object to be measured should be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.10.4.2 The instrument specified in industry standards for measuring ionizer performance is known as a Charged Plate Monitor (CPM). It basically consists of an isolated conductive plate of known capacitance, a power source for charging the plate to a known voltage or zero, and means to measure the voltage on the plate and the time it takes to reach a preset level. Consult the manufacturer's instructions for operating procedures.

11.10.4.3 With the CPM placed in the specified measuring point(s), use the power source to charge the isolated conductive plate to a known positive voltage.

11.10.4.4 As the static charge of the plate is reduced by the ionizer, measure the time for the static voltage on the plate to be reduced to 10% of the initial voltage condition which is the discharge time. Record the measurements at each specified measurement point.

11.10.4.5 Repeat this procedure with the plate charged to a known negative voltage. Record the measurements at each specified measurement point.

11.10.5 TEST PROCEDURES – MEASUREMENT OF OFFSET VOLTAGE

11.10.5.1 The measuring point(s) or the object to be measured should be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.10.5.2 With the CPM placed in the specified measuring point(s), connect the isolated conductive plate to ground to remove any residual charge. Adjust the reading of the CPM to zero, if necessary. Remove the ground connection.

11.10.5.3 Allow sufficient time (typically 1 minute) for the isolated plate to acquire a charge from the ionizer and the reading to stabilize. Record the reading of the offset voltage. (Note – some ionizers "pulse" from positive to negative as part of their normal operation. In this case, record the maximum positive and negative readings of the offset voltage.)

11.10.6 ACCEPTANCE

Acceptance criteria shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Note: The Owner / Buyer's criteria will depend on the electrostatic sensitivity of devices that are located in the work area.

11.10.7 REPORTING

See Section 5.22 for reporting requirements.

11.11 CONDUCTIVITY TESTS

The purpose of the conductivity test is to measure resistance between specified points on the floor covering, and from the floor covering to the building ground at strategic locations within the building. The tests are similar to the requirements of the current edition of NFPA 99, except as modified in the test procedures. The scope of services for these conductivity tests shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.11.1 INSTRUMENTATION AND EQUIPMENT

11.11.1.1 An Ohm-meter which meets the requirements of Table 4-2.

11.11.1.2 Two (2) electrodes which meet the requirements of Table 4-2.

11.11.2 TEST PROCEDURES – FLOOR TILE TO TILE

Perform conductivity tests between points on the floor covering as follows:

11.11.2.1 Floor shall be tested with temperature and relative humidity maintained as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.11.2.2 Measurements, on continuous flooring, shall be made between five pairs of test locations in each cleanroom or clean space and the results averaged. Measurements shall be made with the electrodes 0.9 m (3 feet) apart.

11.11.2.3 Measurements on raised floor tiles shall be made between pairs of points and may include some, or all, of the following:

a. Diagonal opposite corners of a single tile to test for surface conductivity; i.e .floor waxes that are insulting (non-conductive)

b. Corner of test tile to corner of any tile two positions away

c Center of test tile to any supporting pedestal

d. Center of test tile to conductive paint finish covering main structural concrete floor

11.11.3 TEST PROCEDURES – FLOOR TO BUILDING GROUND

Perform conductivity tests from the floor covering to the building ground (raised floors only).

11.11.3.1 Floor shall be tested with temperature and relative humidity maintained as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.11.3.2 Measurements shall be made at 20 tests locations as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm. Measurements may be made between up to five pairs of test locations at each of the 20 test locations in each room and the results averaged.

11.11.3.3 Measurements shall be made with the one electrode on the floor connected to the ohmmeter. The other terminal of the ohmmeter shall be connected to the nearest building column or exposed grounding conductor.

11.11.4 ACCEPTANCE

11.11.4.1 Acceptance criteria shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

Note: Typically, the floor panel-to-panel tests achieve average values less than 1 mega ohm and the floor-to-building ground tests achieve average values less than 1 mega ohm.

11.11.5 REPORTING

See Section 5.23 for reporting requirements.

11.12 ELECTROMAGNETIC INTERFERENCE (EMI) TEST

The purpose of the Electromagnetic Interference (EMI) Test is to determine the amount of electromagnetic radiation that is being emitted by electrical circuits. The magnetic fields around the electrical source can effect sensitive equipment, especially those that use electron beams. Examples are electron microscopes and e beam lithography equipment. The electron beams are controlled and focused with magnets. Unwanted and uncontrolled magnetic fields in close proximity to the equipment results in reduced performance of the instrumentation.

11.12.1 INSTRUMENTATION AND EQUIPMENT

11.12.1.1 A magnetic field meter that meets the requirements of Table 4-2.

11.12.1.2 A magnetic field sensor that meets the requirements of Table 4-2

11.12.2 TEST PROCEDURES

11.12.2.1 Determine the expected cleanroom position of the electron beam in the equipment to be installed. Conduct an extensive survey along the position of the future e beam by measuring three axis (x, y, and z) in at least four locations. Additional locations may be measured 0.5 meters around the expected path of the e beam when is installed. Test other locations as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.12.2.2 The source of any readings exceeding 1.0 milligauss shall be determined.

11.12.3 ACCEPTANCE

Acceptance criteria shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.12.4 REPORTING

See section 5.24 for reporting requirements.

11.13 AIR CHANGE RATE (ACH) TEST

The purpose of the air change rate test is to determine the number of times the air is being exchanged within the cleanroom on an hourly basis. The Air Change Rate per Hour (ACH) is determined by measuring the total amount of airflow being supplied or returned from the cleanroom and by calculating the overall volume of the cleanroom.

11.13.1 INSTRUMENTATION AND EQUIPMENT

11.13.1.1 A direct reading flowhood meeting the requirements of Table 4-2

or

11.13.1.2 A manometer and a Pitot tube meeting the requirements of Table 4-2

11.13.2 TEST PROCEDURE

11.13.2.1 Determine if the cleanroom is under a positive or negative pressure.

11.13.2.2 If the pressure is positive, measure and record the supply airflow volume delivered through the filter using a flow hood. Use appropriate size capture enclosure for each filter application when using an airflow volume direct reading flowhood.

11.13.2.3 If the pressure is negative, measure and record the return / exhaust airflow volumes being captured by all return openings and process exhaust devices using the appropriate instrumentation for the application.

11.13.2.4 Measure the volume of the cleanroom space.

11.13.2.5 Calculate the Air Change Rate per Hour. See Appendix C, Section C.10.

11.13.3 ACCEPTANCE CRITERIA

Acceptance criteria shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.13.4 REPORTING

See section 5.25 for reporting requirements.

11.14 BENCH SCAN FILTER LEAK TESTS

The purpose of this test is to determine the integrity of each filter shipment by spot testing random statistical samples prior to filter installation.

11.14.1 INSTRUMENTATION AND EQUIPMENT

11.14.1.1 An aerosol photometer, aerosol generator and scanning probe that meet the requirements of Table 4-2.

or

11.14.1.2 A particle counter, microsphere generator and scanning probe that meet the requirements of the requirements of Table 4-2.

11.14.1.3 A test bench with a fan capable of delivering the specified airflow volume of the installed filter(s). The fan shall be capable of supplying the air in a uniform manner upstream of the face of filter(s). The bench filter seal must prevent excessive aerosol from escaping into the environment

around the filter(s) under test.

11.14.2 TEST PROCEDURE

11.14.2.1 Test every filter, or if owner approved, develop a statistical sample based on the following:

a. Test all filters which show signs of damage
b. Test every fifth filter and upon failure, test additional untested filters as agreed to between the NEBB Certified CPT Firm and the Owner

11.14.2.2 Provide flow test bench, aerosol photometer and oil generator (either Laskin nozzle or thermal) or optical laser particle counter, and microsphere generator and a particle controlled environment.

11.14.2.3 Introduce aerosol oil challenge or microsphere challenge upstream of the filter. A minimum challenge shall be 10µg/l of oil or at least 210,000,000 particles per cubic meter (6,000,000 particles per cubic foot).

11.14.2.4 Measure the upstream challenge of each filter.

11.14.2.5 Scan the entire downstream filter face area in overlapping strokes, moving at the calculated scan rate spaced a distance of 25 mm (1 inch) from the filter face.

