CLEANROOM DESIGN

by

Douglas H Erickson

Bachelor of Architecture
Bachelor of Science in Architectural Studies
Washington State University
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Signature of Author _____

Douglas H Erickson
Department of Architecture
May 8, 1987

Certified by _____

Dr. Leon Glicksman
Senior Research Scientist
Thesis Advisor

Accepted by _____

Julian Beinart
Chairman
Department Committee for Graduate Students

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ABSTRACT

The development of the integrated circuit which replaced the vacuum tube, started the size reduction process for computer components. These integrated circuits are made from silicon (chips) and are comprised of electronic switches, or gates. The gates are measured in size of microns. The diameter of a human hair is approximately 60 microns across.

Facilities that develop, and manufacture these integrated circuits require the strictest quidelines for environmental controls and prevention of potential health hazzards that personnel may encounter while working in these facilities. The major environmental controls are particle size and number, temperature, relative humidity, air flow velocity, and pressure. Providing this and other forms of control are used to develop what are called cleanrooms. Cleanrooms are used for the manufacture of a number of different kinds of products. The focus of this research will be on the microelectronics industry. This industry leads all other industries in developing systems, standards, and monitoring technologies, to control microcontamination which is the essence of what a cleanroom does.

This thesis will be divided into two parts. The first part defines what a cleanroom is and what it is comprised of. Next, there will be methods presented to design this type of space in a more energy and cost efficient manner.

The second part involves the research in the vertical laminar flow aspect of operating a cleanroom. The vertical laminar flow offers a stru ctured method for controlling air flow and provides an effective means for discharging particulates out of the cleanroom. By comparison, the conventional air flow system throws the particulates in a random fashion. The vertical laminar flow has its limitations. By itself, the vertical flow operates well, but people, and equipment cause turbulence which disrupts its effectiveness. Working with these variables through research, an alternate method of working with this vertical laminar flow was developed. The results, recorded by photographs show an alternative for dealing with the turbulence and eddys caused by the operations in the cleanroom. There will be a discussion followed by a number of questions, and responses which will be the basis for this research on vertical laminar flow.

Thesis Supervisor: Dr. Leon Glicksman
Title: Senior Research Scientist

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CLEANROOM DESIGN (Energy Efficient Design)

PART II VERTICAL LAMINAR FLOW (RESEARCH)

1.1 Introduction

Recent growth in high technology industries, especially electronics, has increased the demand for what are called cleanrooms. Simply stated, a cleanroom is a controlled environment in which temperature, humidity and airborne particulates are all carefully regulated the predetermined standards. Generally speaking, the cleanroom controls three major types of contamination. The first is airborne contaminations. This type of contamination can be of any shape, size, or nature and is transferred by either air convection currents or trajectory off of other particles. In either case, the medium of transfer is air. The second type of contamination is control of particulate matter transferred from one object to another by direct contact. The third type of contamination is the transfer of particulates by means of fluids. This can occur with cleaning solution as well as with lubricants.

Cleanrooms are classified by the number of particles of certain sizes that are present in a cubic foot of air. A class 1,000 cleanroom has, on average, no more than 1,000 particles of 0.5 microns or larger per cubic foot. And a class 10 cleanroom has just 10 or fewer particles of .10 microns in a cubic foot of air. (see figure 1) In contrast to this, a normal office space will have millions of particles 0.5 microns or larger in a cubic foot of air.

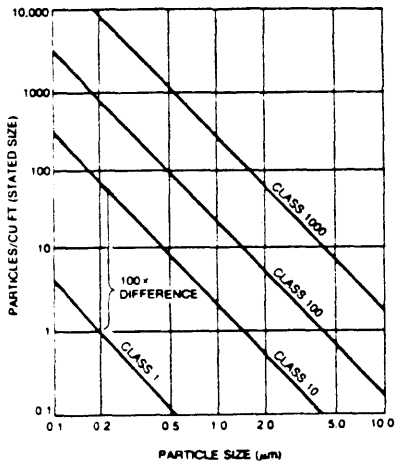


figure 1

1.2 TERMINOLOGY

In the following report, there will be a number of words referring to cleanroom technology. The meanings to these words will be defined here.

ADSORPTION: Water purification utilizing activated carbon to remove organic contaminants. The porous surfaces of the carbon also trap and retain free chlorine found in municipal water supplies.

CHIP (MICROCHIP) : A square of primarily silicon that is processed to ultimately be an intergrated circuit.

CLASS 100,000: Particle count not to exceed 100,000 particles of a size 0.5 microns and larger per cubic foot.

CLASS 10,000: Particle count not to exceed 10,000 particles of a size 0.5 microns and larger per cubic foot.

CLASS 100 : Particle count not to exceed 100 particles of a size 0.5 microns and larger per cubic foot.