11.14.2.6 Repairs, leaks and retesting of filters shall be performed in accordance with the requirements as stated in the contract documents or as agreed to between the Owner/Buyer and the NEBB CPT Firm.

11.14.3 ACCEPTANCE CRITERIA

Acceptance criteria shall be as specified in the contract documents or as agreed to between the Owner / Buyer and the NEBB Certified CPT Firm.

11.14.4 REPORTING

See section 5.26 for reporting requirements.

APPENDIX A SAMPLE CLEANROOM SPECIFICATIONS

The NEBB CPT Committee has developed Cleanroom Performance Testing specifications that can be utilized by a design professional and incorporated into their contract documents. They are available for download on the NEBB website at: www.nebb.org.

There are two distinct complete specifications that have been developed:

APPENDIX A-1

Appendix A-1 Sample Specification is for the Microelectronics and Semiconductor industry requirements.

APPENDIX A-2

Appendix A-2 Sample Specification is for the Bio-Medical and / Pharmaceutical industry requirements.

Both specifications are identical for Part 1 – *General* and for Part 2 – *Products*. Part 3 – *Execution* has been tailored for each of the industry requirements.

Either of the specifications is available in electronic format (MS Word®) for the design professional to edit for each project's specific requirements.

As with any sample or master format specification, it is the responsibility of the design engineer of record to edit the specification for each project's unique specific requirements. These requirements should include, but are not limited to the following:

a. Specifying the tests to be performed, the parameters to be measured and the acceptable tolerances. NEBB standards and procedures define industry best practices to perform the testing.

b. Defining who retains the services of the NEBB Certified CPT Firm and require that the NEBB Certified CPT Firm be retained early in the construction process.

c. Defining the applicable standards, cleanliness classification(s), acceptance criteria, etc. prior to submission of project fees; i.e. ISO Class 4 at 0.3 microns (µm).

d. Clearly identifying on the architectural, mechanical and electrical plans and in the specifications, the system components required for cleanroom testing; i.e. pressure relationships, cleanroom reflected ceiling plans, cleanroom floor plans, etc.

e. Specifying that the building and/or HVAC control system be commissioned and documented per NEBB Commissioning Standards and Procedures before the cleanroom testing work begins.

f. Specifying that the air and water systems be Tested, Adjusted and Balanced (TAB) and documented per NEBB *Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems* before the cleanroom testing work begins.

g. Specifying that the building control system firm provides access to hardware and software, or onsite technical support required to assist the cleanroom testing effort. The hardware and software or the onsite technical support shall be provided at no cost to the NEBB Certified CPT Firm.

h. Providing adequate access to all equipment and components required by the cleanroom testing process.

i. Completely defining validation / commissioning support responsibilities for the NEBB Certified CPT Firm.

j. Identifying all project specific requirements that relate to unique safety, reporting, facility access, etc. which may affect the cleanroom performance testing.

See Section 3 for additional content.

APPENDIX A-1 SAMPLE CLEANROOM SPECIFICATIONS

MICROELECTRONICS & SEMICONDUCTORS

The suggested specification is available on the NEBB website at: www.nebb.org

APPENDIX A-2 SAMPLE CLEANROOM SPECIFICATIONS

BIO-MEDICAL & PHARMACEUTICAL

The suggested specification is available on the NEBB website at: www.nebb.org

APPENDIX B REFERENCES AND REFERENCED PUBLICATIONS

American Conference of Governmental Industrial Hygienists (ACGIH)
Kemper Meadow Drive, Cincinnati, Ohio 45240

ACGIH *Industrial Ventilation, A Manual of Recommended Practice*
Contains information on the design and installation of industrial ventilation systems and exhaust systems and hoods.

American Glovebox Society (AGS)
P.O. Box 9099, Santa Rosa, California 95405

AGS *GUIDELINES FOR GLOVEBOXES*
This document provides information for designers, fabricators, and users regarding the proper, safe, and consistent design, fabrication, and operation of gloveboxes, while minimizing the cost involved. It guides the designer away from common ergonomic mistakes made when designing gloveboxes and provides information on installation, maintenance, decontamination, and decommissioning considerations. The document establishes standard features for design and fabrication of gloveboxes such that, when followed, minimize fabrication costs and improve operability. Other important issues relevant to gloveboxes that are addressed in the Guideline include quality assurance, glovebox-interior protective linings and coatings, safety, considerations for interior equipment, and radiological shielding.

AGS *STANDARDS OF PRACTICE (SOPs)*
The AGS has also published several **Standards of Practice (SOPs)**. Three that are currently available for purchase are The Standard of Practice for the Design and Fabrication of Glovebags, AGS-G002, The Standard of Practice for the Application of Linings to Gloveboxes, AGS-G003, The Standard of Practice for the Specifications of Gloves for Gloveboxes AGS-G005 and The Standards of Practice for the Design & Fabrication of Nuclear Application Gloveboxes AGS-G006.

American Society of Heating, Air Conditioning and Refrigerating Engineers (ASHRAE)
1791 Tullie Circle Northeast, Atlanta, Georgia 30329

ASHRAE Handbook—*HVAC Applications*
Chapter on Health Care Facilities
Chapter on Laboratory Systems
Chapter on Clean Spaces

ASHRAE Standard 52.2 *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.*
This standard defines unified test procedures and apparatus for evaluating filters with efficiencies below that of HEPA filters.

American Society for Testing and Materials (ASTM)

100 Barr Harbor Drive, West Conshohoken, Pennsylvania 19428

ASTM—F 50 *Practice for Continuous Counting and Sizing of Airborne Particles in Dust-Controlled Areas and Clean Rooms Using Instruments Capable of Detecting Single Sub-Micrometer and Larger Particles*
Particle concentration and size distribution of airborne particles are determined in cleanrooms for particles of approximately 0.01 µm to 5 µm in concentrations up to 3.5 x 10^6 per cubic meter. Sample acquisition and instrument performance requirements are stated.

ASTM—F 328 *Practice for Determining Counting and Sizing Accuracy of an Airborne Particle Counter Using Near-Monodisperse Spherical Particles.*
Size and counting accuracy determination procedures are given for verifying operation of an optical airborne particle counter. Monosized latex particles are used for size definition and counting data are obtained in comparison with a referee method to define counting accuracy.

ASTM—F 649 *Practice for Secondary Calibration of Airborne Particle Counter using Comparison Procedures*
Procedures are given for fine-tuning response of an airborne particle counter to match that of a standard counter for defining atmospheric dust, following calibration with mono-disperse latex particles. The procedures are helpful in correlating different counters.

ASTM-F 1471 *Air Cleaning Performance of High-Efficiency Particulate Air Filter Systems*

Institute of Environmental Sciences and Technologies (IEST)

Arlington Place One, 2340 South Arlington Heights Road, Suite 100, Arlington Heights, Illinois 60005

IEST-RP-CC001 *HEPA and ULPA Filters*
This recommended practice covers basic provisions for HEPA and ULPA filter units. Filter performance, materials, design, construction, and testing are covered. Six levels of performance and six grades of construction are included.

IEST-RP-CC006 *Testing Cleanrooms*
This recommended practice covers testing methods for characterizing performance of cleanrooms. Airflow, filter integrity, particle levels, air pressure, air flow parallelism, room integrity, particle fallout, temperature and relative humidity, light, noise, and vibration are tested.

IEST-RP-CC013 *Equipment Calibration of Validation Procedures*
This recommended practice defines applicable test procedures for calibrating instruments used in cleanrooms and clean air devices, and defines calibration intervals.

IEST-RP-CC014 *Calibration of Particle Counters*
This recommended practice establishes definitions and procedures for calibrating counting devices used in cleanroom and establishes some instrument specifications.

IEST-RP-CC018 *Cleanroom Housekeeping—Operating and Monitoring Procedures*
This recommended practice provides guidance for maintaining a cleanroom at the level for which it was designed. It is a guide for establishing appropriate housekeeping

procedures, along with provision of test procedures to verify effectiveness of the housekeeping operations.

IEST-RP-CC022 *Electrostatic Charge in Cleanrooms and Other Controlled Environments*
This practice discusses methods for specifying and evaluating effectiveness of techniques for controlling electrostatic charge. Test methods are given, along with guidelines for verifying charge neutralization and resistivity of materials.