CLEAN ROOM: A cleanroom is an enclosed area employing control over the particulate matter in air with temperature, humidity, air flow patterns, air motion, pressure control and lighting as required. Cleanrooms must not exceed the particulate count specified in the air cleanliness class.

CONVENTIONAL FLOW (Nonlaminar Flow) Clean Room: A clean room with no requirements for uniform air flow patterns and air velocity

DEIONIZATION : (demineralization) Method of water purification which is accomplished by passing water through synthetic resins which exchange H+ (cation) and OH- (anion) ions for ionized impurities in water.

DESIGN CONDITIONS: The environmental conditions for which the clean space is designed.

DIE: A seperate chip on a wafer.

DISTILLATION: Water purification by phases. Water is first evaporated, leaving impurities behind, and then condensed in a water cooled heat exchanger (condenser).

DOP: (Dioctyl Phthalate) Smoke test that determines the amount of smoke penetration through a filter.

EDDY: Air running contrary to to the main current.

GATES: A circuit that has an electrical output dependent on its input. Smallest subclass of current on a chip.

HIGH EFFICIENCY PARTICULATE AIR FILTER (HEPA): A filter with an efficiency in excess of 99.97% for 0.3 micron particles as determined by what is called a Dioctyle Phithalate (DOP) test.

HIGH EFFICIENCY PARTICULATE AIR FILTER (VLSI): A filter with an efficiency in excess of 99.9995% for 0.12 micron particles.

INTERGRATED CIRCUIT (IC) : An electronic device that performs the functions of many thousands of transistors.

LAMINAR FLOW: Air flow in which the entire body of air within a confined area moves within a uniform vertical air pattern along parrallel flow lines.

LAMINAR FLOW ROOM: A cleanroom with a laminar flow requirement.

LARGE SCALE INTEGRATION: Microelectronics manufacturing technology for intergrated circuits with line geometrics of 2-micron widths..

MEMBRANE FILTRATION: Water purification sometimes called "absolute filtration", this method employs a non-contaminating screen of carefully controlled pore size to trap non-dissolved impurities on the surface of the membrane. These filters, typically with a pore size of 0.2 or 0.45 micron, are used to remove particles and bacteria from water

MICRON: A unit of measurement equal to one-millionth of a meter (0.000039"). Twenty-five microns equal 0.001".

NON-LAMINAR FLOW ROOM: A clean room that does not require a laminar flow pattern.

PARTICLE SIZE: The maximum linear dimension of the diameter of a particle usually measured in microns.

PREFILTERS: A filter to trap gross particulates located upstream from and with lower collection efficiency than the HEPA filter.

TURBULENT FLOW: A Fluid flow in which the velocity at a given point varies erratically in magnitude and direction.

UNIFORM AIRFLOW: Unidirectional airflow pattern in which the point-to point readings are within plus or minus 20 % of the average air flow velocity for the total area of the laminar flow work zone.

VERY LARGE SCALE INTERGRATION (VLSI) : Microelectronics manufacturing technology for intergrated circuits with line geometrics as small as 0.1-micron widths.

WAFER: A thin, flat circular disk of primarily silicon that is masked, oxidecoated, doped and processed for separation into numerous electronic devices or for packaging as an intergrated circuit.

1.3 FACTORS AND FUNDAMENTAL DESIGN CONCEPTS THAT ARE IMPORTANT IN CLEANROOM DESIGN

Precision manufacturing of microelectronics devices is possible only when it is carried out in cleanrooms where there are extremely clean environments. For integrated circuits The fabrication process begins with the slicing of thin wafers from single-crystal silicon boules 100 mllimeters or greater in diameter. Th wafers are cleaned, and various semiconductor materials are deposited in discrete patterns in a series of layers. The patterns are repetitively deposited to form circuitry contained within a die that is a few millimeters on each side and has component widths and spacings that are a few microns wide. The pattern preparation method is based on the depositing of a layer of semiconductor material, followed by lithographic imaging on a layer of photosensitve material. This material is selectively removed, leaving the desired pattern exposed for further processing through one of several methods. Processing methods include liquid phase or dry gas etching, sputtering, vapor phase deposition, etc.

Following the pattern development steps, the wafer is cut into discrete chips. Each chip is then mounted on a suitable holder, and electrical connections are made for subsequent use.

At any step, the wafer or chip may be exposed to the ambient environment, and particulate contaminants can be either ingested or deposited on critical surfaces. The prevention of these contaminants is curtailed by good fundamental design factors in cleanroom design. There are many factors that play an important part in the design and total expense of a cleanroom installation. Along with these factors is the recent concern about the health risks involved with personnel in the cleanroom environment. In the initial planning stage, two basic considerations should be answered first:
1. What will be the purpose of the room? **2.** What degree of cleanliness will be required? After this has been established, emphasis should next be placed on the allocation of space; position and type of equipment to be installed within the room; the number and placement of personnel and their internal traffic pattern.

Also, the compatibilty of processes, the equipment operating processes and maintenance techniques to economically achieve the project manufacturing requirements should be established.

After these factors have been layed out and the design is set, the fundamental criteria for good design and control should be considered.

These fundamental issues are:

1. **Airborne Particle Control**
2. **Particulate Control**
3. **Air Pattern Control**
4. **Pressurization**
5. **Lighting**
6. **Temperature Control**
7. **Humidity Control**
8. **Cleanliness**
9. **Control**
10. **Vibration / Acoustics**
11. **Room Construction Specifications and Operations**

1. Airborne Particles

Airborne particulate matter can be organic or inorganic. Most contamination control problems concern the overall contamination within the air, but applications exist for specific contamination control of bacteria, spores, and viruses that are contained in the air.

Airborne particles range in size from 0.01 microns to several hundred microns. Conditions for clean space vary widely with industrial and research requirements. A reference on the control of airborne particulates is the Federal Standard No. 209B. (see appendix)

2. Particulate Control

Before any methods of contamination control of airborne particles can be used successfully, a decision must be made as to how critical this particulate matter is to the process or operation in question. The allowable size of an airborne particle at a point within an area depends on the most critical dimensions and tolerances of the process to be performed at that particular point.

At the same time, consideration must be given to the quanity of the particles of a given size that might be present at a particular point with the area.

It has been proven in studies that there is a definite relationship between the size of a particle and the time in which it may be airborne, (1. Austin, 1970.) so it is beneficial to discuss airborne particles by quanity of a given size. Federal Standard209B discusses this relationship see appendix to further analyze the level of contamination to be considered.

This can be divided into external sources and internal sources.

External Sources: For any given space, there exists the external influence of gross atmospheric contamination of air pollution which tends to find its way into all areas of a working environment.

The external contamination is brought in primarily through the air-conditioning system which supplies the working space with outdoor ventilation makeup air. In addition to the air-conditioning system, external contamination can infiltrate through doors, windows, and cracks in the structure. The contamination generated to the process is controlled primarily by the type of filtration used.

Internal Sources: The greatest source of internal contamination is the personnel themselves. All people continually shed particles (organic and inorganic);
The amount can vary from as few as several hundred particles per hour to several thousand particles per hour, depending on the indivivual.

Skin is constantly flaking off and generating particles in the 1 micron range, and exaled breath contains large quantities of particles ranging in size from sub-microns to several hundred microns. (2. Cambridge Filters, 1986.)

In addition to people, and processing, every activity involving friction of surfaces creates some type of contamination. Besides the contaminants from processing, " the simple act of writing with a pencil on a piece of paper generates an aerosol cloud of many thosands of very fine carbon particles and paper fibers. Even the movement of two pieces of metal together generates a certain amount of particulate matter which can be forçed to be an airborne contaminant." (3. Cambridge Filters,1986.)

Within any working environment, a certain dynamic situation exists in the air. Movement results from people working, activity of service equipment within the processing area, fans blowing, motors rotating, etc.

All of these motions impart kinetic energy to the air and cause it to move at random velocities within the space.

An example of this would be a person walking down an aisle or hallway, imparting kinetic energy into the air causing air motion as the gas molecules in front of him are put into motion.

Fine particles are caught up in a random current within a room and are easily moved from one location in the room, to another. This transfer of contamination through random air currents from one part of the room to another is known as cross-contamination and is a significant contribution to the contamination level at the worksite. A resulting contamination buildup occurs within a space and reaches a plateau or steady state condition. A plateau count of 0.5 microns and larger would range anywhere from several thousand to several million particles in a typical manufacturing environment. During off hours or lunch breaks a noticeable reduction in the contamination level will occur,in the location of processing equipment.
(4. Cambridge Filters, 1986.)

Once the required cleanliness level is established for a facility or room the location of each process to be performed within this area should be decided. This location of each process should include the position of each operator in the facility. While preparing this layout, consideration should be required for the area for each process, each operator, and necessary service equipment.

The position of the operative relative to the process, and the location of each process relative to another will indicate the need for laminar flow.

Other factors, in conjunction with the size and quanity of airborne particles, can also influence the degree and method of contamination control. Some typical considerations are:

1. How the product is affected by particles?
2. Will toxic, explosive, or other harmful fumes be present in the process?
3. Will oders be generated?
4. What type of airborne contamination will the process be affectrd by?

The answers to these questions could determine:

A. If the primary air may be recirculated.

B.If it must be exhausted, and in what quanity.