IEST-RP-CC023 *Microorganisms in Cleanrooms*
This recommended practice provides guidelines for the control and measurement of viable contamination in the air and on surfaces in cleanrooms. Some of the disinfectants now available are also described.

IEST-RP-CC026 *Cleanroom Operations*
This recommended practice provides guidance for maintaining integrity of the cleanroom during ancillary operation, as material preparations, facility modifications, equipment repair, etc. Procedures are given for verifying cleanliness of equipment and work areas.

IEST-RP-CC034 *HEPA and ULPA Filter Leak Tests*
This recommended practice covers definitions, equipment, and procedures for leak testing HEPA and ULPA filters at the factory, the site of installation and after installation.

ISO 14644-1 *Classification of Air Cleanliness*
This is the first in a series of standards developed by the International Standards Organization (ISO) addressing contamination control. This standard addresses the requirements for the different cleanliness classifications. Cleanrooms and associated controlled environments provide for the control of airborne particulate contamination to levels appropriate for accomplishing contamination-sensitive activities. Products and processes that benefit from the control of airborne contamination include aerospace, microelectronics, pharmaceuticals, medical devices, healthcare, food, and others. Many factors besides airborne particulate cleanliness must be considered in the design, specification, operation, and control of cleanrooms and other controlled environments. These are covered in some detail in other parts of the ISO 14644.

ISO 14644-2 *Specifications for Testing and Monitoring to Prove Continued Compliance with ISO 14644-1*
This document provides a mechanism to prove continued compliance with ISO 14644-1 and specifies minimum requirements for testing and monitoring. In any testing plan, consideration should also be given to the particular operational requirements, risk assessment of the installation and its use.

ISO 14644-3 *Test Methods*
This part of ISO 14644 specifies test methods for designated classification of airborne particulate cleanliness and for characterizing the performance of cleanrooms and clean zones. Performance tests are specified for two types of cleanrooms and clean zones: those with unidirectional flow and those with non-unidirectional flow, in three possible occupancy states: as-built, at-rest and operational. The test methods recommend test apparatus and test procedures for determining performance parameters. Where the test method is affected by the type of cleanroom or clean zone, alternative procedures are suggested. For some of the tests, several different methods and apparatus are recommended to accommodate different end-use considerations.

ISO 14644-4 *Design, Construction and Start-up*
This document specifies the requirements for the design and construction of the cleanroom facilities but does not prescribe specific technological nor contractual means to meet the requirements. It is intended for use by purchasers, suppliers, and designers of cleanroom installations and provides a check list of important parameters of performance. Construction guidance is provided, including requirements for start up and qualification. Basic elements of design and construction needed to ensure continued satisfactory operations are identified through the consideration of relevant aspects of operation and maintenance.

ISO 14644-5 *Operation*
This document provides those basic requirements for operating and maintaining cleanrooms and associated controlled environments to meet the standards of the particular cleanroom as designed, built, and used. This standard addresses requirements that are basic to the operation of all cleanrooms regardless of the application.

ISO 14644-6 *Vocabulary*
This document harmonizes the definitions of terms used in describing materials and processes relating to cleanrooms and associated controlled environments.

ISO 14644-7 *Separative Devices(Clean Air Hoods, Gloveboxes, Isolators, and Minienvironments)*
This section defines the performance requirements in areas of minienvironments and isolators. These requirements will focus on ways that minienvironments differ from cleanrooms in the area of monitoring, design, testing, molecular contamination, material compatibility, integrity, and microbial contamination.

ISO 14644-8 *Classification of Airborne Molecular Contamination*
This part of ISO 14644 covers the classification of airborne molecular contamination (AMC) in cleanrooms and associated controlled environments, in terms of airborne concentrations of specific chemical substances (individual, group or category) and provides a protocol to include test methods, analysis and time weighted factors within the specification for classification.

National Environmental Balancing Bureau (NEBB)
8575 Grovemont Circle, Gaithersburg, Maryland 20877

Procedural Standards for Certified Testing of Cleanrooms
This manual provides an extensive array of information on cleanroom testing, technology and test procedures. It includes: standards issues dealing with the NEBB Cleanroom program, requirements of the Certified CPT Firm, Certified CPT Professionals, instrumentation requirements, reporting requirements, standard operating procedures and exacting procedural issues for all primary and secondary cleanroom tests. Also included is a sample specification, listing of cleanroom references, and engineering and statistical data and examples.

Study Course for Certified Testing of Cleanrooms
This is a self-study course in cleanrooms, cleanroom design and systems including cleanroom testing equipment, control systems, cleanroom test procedures and cleanroom equipment and accessories. The package includes multiple lessons plus a

study course examination, reference material and associated engineering and statistical materials.

Procedural Standards for Fume Hood Performance Testing
This manual provides a basis for the fume hood testing program by providing Certified Firm and Certified Professional requirements, instrumentation and reporting requirements and step-by-step testing procedures in evaluating fume hood performance. It also includes a sample specification, references, and sample reporting forms.

Procedural Standards for the Measurement of Sound and Vibration
This publication provides step-by-step comprehensive guidance for obtaining and recording sound and vibration data on HVAC systems. Topics include: instrumentation, inspection of building construction and conditions, interior and exterior sound measurement, and vibration measurement procedures. Also covered are sample specifications and sample reporting forms.

Sound and Vibration Design and Analysis
A concise coverage of sound and vibration as it relates to HVAC systems. Basic concepts of the science of sound and vibration are covered, plus the most current information on equipment sound levels, duct element regenerated and sound power and attenuation, duct breakout and break-in, sound transmission in indoor and outdoor spaces, and vibration analysis. It includes references and glossary.

Study Course for Measuring Sound and Vibration
A home study course on measuring sound and vibration, it guides the student in an orderly sequence, with diagrams, charts and problems to recognize principles and procedures. The package includes multiple lessons and final examination, associated reference texts and binder.

Environmental Systems Technology
A full length, hard-back "collectors type" textbook in a distinctive Victorian style incorporating HVAC system history and fundamentals, engineering principles, system design, equipment components and installation, testing and balancing, controls, acoustics, and an extensive glossary and set of engineering tables.

Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems
A "how-to" set of procedural standards that provide systematic methods for testing, adjusting, and balancing (TAB) of HVAC systems includes sections on TAB instruments and calibration, report forms, and sample specification.

Testing, Adjusting, Balancing Manual for Technicians
A practical field-use manual for balancing technicians designed to be used for reference and job site application as well as for training balancing crews. This edition includes a section on mathematics and equations for field use.

Procedural Standards for Building Systems Commissioning
This manual serves a comprehensive guide for commissioning building systems. The text describes the commissioning process, organization, planning, procedures and methods for verifying and documenting the performance of building systems. There are focus section on the commissioning of HVAC, Plumbing and Fire Protection Systems.

National Fire Prevention Association (NFPA)
1 Batterymarch Park Quincy, Massachusetts

NFPA 318 *Standard for the Protection of Semiconductor Fabrication Facilities*
The document provides requirements for fire protection systems utilized in semiconductor fabrication facilities.

NSF International (National Sanitation Foundation) (NSF)
789 N. Dixboro Road, Ann Arbor, Michigan 48113

NSF 49 *Class II (Laminar Flow) Biosafety Cabinetry*
This document applies to cabinetry designed to minimize hazards inherent in work with low and moderate risk biological agents and defines tests which must be passed.

United States of America, Agencies & Departments
Air Force Headquarters, AFCL/DAPD
Wright-Patterson AFB, Ohio 45433

H.1 AFM 88-4 Chapter 5 *Criteria for Air Force Clean Facility Designs and Construction*
Prescribed criteria for the design and construction of Air Force clean facilities. It specifies the real property standards for meeting the requirements of Air Force TO 00-25-203.

H.2 TO 00-25-203 *Contamination Control of Aerospace Facilities, U.S. Air Force*
This document specifies cleanroom design, operating, and test procedures. It also includes recommended cleanliness levels for typical operations.

Food and Drug Administration
5600 Fishers Lane, Rockville, Maryland 20857

Current Good Manufacturing Practice 21CFR 211(cGMP)
Required facility status, manufacturing procedures, personnel action, facility and product cleanliness as well as required record formats are summarized. This document is vital for all pharmaceutical manufacturing.