C. How the supply or exhaust air must be treated or conditioned.

Isolation is one of the most important considerations in applying contamination control. Isolation may be divided into direct, reverse, and mutual isolation.

Direct isolation occurs when the product is to be protected from contamination generated by an external source, service equipment, or personnel. This tends to be the simplest type of contamination control, because consideration of the required cleanliness level can be limited to the product only, the air content need not be considered once it has passed over the product.

Reverse isolation is used when the product generates contamination; the service equipment or personnel, or both must be protected from this contamination. In most cases, the air requires special care after it has been exhausted from the area, and before it is reintroduced to ambient conditions.

Mutual isolation is recommended when the product is to be protected as in direct isolation but the contamination generated by the product needs control. Mutual

isolation is also necessary when two adjacent products or processes must be protected from contaminating each other. This type of isolation is not only the most difficult to control but the most required. Mutual isolation normally requires the use of laminar control.

3. Air Pattern Control

Air should be directed to obtain the cleanest air at the most critcal work areas. As contaminants are entrained, they are easier to be removed from the room. Two options are available:

1. The introduction of large quanities of air at low velocities in the area of the most critical work areas.
2. An unidirectional movement, usually downward or across the room, prior to removal from the space. The choice of specific air arrangement should be based on the criticality, of the conditions to be maintained in the space, size, and the ratio of space occupied by the nature of these operations to be performed in the room.

Laminar Flow: In a laminar flow system, air is introduced evenly from one entire surface of the room, such as the ceiling or a wall, with flow at constant velocity across the room and removal through the entire area of an opposite surface. Laminar flow provides a direct, predictable path which a micron size particle will follow through the clean room, with the minimum opportunity for contaminating any room component.

It also provides a mechanism for directly removing the particles constantly generated within the room introduced into the air stream. Ideally, the flow sreamlined would be uninterrupted and, although personnel and equipment in the air stream do distort the streamlines, a state of constant velocity and static pressure is approximated. Most particles that encounter obstructions in a laminar air flow like personnel and equipment, will strike and continue around it as the laminar air stream re-establishes itself downward. There are, among other conditions two possible conditions that may arise from laminar flow striking obstructions. These are called eddys, and the area of virtually zero velocity at surfaces parallel to the air stream (This action will be further discussed in Part II) to provide good air movement to prevent settling of particles, air flow velocities of approximately 100 f.p.m. are recommended as standard design of laminar flow cleanroom systems.

These average air velocities can be used in laminar flow rooms because of local high velocity are minimized. Although it has been stated by sources that air velocities below 70 f.p.m., will cause prevention of particles to settle. Normal body movement has little effect above 70 f.p.m., while air velocities above 110-120 f.p.m. contribute little contamination control advantage. (5. Cambridge Filter, 1986.)

Laminar flow rooms can usually be operated without the need for air locks, air showers, and restrictions on occupant movement. These rooms fall into three categories; **vertical flow, horizontal flow,** and **diagonal flow** with diagonal flow used very seldom except on certain kinds of equipment processings.

Vertical flow consists of an entire ceiling of HEPA filters. Ideally, a grated floor serves the air exhaust. As it moves through the ceiling, it is filtered essentially free of all particles 0.3 microns and larger. This type of air flow provides a uniform shower of air which bathes the entire room in a downward flow of clean air. Contamination generated in the space will not move laterally against the downward flow of air and will not contribute to a contamination level buidup in the room. This type of design provides the cleanest working environment that is presently available.

Horizontal flow uses the same filtration air flow technique as the vertical flow system, except that the air flows from one wall of the room to the opposite walls. The supply wall consists entirely of HEPA filters supplying air at approximately 100 f.p.m. across the entire section of the room. This air then exits through the return wall, or ceiling return, at the opposite end of the room and is recirculated within the system. This type of flow has the same degree of filtration and the same air flow characteristics as the vertical air flow sytem.

As with the vertical air flow, this design removes contamination generated in the space at a rate equal to the air velocity and does not allow cross contamination from one side of the room to another perpendicular to the air flow. However, a major limitation to this design is that vertical contamination in the direction of the air flow will occur.

In this design, the first air, or air first coming out of the filter wall, is as clean as air in the vertical flow room. The process activities can be oriented mostly to have the cleanest, most crical operations in the first air, or at the clean end of the room, with progressively less crical operations located toward the return air, or dirty end of the room.

Point of use: All laminar flow arrangements are applicable to point of use stations as well as entire rooms. In combination with conventional flow systems, they can provide small areas with very high degrees of contamination control. Where critical control is required, the laminar work station is often the only acceptable means for meeting the operational criteria.

Conventional Flow: An arrangement for conventional flow air distriution. Air is supplied through large ceiling outlets, flows generally downward, and is removed near the floor level. Air velocities across the room should be approximately 50 f.p.m. Lower floor velocities may permit particles to settle, while with conventional distribution, higher velocities may generate objectional local turbulance and drafts. Although the contamination level is greatly reduced. This method does not offer the same protection as laminar flow. (See Figure 2.)

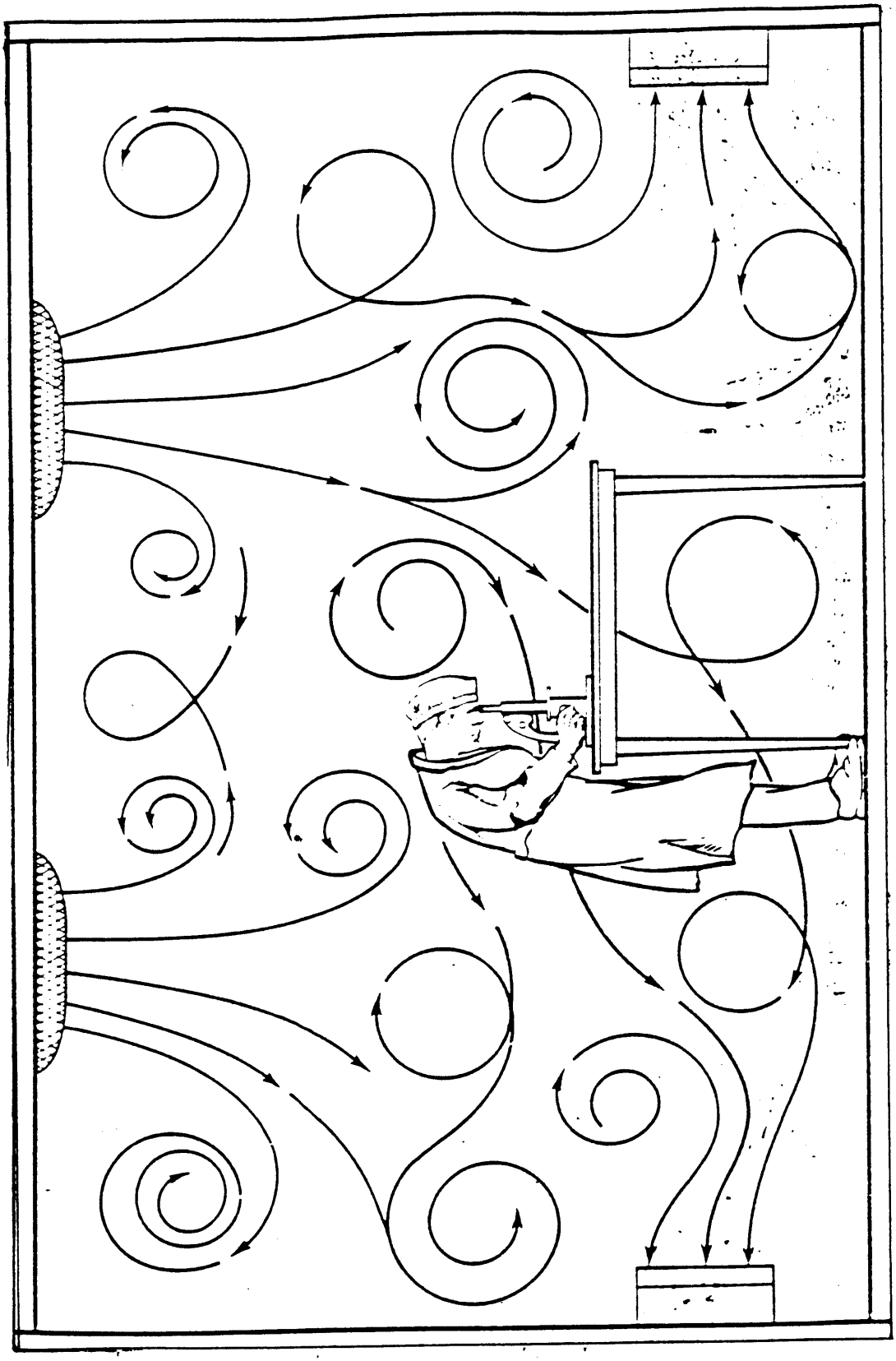


figure 2 Conventional Air Flow

4. Pressurization

Pressurization in a cleanroom facility is required to provide a purposeful migration of air from the most clean space to areas of progressively less cleanliness. The design should be based on a nominal 0.05 in pressure diffrerential between clean and less clean zones. Pressures greater than this will result in greater make-up air and can begin creating problems with personnel doors.

There are two primary considerations to recognize when designing for pressurization.

1. Differential pressure between functional spaces.
2. Building differential pressure.

Pressure between functional spaces will be influenced by both recirculation air quantity and make-up airflow, while building pressurization is ultimately affected only by make-up air flow quanity. To provide control over room pressures, air flow variations should be minimized.