Guidelines to Inspections of Aseptic Processing and Packaging for the Food Industry
This document is reference materials for investigators and other FDA personnel and provides aseptic processing guidelines.

NASA
John F. Kennedy Space Center, Orlando, Florida 32815

MSFC-STD-246A Standard *for Design and Operation Criteria of Controlled Environmental Areas*
Design criteria and operating guide lines are given for clean areas at MSFC facilities.

Standardization Documents Order Desk
Building 4D, 700 Robbins Avenue, Philadelphia, Pennsylvania 1911-5094

MIL-STD-1246C *Product Cleanliness Levels and Contamination Control Program*
This document provides a basis and a uniform method to specify cleanliness levels and contamination control program requirements. Cleanliness classification levels are given.

National Technical Information Service
U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161

NTIS/NASA SP-5045 *Contamination Control Principles*
Document provides a broad overview and guidelines to those designing or planning cleanroom facilities.

NTIS/NASA SP-5074 *Cleanroom Technology*
Document provides considerable information on history, need, nature and type of cleanrooms with details of cleanroom environment and operation.

NTIS/NASA SP-5076 *Contamination Control Handbook*
Extensive detail on contaminants and their control and cleaning methods.

The Naval Publications and Forms Center
5801 Tabor Avenue, Philadelphia, Pennsylvania 19120

NPFC/MIL-HDBK-406 *Contamination Control Technology—Cleaning Materials for Precision Precleaning and Use in Clean Rooms and Clean Work Stations*
Document contains extensive information on selection and use of cleaning materials developed by DOD.

NPFC/MIL-HDBK-407 *Contamination Control Technology—Precision Cleaning Methods and Procedures*
Document contains extensive information on cleaning methods used by the military services for gross and precision cleaning of work processed under controlled environment conditions.

NPFC/MIL-F-0051068 *Military Specification: Filter, Particulate, High-Efficiency, Fire Resistant*
Document covers design, construction, and performance of HEPA filters in six sizes and seven types.

NPFC/MIL-F-51079 *Military Specification: Filter Medium, Fire-Resistant, High-Efficiency*
Provides requirements and test methods for determining compliance for one grade of HEPA filter medium.

NPFC/MIL-F-51477 *Military Specification: Filters, Particulate, High-Efficiency, Fire Resistant, Biological Use*
Covers general requirements for particulate filters for use in air cleaning or air filtration systems involving chemical, carcinogenic, radiogenic, or hazardous biological particles.

Federal Std. 209E *Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones*
This document establishes standard cleanliness classes for cleanrooms and clean zones, based on specified concentrations of inert airborne particles. It prescribes methods for verifying air cleanliness using statistical methodology.

USP Publication 797 *Pharmaceutical Compounding – Sterile Preparations*
This document provides sample documents describing high-level pharmacy requirements for compliance with the regulation …

British Standard (BS EN 1822)
789 N. Dixboro Road, Ann Arbor, Michigan 48113

NSF 49 *Class II (Laminar Flow) Biosafety Cabinetry*
This document applies to cabinetry designed to minimize hazards inherent in work with low and moderate risk biological agents and defines tests which must be passed.

European Commission (EU)
B1029 Brussels, Belgium, Europe phone (32-2) 299 11 11

EU Guidelines to Good Manufacturing Practice of Medicinal Products for Human and Veterinary Use.

Annex 1 *Manufacture of Sterile Medicinal Products*

This document provides guidance for particle limits in cleanrooms within the European community.

APPENDIX C ENGINEERING FORMULAS, EQUIVALENTS & EXAMPLES

C.1 HVAC ENGINEERING FORMULA (SI UNITS)

C.1.1 AIR EQUATIONS

A. $V = 1.414 \bullet (V_P/d)^{½}$

where
V = Velocity
d = density, "d" = 3.48 (P_b/T)

B. $V = (1.66 \bullet V_P)^{½}$ for Std. air (d = 1.204 kg/m^3)

C. $TP = V_P + SP$

D. $V = V_M (d / 1.204)$

E. Airflow Volume (L/s) = 1000 ● Area ● Volume

C.2 HVAC ENGINEERING FORMULA (IP UNITS)

C.2.1 AIR EQUATIONS

A. $V = 1096 \bullet (V_P/d)^{½}$

where
V = Velocity
d = density, "d" = 1.325 (P_b/T)

B. $V = 4005 \bullet (V_P)^{½}$ for Std. air (d = .075 lbs/ft^3)

C. $TP = V_P + SP$

D. $V = V_M (d / 0.075)$

E. Airflow Volume (cfm) = Area ● Volume

C.3 METRIC EQUIVALENTS

QUANTITY	SYMBOL	UNIT	IP RELATIONSHIP
acceleration	m/s^2	meters per second squared	1 m/s^2 = 3.281 ft/sec^2
airflow volumetric flow rate	m^3/s	cubic meters per second	1 m^3/s = 2118.88 cfm
	L/s	liters per second	1 L/s = 2.12 cfm
	m^3/hr	cubic meters per hour	1 m^3/hr = 0.589 cfm
area	m^2	square meter	1 m^2 = 10.76 ft^2
	mm^2	square millimeters	1 mm^2 = 0.0016 in^2
atmospheric pressure	kPa	kiloPascals	101.325 kPa = 29.92 in. Hg = 14.696 psi
	Bar	Barometers	1 Bar = 29.92 in. Hg = 14.696 psi
distance, length, or displacement	M	meter	1 m = 3.281 ft.
	M	meter	1 m = 39.37 inches
	mm	millimeter	1 mm = 0.039 inches, 1 inch = 25.4 mm
lighting intensity	Lx	Lux	1 lx = 0.0929 fc
	lm/m^2	Lumens/square meter	1 lm/m^2 = 0.0931 fc
lighting power	Lm	Lumen	1 Lm = 0.001496 watts
pressure	kPa	kiloPascals =1000 Pascals	1 kPa = 0.296 in. Hg = 0.145 psi
	Pa	Pascals	1 Pa = 0.004015 in.w.g.
temperature	°C	degrees Celsius	°C = (°F – 32)/1.8
velocity	m/s	meters per second	1 m/s = 196.9 fpm
volume	m^3	cubic meters	1 m^3 = 35.31 ft^3

C.4 AIR DENSITY CORRECTION FACTORS

Table C-1: Air Density Correction Factors (SI Units) Standard Air Density (Sea Level and 20ºC) = 1.204 kg/m^3 at 101.325 kPa

Altitude (m)	Sea Level	250	500	750	1000	1250	1500	1750	2000	2500	3000
Barometer (kPa)	101.3	98.3	96.3	93.2	90.2	88.2	85.1	83.1	80.0	76.0	71.9
Air Temp ºC 0º	1.08	1.22	1.17	1.13	1.09	1.05	1.01	0.97	0.93	0.90	0.87
20º	1.00	1.11	1.07	1.03	0.99	0.95	0.91	0.89	0.85	0.82	0.79
50º	0.91	1.02	0.99	0.95	0.92	0.88	0.85	0.82	0.79	0.76	0.73
75º	0.85	0.96	0.93	0.89	0.86	0.83	0.80	.077	0.74	0.71	0.69
100º	0.79	0.92	0.88	0.85	0.81	0.78	0.75	0.73	0.70	0.68	0.65
125º	0.74	0.84	0.81	0.78	0.75	0.72	0.69	0.67	0.65	0.62	0.60
150º	0.70	0.77	0.74	0.71	0.69	0.66	0.64	0.62	.060	0.57	0.55
175º	0.66	0.72	0.70	0.67	0.64	0.62	0.60	0.58	0.56	0.54	0.51
200º	0.62	0.67	0.65	0.62	0.60	0.58	0.56	0.54	0.52	0.50	0.48
225º	0.59	0.62	0.60	0.58	0.56	0.54	0.52	0.51	0.49	.047	0.45
250º	0.56	0.60	0.57	0.55	0.53	0.51	0.49	0.48	0.46	0.44	0.42
275º	0.54	0.56	0.54	0.52	0.50	0.48	0.46	0.45	0.43	0.42	0.40
300º	0.51	0.53	0.51	0.49	0.47	0.45	0.44	0.43	0.41	0.39	0.38
325º	0.49	0.51	0.49	0.47	0.45	0.44	0.42	0.41	0.39	0.38	0.36
350º	0.47	0.48	0.46	0.45	0.43	0.41	0.40	0.39	0.37	0.35	0.34
375º	0.46	0.44	0.43	0.41	0.39	0.38	0.37	0.35	0.34	0.33	0.32
400º	0.44	0.40	0.39	0.37	0.36	0.35	0.33	0.32	0.31	0.30	0.29

Table C-2: Air Density Correction Factors (U.S. Units) Standard Air Density (Sea Level and 70ºF) = 0.075 lb/ft^3 at 29.92 in. Hg.

Altitude (ft)	Sea Level	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
Barometer (in. of Hg.) (in. w.g.)	29.92 407.50	28.86 392.80	27.82 378.60	26.82 365.00	25.84 351.7	24.90 333.90	23.98 326.40	23.09 314.80	22.22 302.10	21.39 291.10	20.58 280.10
Air Temp ºF -	1.26	1.22	1.17	1.13	1.09	1.05	1.01	0.97	0.93	0.90	0.87
40º	1.15	1.11	1.07	1.03	0.99	0.95	0.91	0.89	0.85	0.82	0.79
0º	1.06	1.02	0.99	0.95	0.92	0.88	0.85	0.82	0.79	0.76	0.73
40º	1.00	0.96	0.93	0.89	0.86	0.83	0.80	.077	0.74	0.71	0.69
70º	0.95	0.92	0.88	0.85	0.81	0.78	0.75	0.73	0.70	0.68	0.65
100º	0.87	0.84	0.81	0.78	0.75	0.72	0.69	0.67	0.65	0.62	0.60
150º	0.80	0.77	0.74	0.71	0.69	0.66	0.64	0.62	.060	0.57	0.55
200º	0.75	0.72	0.70	0.67	0.64	0.62	0.60	0.58	0.56	0.54	0.51
250º	0.70	0.67	0.65	0.62	0.60	0.58	0.56	0.54	0.52	0.50	0.48
300º	0.65	0.62	0.60	0.58	0.56	0.54	0.52	0.51	0.49	.047	0.45
350º	0.62	0.60	0.57	0.55	0.53	0.51	0.49	0.48	0.46	0.44	0.42
400º	0.55	0.56	0.54	0.52	0.50	0.48	0.46	0.45	0.43	0.42	0.40
450º	0.58	0.53	0.51	0.49	0.47	0.45	0.44	0.43	0.41	0.39	0.38
500º	0.53	0.51	0.49	0.47	0.45	0.44	0.42	0.41	0.39	0.38	0.36
550º	0.50	0.48	0.46	0.45	0.43	0.41	0.40	0.39	0.37	0.35	0.34
600º	0.46	0.44	0.43	0.41	0.39	0.38	0.37	0.35	0.34	0.33	0.32
700º	0.42	0.40	0.39	0.37	0.36	0.35	0.33	0.32	0.31	0.30	0.29
800º											

C.5 TAB ENGINEERING

C.5.1 TRAVERSE CALCULATIONS

The purpose of this section is to perform a sample duct traverse layout and perform a sample airflow calculation.

Traverse measurements are performed in order to calculate the airflow volume (m^3/s or cfm) flowing inside of a duct from actual field measurements. The airflow volume is a function of two components: the cross sectional area of the duct (m^2 or ft^2) and the velocity of the air (m/s or fpm) flowing inside that duct. Equation C.5.1 identifies the relationship.

Equation C.5.1 $Q = V \times A$

where: Q = Airflow Volume (m^3/s or cfm)
V = Velocity (m/s or fpm)
A= Cross-sectional area of the traverse plane (m^2 or ft^2)

Measurements of airflow velocity are usually performed with a manometer and a Pitot tube. An analog manometer will provide measurements in units of velocity pressure (Pa or in. w.c). Velocity pressure measurements can be converted to units of velocity using Equation C.5.2.

Equation C.5.2 (SI): $V = 1.414 \bullet (V_P/d)^{½}$

where: V = Velocity in m/s
V_P = Velocity pressure in Pa
D = Density in kg/m^3

or, for Standard Air (d = 1.204 kg/m^3)
$V = (1.66 \bullet V_P)^{½}$

Equation C.5.2 (IP): $V = 1096 \bullet (V_P/d)^{½}$

where: V = Velocity in fpm
V_P = Velocity pressure in in. w.c.
D = Density in lbs/ft^3

or, for Standard Air (d = .075 lbs/ft^3)
$V = 4005 \bullet (V_P)^{½}$

Digital manometers also measure velocity pressure and automatically perform the conversion and display the velocity value directly. In either case, the important feature to note is that individual velocity pressures shall be converted to individual velocities and then averaged to obtain the average airflow velocity in the duct.

NOTE: Because the velocity varies directly as the square root of velocity pressure, it is incorrect to simply average the velocity pressures and then make one conversion to velocity.

Regardless of the type and size of duct insulation (none, lined, or wrapped), the shape of the duct, or materials of construction, there are several uniform concepts that apply to all duct traverse measurements and calculations:

1. The cross sectional area and the shape of the duct at the location of traverse plane shall be uniform. The traverse plane should not be located in a transition.
2. The traverse plane should be located in a straight run of duct, sufficiently upstream and downstream of elbows, transitions, obstructions, equipment, fans, etc.
3. The direction of the air stream should be at right angles to the traverse plane and the Pitot tube position should be within 5° of perpendicular to the traverse plane at the maximum velocity pressure.
4. No readings shall be less than zero.
5. An accuracy of ±10% is usually achieved when 75% of the velocity pressure readings are greater than 0.10 of the maximum velocity pressure reading.

There are two methods for traverse layouts in rectangular ducts: the Equal Area Method and the Log Tchebycheff Rule (named after the Russian physicist who created the method) or more simply, the Log T Method. Either layout method is acceptable. Duct traverse layouts in round ducts follow a method known as Log Linear. Finally, there are referenced traverse layouts for flat oval duct also. Examples of layouts and the requirements for round ducts, flat oval ducts, or either the Equal Area or the Log T method for rectangular ducts can be found in the current edition of the NEBB *Testing Adjusting Balancing Manual for Technicians.*

C.5.2 SAMPLE TRAVERSE LAYOUT AND AIRFLOW CALCULATION

The traverse layout and calculations presented in this example are intended to serve as a working illustration of the correct procedures and methods involved in determining airflow volume in a duct. For this example we have a 750 mm x 450 mm (26" X 14") OD duct that is lined with 25 mm (1") of fiberglass insulation. You are required to layout an Equal Area Traverse, take the appropriate velocity pressure measurements, and determine the actual airflow volume flowing in the duct. According to NEBB requirements, an Equal Area Traverse is to have a minimum of 16 readings with a maximum spacing of 150 mm (6") between readings. The maximum number of readings is 64. After 64 readings the center-to-center distance may be increased accordingly. Each reading is to be located in the center of each equal area duct section.

Solution: The Equal Area Method creates equal area sections inside the duct opening. It is only concerned about the internal, or inside, dimensions of the duct. Our duct in this example has an outside dimension of 750 mm x 450 mm (30" X 18"), but the inside free area is 700 mm by 400 mm (28" x 16"). So, we need to layout a minimum of 16 equal are sections within the 700 mm x 400 mm (28" x 16") opening.

For this example, we have selected to perform a traverse with 7 sets readings across the bottom of the duct and 4 sets of reading down the vertical side. This would produce a 7x 4 averaging grid, or 28 points of measurement. That exceeds the minimum requirement of 16 readings which is acceptable. Additionally, each equal area section is 100 mm x 100 mm (4" x 4") and the location of each measurement point is exactly centered in the middle of each equal are section. Other traverse layouts are acceptable as long as the minimum number of points is 16 and the maximum spacing is followed.