5. Lighting

In cleanrooms, lighting must be supplied as part of the design system, because of design and application of uniform contamination control equipment. The normal lighting level is established at 100 footcandles at 30-42 inches from finished floor, (table-top height) to provide a reasonable level to adequately see the process without eye fatique.

6. Temperature Control

In many cleanroom applications, particularly semi- conductor facilities, the ability to hold temperature constant is more important than the absolute value. As the precision of the process increases, the need for accurate temperature control increases. Control of plus or minus one degree fahrenheit is common for such processes as x-ray, and laser lithography.

In cleanrooms of cleanliness class 1000 or better where full protective clothing (bunny suit) is required, temperatures of 68-72 degrees fahrenheit (20-22, centigrade) are necessary to satisfy human comfort. Generally, these temperatures will also satisfy process requirements. For less stringent functions such as assembly or packaging, where cleanliness classifications of 100,000 are common and protective clothing is less restrictive.Temperatures of 70 -74 degrees fahreheit ; (21-23, centigrade) is adequate.

7. Humidity Control

Humidity control for cleanrooms can be extremely important in many processes. Humidity control of 40% R.H. to 45% R.H. is desired with tolerance of 2-5 degrees plus or minus will satisfy most conditions. Generally, the specific process will dictate the humidity requirements. For energy considerations, it should be specified with as wide a tolerance as possible.

Humidity control is necessary to, among other things:

1. prevent corrosion
2. prevent condensation on work surfaces.
3. eliminate static electricity.
4. provide personnel comfort.

Corrosion of precisely manufactured surfaces including bearings electrical contact surfaces, ball-bearing raceways, and miniature-gear trains occurs with above 50% R.H. At relative humidities much below 40%, static changes may form, attracting dust particles which later may become airborne in massive concentrations.

8. Cleanliness

The primary purpose of a cleanroom is to provide an environment in which particulates are contained within some specified unit. Federal Standard 209B, provides the criteria for defining clean -rooms. This standard is primarily a definition and does not prescribe methods for achieving cleanliness levels. The current definition of classes 100, 1000, and 100,000 refers to the maximum number of particles 0.05 microns or greater per cubic foot of cleanroom volume. (Federal Standard 209B, see appendix)

The primary sources of particle contamination besides personnel which is primarily a management issue is:

I. Infiltation
II. Internal generation
III. Introduction of make-up air

I. Infiltration: High Efficiency Particulate Air (HEPA) filters are used in both vertical and horizontal types of design in the control of infiltration into the cleanroom. Air flows into the work area, and exits in either one of two ways; through perforated floor sections into an air plenum; or through air grills at the floor level or side walls.

For the filtering of suspension matter," three effects are performed:

1. screening effect: not only particles bigger than the distance between fibres are retained, but also particles whose streamline passes so near to a fibre that they collide.
2. inertia effect: Particles above 1 micron, where they are thrown out of their streamline when it deviates sharply to pass a fibre of the filter median.
3. diffuse effect: Particles below 1 micron, where constant collision with the molecules of the surrounding gas lead to an erratic path (Brownian movement.)"
(6. Schicht, 1985.)

Due to the low penetration velocity of the air through the filter paper, pleating is necessary in order to arrive at compact filter units.

There are two philosophies as to pleating.
1. American: Pleats of 15-30 cm. in depth, with distance holders of corrugated aluminum sheet metal in between paper pleats.
2. European: Employs low depth pleats of narrow spacing,with distance holding by threads. (7. Schicht,1985.)

An important item to emphasis is the location of the HEPA filters. "The HEPA filters should always be located so that they are the last items of the mechanical equipment. This insures that all the air entering the cleanroom is filtered and that there is no possibility of contamination with unfiltered air." (8. Kilpatrick, 1984.) Careful installation of the HEPA filters is important as to not cause leakage around the edges. The ratings of a filter is based on the resistance to air flow, its aerosol removal capabilities, and its dust holding capabilities.

By definition, the HEPA filter must demonstrate a minimum collective efficiency of 99.97% for 0.3 microns (DOP) test, and a maximum filter pressure drop of 1.0" w.g.

"The 0.3" micron challenge aersol was selected since both theory (OSPD) reports 3460) and experiments indicate that a particle of this size is the most difficult type to capture by a fibrous filter." (9. Kilpatrick, 1984.) This form of resistance has strongly emerged within the last ten years.

Particulate filtration is predominately done by two generic classes of fibrous filters.

1. **viscous impingement.**
2. **dry type.**

Impingement type filters are constructed of coarse fibers arranged in a porous bed. **Dry types** differ from impingement types in that they have smaller sized fibers of more densely spaced media. In both types, the pressure drop across the filter increases with dust loading to a point where they should be replaced. This is normally done when the air resistance reaches 2" w.g.