The solution is shown in Figure C.5.1 below:

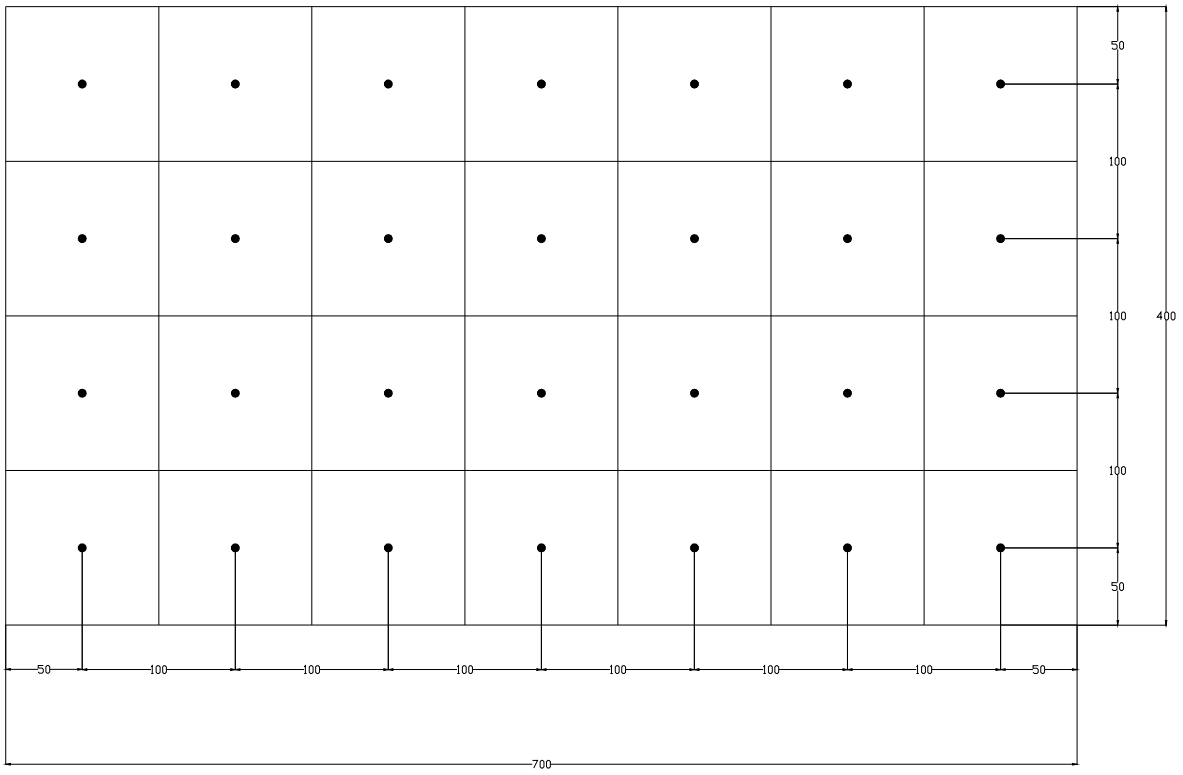

FIGURE C5.1

Assuming we have now correctly laid out the traverse point grid, the actual velocity pressure measurements are made. Table C-3 identifies the field measurements.

Table C-3 (SI) Velocity Pressure Measurements (Pa)

Location	1	2	3	4	5	6	7
1	8	9	9	10	11	11	8
2	14	19	19	20	21	16	10
3	16	17	18	19	14	13	10
4	14	14	17	17	13	11	11

Table C-3 (IP) Velocity Pressure Measurements (in. w.c.)

Location	1	2	3	4	5	6	7
1	0.032	0.036	0.036	0.040	0.044	0.044	0.032
2	0.056	0.076	0.076	0.080	0.084	0.064	0.040
3	0.064	0.068	0.072	0.076	0.056	0.052	0.040

4	0.056	0.056	0.068	0.068	0.052	0.044	0.044

As previously mentioned, each velocity pressure must now be converted to individual velocities and then the individual velocities are averaged. Table C-4 has converted each velocity pressure to velocity.

Table C-4 (SI) Velocity Measurements (m/s)

Location	1	2	3	4	5	6	7
1	3.69	3.95	3.95	4.08	4.27	4.27	3.69
2	4.78	5.62	5.62	5.75	5.84	5.16	4.08
3	5.16	5.30	5.52	5.62	4.78	4.64	4.08
4	4.78	4.78	5.30	5.30	4.64	4.27	4.27

Table C-4 (IP) Velocity Measurements (fpm)

Location	1	2	3	4	5	6	7
1	716	760	760	801	840	840	716
2	948	1104	1104	1133	1161	1013	801
3	1013	1044	1075	1104	948	913	801
4	948	948	1044	1044	913	840	840

The average velocity can now be calculated by adding all of the individual velocities and dividing by the total number of readings. The average velocity is 5.15 m/s (1014 fpm). The total airflow volume in the duct can now be determined by using Equation C.5.1

Equation C.5.1 (SI) $Q = V \times A$
$Q = 5.15 \text{ m/s} \times (700 \text{ mm} \times 400 \text{ mm}) / 1{,}000{,}000 = 1.44 \text{ m}^3/\text{s}$

Equation C.5.1 (IP) $Q = 1014 \text{ fpm} \times (28 \times 16'') / 144 = 3154 \text{ cfm}$

Comparing the metric to IP values is not an exact conversion as 1.00 m³/s should equal 2119 cfm. The reason this sample calculation did not come out to the exact value is that we used "soft" conversions in length, area, velocity and velocity pressure. 700 mm is exactly 27.56", not 28". The purpose of the example was not to demonstrate metric to IP conversions but rather to demonstrate the correct procedure to layout a duct traverse, take the correct velocity pressure measurements, convert the measurements to individual velocities, obtain an average velocity and then finally determine the actual airflow volume in the duct.

C.6 STATISTICAL FORMULA AND EXAMPLES

C.6.1 95% UPPER CONFIDENCE LIMIT (UCL) CALCULATIONS

In calculating the 95% upper confidence limit, you must first calculate the average particle concentration. After determining the average particle calculations, you must then calculate the mean of the averages. The standard deviation can then be calculated using the mean of the averages. After determining the standard deviation, the standard error may be determined. Then finally, the 95% upper confidence limit may be calculated. This procedure is only required if you take less than 10 sample locations.

Average Particle Concentration

The average particle concentration (A) at a sample location is the sum of the individual sample particle counts (C_1) divided by the number of samples taken at the location (N), as shown in Equation C.6.1. If only one sample is taken, it is the average particle concentration.

Equation C.6.1

$$A = (C_1 + C_2 + ... + C_N) / N$$

C.6.1.1 Mean of the Averages
The mean of the averages (M) is the sum of the individual averages (A_1) divided by the number of locations (L), as shown in Equation C.6.2. All locations are weighted equally regardless of the number of samples taken.

Equation C.6.2

$$M = (A_1 + A_2 + ... + A_L) / L$$

C.6.1.2 Standard Deviation
The standard deviation (SD) of the averages is the square root of the sum of the squares of differences between each of the individual averages and the mean of the averages $(A_1–M)^2$ divided by the number of locations (L) minus one, as shown in Equation C.6.3.

Equation C.6.3

$$SD = \sqrt{\frac{(A_1 - M)^2 + (A_2 - M)^2 + ... + (A_L - M)^2}{L-1}}$$

C.6.1.4 Upper Confidence Limit (UCL)
The 95 percent UCL of the mean of averages (M) is determined by adding to the mean the appropriate UCL factor (see Table C-5 for UCL factor) times the standard error (SE), as shown in Equation C.6.5.

Equation C.6.5

$$UCL = M + \frac{UCL Factor x SD}{\sqrt{L}}$$

Note: This statistical analysis deals only with random errors (lack of precision), not errors of a nonrandom nature ("bias"), such as erroneous calibration.

TABLE C-5 UCL Factor for 95 Percent Upper Confidence Limit

No. of Locations (L)	1	2	3	4	5	6	7	8	9	>9*
95 percent UCL factor	NA	6.3	2.9	2.4	2.1	2.0	1.9	1.9	1.9	NR

*When the number of locations is greater than 9, the calculations of a UCL is not required (NR).
*When the number of locations is only one, the calculation of a UCL does not apply (NA).

C.6.2 RESULT INTERPRETATION OF DATA STATISTICAL ANALYSIS

C.6.2.1 Acceptance Criteria
The cleanroom or clean zone shall meet the acceptance criteria for an airborne particulate cleanliness class if:

a. the average of the particle concentration (see Table 10 – 1) measured at each location falls at, or below, the class limit, and
b. if only one sample location is used, then the 95% UCL does not apply.
c. the total number of locations sampled is less than ten, the mean of these averages must fall at or below the class limit with a 95 percent confidence limit.

C.6.2.2 Outliers
If the results are non-compliant due to a single "outlier" value, (due to procedural error or equipment malfunction), it does not need to be included in the analysis provided that the calculation is repeated, and at least three measurements values remain in the calculation

C.6.3 Example Calculation #1 (Cleanliness Classification Tests Calculation Procedure)

The data and calculations presented in this example calculation are intended to serve as a working illustration of the statistical procedures involved in determination of acceptance criteria for cleanrooms and clean zones. The data and calculations are based upon a 28.3 Liters (1 cubic foot) sample volume and testing at 0.3 µm measured particle size for ISO Class 4.

Particle counts have been taken in a cleanroom. The number of particle counts, the actual sample counts and the number of sample locations is presented in Table C-7.1. The Owner has stated the cleanroom classification is an ISO Class 4 room at 0.3 µm. Calculate the 95% UCL and determine if the cleanroom meets that cleanliness classification.

TABLE C-7.1 Tabulation of Particle Count Data

	Particle Counts (C_1)					Total No. of Samples (N)	(C_1) Total Count	(A_1) Average Counts
Location	**1**	**2**	**3**	**4**	**5**			
A	1010	744	557	697	NR	4		
B	989	NR	633	455	NR	3		
C	765	334	NR	544	333	4		
D	868	NR	454	988	999	4		
E	799	1050	455	NR	NR	3		

(NR – no reading taken)

C.6.3.1 Average Particle Concentration
As stated above, the average particle concentration (A) at a location is the sum of the individual sample particle counts (C_1) divided by the number of samples taken at the location (N), as shown in Equation C.6.1. If only one sample is taken, it is the average particle concentration.

Equation C.6.1

$A = (C_1 + C_2 + ... + C_N) / N$, Thus:
$A_1 = (1010 + 744 + 557 + 697) / 4 = 3008/4 = 752.0$
$A_2 = (989 + 633 + 455) / 3 = 2077/3 = 692.3$
$A_3 = (765 + 334 + 544 + 333) / 4 = 1976/4 = 494.0$
$A_4 = (868 + 454 + 988 + 999) / 4 = 3309/4 = 827.3$
$A_5 = (799 + 1050 + 455) / 3 = 2304/3 = 768.0$

This data can now be inserted into its appropriate space in the table and the completed table is shown in Table C-7.2.

TABLE C-7.2 Tabulation of Particle Count Data

	Particle Counts (C_1)					Total No. of Samples (N)	(C_1) Total Count	(A_1) Average Counts
Location	**1**	**2**	**3**	**4**	**5**			
A	1010	744	557	697	NR	4	3010	752.0
B	989	NR	633	455	NR	3	2077	692.3
C	765	334	NR	544	333	4	1976	494.0
D	868	NR	454	988	999	4	3309	827.3
E	799	457	455	NR	NR	3	2304	768.0

C.6.3.2 Mean of the Averages
The mean of the averages (M) is the sum of the individual averages (A_1) divided by the number of locations (L), as shown in Equation C.6.2. All locations are weighted equally regardless of the number of samples taken.

Equation C.6.2

$M = (A_1 + A_2 + ... + A_L) / L$, Thus:
$M = (752.0 + 692.3 + 494.0 + 827.3 + 768.0)/5 = 706.1$

C.6.3.3 Standard Deviation
The standard deviation (SD) of the averages is the square root of the sum of the squares of differences between each of the individual averages and the mean of the averages $(A_1–M)^2$ divided by the number of locations (L) minus one, as shown in Equation C.6.3:

Equation C.6.3

$$SD = \sqrt{\frac{(A_1 - M)^2 + (A_2 - M)^2 + ... + (A_L - M)^2}{L - 1}}$$

Thus:

$$SD = \sqrt{\frac{(752.5-706.1)^2 + (692.3-706.1)^2 + (494.0-706.1)^2 + (827.3-706.1)^2 + (768.0-706.1)^2}{5-1}}$$

$$SD = \sqrt{\frac{(46.4)^2 + (-13.8)^2 + (-212.1)^2 + (121.2)^2 + (62.1)^2}{5-1}} = 128.33$$

C.6.3.4 Standard Error
The standard error (SE) of the mean of the averages (M) is determined by dividing the standard deviation (SD) by the square root of the number of locations, as shown in Equation C.6.4.

Equation C.6.4

$$SE = \frac{SD}{\sqrt{L}}$$

Thus,

$$SE = \frac{128.33}{\sqrt{5}} = 57.4$$

C.6.3.5 Upper Confidence Limit (UCL)
The 95 percent UCL of the mean of averages (M) is determined by adding to the mean the appropriate UCL factor (see Table C-5 for UCL factor) times the standard error (SE), as shown in Equation C.6.5.

Equation C6.5

$$UCL = M + (UCL_{factor} \times SE)$$

$$UCL = 706.1 + (2.13 \times 57.4) = 828.36$$

C.6.3.6 Summary
As stated above, the cleanroom or clean zone shall meet the acceptance criteria for an airborne particulate cleanliness class if:

a. the average of the particle concentration (see Table 10 – 1) measured at each location falls at, or below, the class limit, and
b. if only one sample location is used, then the 95% UCL does not apply.
c. the total number of locations sampled is less than ten, the mean of these averages must fall at or below the class limit with a 95 percent confidence limit

Conclusion

For this example calculation, the 95% UCL is 828.36. The Owner has stated that the cleanroom's cleanliness classification is an ISO Class 4 at 0.3 µm. From Table 10-1, the class limit for these conditions is 1020 particles per cubic meter. Since the upper 95 percent confidence limit (UCL) is less than 1020 particles per cubic meter and all location average particle concentrations (A_1) were less than 1020 particles per cubic meter, the above data meet the acceptance criteria for an ISO Class 4 at 0.3 µm. Even though one or more of the individual particle counts is above 1020 particles per cubic meter, the room still passes the acceptance criteria.

C.6.4 Sample Calculation for Uniformity (Applies to Airflow Velocity Uniformity Tests, Airflow Volume Uniformity Tests, Temperature and Humidity Uniformity Tests and Lighting Level Uniformity Tests)

This calculation procedure is performed when taking 5 or more data points to determine the uniformity of the data. The method described is applicable to all of the uniformity tests, such as velocity, volume, temperature and humidity, lighting levels, and sound levels.

The data and calculations presented in this example calculation are intended to serve as a working illustration of the statistical procedures involved in determination of the relative standard deviation. For this example, airflow volumes readings have been taken at 5 HEPA filters. The results are identified in Table C-8.

TABLE C-8 Tabulation of Airlfow Volume Data

HEPA Filter	Measured Volumes (cfm)
A	710
B	725
C	690
D	701
E	744
Average	714.0

C.6.4.1 Standard Deviation

The standard deviation (SD) of the readings is the square root of the sum of the squares of differences between each of the individual readings and the average reading $(A_1–M)^2$ divided by the number of locations (L) minus one, as shown in Equation C.6.3:

Equation C.6.3

$$SD = \sqrt{\frac{(A_1 - M)^2 + (A_2 - M)^2 + ... + (A_L - M)^2}{L - 1}}$$ Thus:

$$SD = \sqrt{\frac{(710 - 714)^2 + (725 - 714)^2 + (690 - 714)^2 + (701 - 714)^2 + (746 - 714)^2}{5 - 1}}$$

$$SD = \sqrt{\frac{(-4)^2 + (11)^2 + (-24)^2 + (-13)^2 + (32)^2}{5-1}}$$

$$SD = \sqrt{\frac{(16) + (121) + (576) + (169) + (1024)}{4}}$$

$$SD = \sqrt{\frac{1096}{4}} = 16.55$$

C.5.4.2 Relative Standard Deviation
The relative standard deviation is standard deviation divided by the average and is shown is Equation C.6.6.

Equation C.6.6

$$RSD = \frac{SD}{M}$$

$$RSD = \frac{16.55}{714} = 0.02318 = 2.32\%$$

C.7 SCAN RATE DETERMINATION AND EXAMPLE

C.7.1 Example Scan Rate

Section 10.13 details the requirements to perform the Filter Installation Leak Tests – Discrete Particle Counter Test Method. Section 10.13.2.4 identifies the formula to calculate the Acceptable Scan Rate (S_r). The formula is re-stated below as Equation C.7.1.