II. Internal generation:

A. Equipment and materials in clean area
B. Maintenance
C. Process Equipment.

III. Introduction of make-up air.

9. Controls

Controls are critical to the overall system design and required performance. However, two things should be kept in mind:

1. A system, no matter how well designed, will operate no better than its controls.

2. Controls cannot correct what is fundamentally a design problem.

A selection and design of the controls is an integral part of the entire design process. Precision instruments should be specified where precision is important. This precision is usually limited to :

1. make-up air system for humidity control.

2. recirculation system temperature control.

3. constant volume control.

10 Noise And Vibration

Noise is one of the most difficult variables to control within contamination control equipment, due to the high volumes of air necessary to provide the cleanliness levels required. For normal applications of laminar flow equipment, the noise level is designed to be below 65 decibels. Air-handling systems, fume hoods, exhaust systems and equipment areas (chillers, boilers, pumps, etc.) must be carefully located and appropriate silencers and sound absorbing elements must be used to attain a sound level that is acceptable to the personnel. Levels of vibration are controlled by utilizing structural designs with stiffness and mass.

Pedestrian traffic within the cleanroom is one of the most important vibration sources. The most reliable solution other than administrative controls are the structural seperation of high traffic areas, or the use of heavier structural components to bring footfall- induced vibrations within accepted limits.

11. Room Construction And Operations

Construction Finishes:

1. General Smooth, monolithic, cleanable, abrasive, and chipping resistant, with a minimum number of seams,joints, and no crevices or mouldings.

2. Floors: Sheet vinyl, epoxy, or polyester coating cove wall base.

3. Walls: Plastic, epoxy, baked enamel, or polyester with minimum projections.

4. Ceilings: Plaster covered with plastic, epoxy, or polyester coating or with plastic-finished acoustical tiles.

5 Lights: Flush mounted, sealed with tube removal preferrably from outside of room.

Personnel And Garments:

1. Hands and face are cleaned before entering area.

2. Lotions and soap containing lanolin are used to tighten skin particles.

3. Solvent contact with the skin is conducive to skin peeling and flaking and is avoided.

4. Wearing cosmetics and skin medications are not permitted.

5. Smoking and eating are not permitted.

6. Lint-free smocks, coveralls, and head and shoe covers are worn.

Materials And Equipment:

1. Equipment and materials are cleaned before entry.
2. Nonshedding paper and ballpoint pens are used. pencils and erasers are not permitted.
3. Work parts are handled with gloved hands, finger cots, tweezers, and other methods to avoid transfer of skin oils and particles.

Particulate Producing operations:

1. Grinding, welding, and soldering operations are shielded and exhausted.
2. Containers are used for transfer and storage of materials.

Entries:

1. Air locks are used to maintain pressure differentials.

Chapter 2 History

2.1 How Cleanrooms Originated

The orgins of cleanrooms today are a result of advancing technology in the field of mechanical science. This advancement is a twentieth-century discovery. Cleanrooms produce many present day products of sophisticated design. Control of the factors in and about a product is a function of tecnological advancement in science. This is true for many sciences. The first of these sciences to recognize this need was medicine. Medical science controlled the environment in what are called "operating rooms". The nature of work performed in an operating room on humans is similar in nature to work performed in cleanrooms on equipment. Room decontamination functions are both necessary and vital to continued, successful cleanroom operation. The events leading to the development of operating rooms were initially paralleled by events leading up to the development of cleanrooms. With greater emphasis being placed on miniaturization of products by the electronic age, however cleanliness requirements for some cleanrooms exceed those for operating rooms. Techniques of workers in operating rooms and cleanrooms are similar in that they are controlled.

Various objects, tools, and areas are considered to be either contaminated or uncontaminated. The worker's actions are goverened by these considerations.

The major difference between operating rooms and cleanrooms is that in operating rooms sterility of objects is of major importance. In cleanrooms, the quanity of particulate matter is of major concern. Particulate matter is of little impotance in an operating room as long as it is sterile. Cleanrooms have experienced little difficulty with bacterial growth on items. This can be attributed to several reasons:

1.Lack of bacteriological food.
2. Lack of bacterial colonies.
3. Low humidity.

Louis Pasteur (1822-1895), recognized in the late 1800's that micro-organisms caused disease. His recourse was to kill these organisms by the use of chemical sterilants. It was this twentieth century discovery that particles too small to be seen could also have a major effect on precision manufacturing product yields.

Cleanrooms or rooms that were the predecessors of modern day clean -room can trace their beginning back to World War I days. At that time there was no "cleanrooms" as we know of today. But there were controlled areas that performed similar functions.