The following example details the procedure. You need to determine the scan rate for a HEPA Filter Installation Leak Test using a discrete particle counter. The upstream concentration is 106,007 particles per liter. The probe dimension is 1.27 cm parallel to the scan direction. The number of particles that indicate a significant leak is 3.0. The sample flow rate is 28.3 lpm. The significant leak percentage is 0.01%. Scanning shall be done isokinetically.

Solution: Use Equation C.7.1 to determine the appropriate scan rate.

Equation C.7.1

$$S_r = \frac{C_c \times L_s \times F_s \times D_p}{60 \times N_p}$$

Where:
S_r = Acceptable Scan Rate—cm/s (in/s)
C_c = Upstream challenge concentration—particles/L (particles/ft^3)

L_s = Significant leak—percentage of upstream concentration (typically 0.01%)
F_s = Sample flow rate of instrument used—L/m (cfm)
D_p = Probe dimension parallel to scan direction—cm (inches)
N_p = Number of particle counts that indicate the leak (1 through 10)
60 = conversion—60 sec/min

Inserting the known data would yield:

C_c = 106,007 ppl (3,000,000 ppcf)
L_s = 0.01% (0.0001)
F_s = 28.3 lpm (1.0 cfm)
D_p = 1.27 cm (0.50 in)
N_p = 3.0 Number of particle counts that indicate the leak
60 = conversion—60 sec/min

Thus Equation C.7.1 (SI) becomes:

$$S_r = \frac{106{,}007 \times 0.0001 \times 28.3 \times 1.27}{60 \times 3} = 2.1167 cm/\sec$$

or, Equation C.7.1 (IP) becomes:

$$S_r = \frac{3{,}000{,}000 \times 0.0001 \times 1.0 \times 0.5}{60 \times 3} = 0.833 in/\sec$$

If a lower value of Np is used (1) the allowable scan rate will be increased but the probability of finding a leak will be decreased. If a larger Np is used (10) the allowable scan rate is decreased but the probability of detecting a leak is increased.

C.8 PARALLELISM ANGULAR OFFSET FROM TRUE VERTICAL DETERMINATION AND EXAMPLE

C.8.1 ANGULAR DETERMINATION

The Airflow Parallelism Test requires that the angular offset of the airflow be determined. To determine the angular offset angle from true vertical as required by the Airflow Parallelism Test, use Equation C.8.1 and Figure C.8.1.

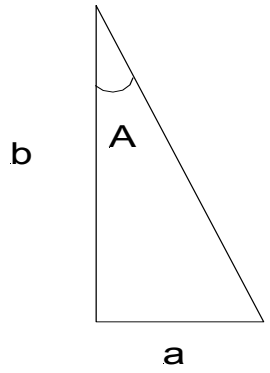

Figure C.8.1

Equation C.8.1 angle A = $\tan^{-1}$ (a/b)
Where:
A = Angular offset—degrees
a = Deflection distance—mm (inches)
b = Vertical height—mm (inches)

Table C-9 provides the tangent value and angle of some pre-calculated offsets.

TABLE C-9: Airflow Parallelism Test Angles

Tangent	Angle "A"
0.070	4°
0.105	6°
0.141	8°
0.176	10°
0.213	12°
0.249	14°
0.287	16°
0.325	18°

C.8.2 ANGULAR DETERMINATION – EXAMPLE

The Airflow Parallelism Test requires that the airflow can not deflect more than 14° from true vertical as it is discharged from the air outlets. Field measurements have indicated the following measurements: a = 369 mm (14.50 inches) and b = 1829 mm (72.00 inches).

Determine if the airflow meets test criteria.

Solution:

Equation C.8.1 angle A = $\tan^{-1}$ (a/b)

angle A = $\tan^{-1}$ (369/1829)

angle A = 11.4°, The test passes because the angle of deflection of the airflow is less than 14° from true vertical.

C.9 FILTER INSTALLATION LEAK TESTS – AMBIENT PARTICULATE TEST METHOD

This test is not recommended by NEBB. It is not to be considered an alternate equal to the either of the methods described Section 10.11 or Section 10.12. The reason that this test is not recommended by NEBB is due to the low upstream particle concentrations normally found in re-circulated air from cleanrooms. Typical users of this test are unable to locate significant leaks. Scan rates as calculated in Section 10.12 would be excessive. See the following example that is based on an airflow velocity of 0.51 m/s (100 fpm).

Example C.9.1

C_c	=	1,767 particles/L (50,000 particles/ft^3)
L_s	=	0.01% (0.0001)
F_s	=	28.3 L/min (1.0 cfm)
D_p	=	1.27 cm (0.50 in)
N_p	=	Number of particle counts that indicate the leak (1 through 10)
60	=	conversion—60 sec/min

Equation 10-3 (SI)

$$S_r = \frac{1767 \times 0.0001 \times 28.3 \times 1.27}{60 \times 1} = 0.1058 \text{ cm/s}$$

Equation 10-3 (IP)

$$S_r = \frac{50{,}000 \times 0.0001 \times 1.0 \times 0.50}{60 \times 1} = 0.0417 \text{ in/s}$$

Thus it would take 172.8 minutes to completely scan a 610 mm x 1220 mm (2 ft x 4 ft) filter. If a lower value of N_p is used, such as 1, the allowable scan rate will be increased but the probability of finding a leak will be decreased. If a larger N_p is used, such as 10, the allowable scan rate is decreased but the probability of detecting a leak is increased. For these reasons, NEBB does NOT recommend this test method.

C.10 SAMPLE AIR CHANGE RATE PER HOUR (ACH) CALCULATION

The following is an example of the procedure to be utilized when trying to determine the number of air changes per hour (ACH) that exist within a cleanroom or space. While the ACH provides a value as to the number of complete air changes occurring within a location, it is NOT an indicator as to the quality of the air or the effectiveness of the exchange rate. It is simply a mathematical relationship.

In order to determine the ACH, the room volume and the air total airflow within the space must be identified.

The formula for determining ACH is identified in Equation C-10.1 below.

Equation C-10.1 (SI): Air Change Rate per Hour (ACH)

$ACH = Q / V$

Where: Q = Airflow m^3 /hr
V = Volume m^3

Equation C-10.1 (IP): Air Change Rate per Hour (ACH)

$ACH = (Q \cdot 60) / V$
Where: Q = Airflow ft^3 /min
V = Volume ft^3
60 = minutes/hour

A final comment pertaining to air change rate relates to which airflow rate is used; total supply airflow or total return/exhaust airflow. Older conventions based the ACH on the supply airflow only regardless if the room was being maintained at a positive or negative pressure. Current thinking utilizes the total supply airflow rate for positively pressurized spaces and the total return/exhaust (which would include the total supply plus any infiltration) for negatively pressurized spaces.

C.11 CALCULATION OF Kv FACTOR TO DETERMINE AIRFLOW VOLUME FROM AVERAGE AIRFLOW FACE VELOCITY

The following procedure should be used when trying to determine a K_v factor. The K_v factor is used in determining the airflow volume from average airflow face velocity.

Select a standard filter that is accessible with the flow-hood. Take several (at least 2) readings to obtain a representative average airflow.

Divide airflow volume (L/s, M^3/m or s, cfm) by the effective filter area. The effective area is the actual area of the filter medium through which air is passing.

Measure the airflow velocity from the same filter using an instrument as listed in Section 4.

Average the readings to obtain average filter velocity.

Divide the actual filter velocity by the measured filter airflow to obtain the K_v factor by using Equation C-11.1.

Equation C-11.1: K_v Factor:

$$K_v = \frac{(Q_a)/(A_e)}{V_m}$$

Where: Kv = correction factor
Qa = Actual volumetric flow rate
Ae = Effective filter area
Vm = measured filter airflow velocity

Measure the inaccessible filter with the same velocity measuring instrument.

Multiply the average measured velocity by the K_v factor as calculated above to obtain actual filter velocity. Multiply the actual airflow velocity by the effective filter area to obtain equivalent volumetric flow rate.