These controlled areas within factories and laboratories attempted to eliminate the gross contamination associated with manufacturing areas. This contamination, consisting of heavy dust- laden air, had caused seizure of small bearings and gears used in the first aircraft instruments. As a result, controlled assembly areas were built.

By segrating the work areas from other manufacturing operations, and by providing a filtered air supply, contamination control was first effected by cleaning practices. With the beginning of the World War II period, better filtration systems were developed: air conditioning and room pressurization were considered essential. Personnel protective clothing were added later, as were air showers and personnel cleaning equipment. In this period there were attempts to improve the quality and reliabilty of such areas as metrology; precision optics such as bombsights, gyroscopes, and timing devices, met limitations which appeared to relate to surface cleanliness. (10. Austin, 1970.) Further study revealed that surface cleanliness was a function of how clean the environment could be made and controlled. Up to this point there was little known about size and quantities of particles in the manufacturing environment especially those carried by air. When the realization of harmful effects caused by these particles on the production of products was established, many organizations like the military started to

write their own independent and operating specifications and standards for cleanrooms.

Many theories were generated and practices were based upon incomplete data. Because of this the field of contamination control lost a lot of credibilty in the 1950's.

The first document accepted as a workable document for cleanrooms was one done by the United states Air Force entitled "Standard Functional Criteria For The Design and Operation Of Clean Rooms". (Air Force Technical Order 00-25-203) It was prepared because of the confusion to the various contamination, temperature, humidity, and pressure requirements for cleanrooms. The Technical Order 00-25-203 was published in 1961. Also, in 1961 the Sandia Laboratories located in Albuquerque, New Mexico started work on a new type of cleanroom design. This facility is a part of the United States Atomic Energy Commission. Sandia has a vital interest in the field of contamination control. Absolute cleanliness of contact points, freedom from corrosion, no shorts from metallic particles were vital for the complexity of the systems at Sandia. (11. King,1986.)

What resulted from such strict specifications was a design team from Sandia who developed what is called "laminar flow" cleanroom design. (1962) This design concept developed many of the designs currently in use; and then developed what is now called "Federal Standard 209B".

During the time of the development of Federal Standard 209B this team had the assistance, among others, all military and government agencies, and NASA. This Federal Standard 209b was first published in December of 1963.

From its inception in 1962, laminar flow technology has been applied to the design and modification of new and existing cleanrooms. Laminar flow systems have taken the form of both rooms and individual work stations.

The years from 1962 to 1965 saw the laminar flow design used for mostly aerospace industry. From the mid to late 1960's the laminar flow design was starting to be used in the pharmaceutical industries, and the application in hospital operating rooms.

In addition to this new laminar design, other advances also occured at this time to make the over all design of the cleanroom more efficient. Among some of these advances were:

1. Increased efficiency in the sealing of HEPA filters
(HEPA Filters were first marketed in 1950.)
2. Instrumentation for particle counting.
3. Filtration of process gases, and liquid starting with treated water that is used in the microelectronic manufacturing industry.

The microelectronic manufacturing industry is the largest user for cleanrooms these days. Other fields include:

1. Medical
2. Pharmaceutical
3. Military
4. Aerospace
5. Food processing
6. Optics
7. Nuclear
8. Precision Manufacturing
9. Research facilities

2.2 Future Trends In Cleanroom Design

Revisions of the Federal Standard 209B are currently being proposed to control particles 0.1 microns in diameter and larger to less than 10 particles per cubic foot (Class 10). Also, for particles 0.1 microns in diameter and larger to less than 1 particle per cubic foot (Class 1). Because of this advancement, laser (light) scattering particle counters are now being used for the counting of these particles.
(12. King, 1986.)

Class 100 is now being tested for lesser needs with class 10, and class1 being specified for the current, high quality production.

Along with these higher standards, the fundamental criteria mentioned in chapter 1 are becoming more precise. New areas of concern are evolving. One of these areas to be looked at is the eletrostatic changes, and electromagnetic interference which is more of a problem with the micro-computer.

With class 10 and class 1, cleanrooms now being used, there will need to be a revision in the Federal Standard 209B to accomodate the proposed revisions.

Chapter 3 MANAGEMENT IN CLEANROOM OPERATION

3.1 Introduction

Proper management of personnel in the operation of a cleanroom is important because personnel are the largest contamination source. "It is recognized that the human can contribute up to 80% of particulate contamination in a clean envoronment with air filtration making a 5% contribution and the work piece and equipment making up the remainder at 15%." (13. Waring, 1984.) The main reason for this is the normal process of the skin regeneration on the body. The body is continually loosing skin flakes all the time. "The body will possibilibly shed up to 250,000 scales per minute in the static state." (14. Waring, 1984.)

It is important to recognize, that the successful achievement of contamination control depends as much on attitudinal factors as on the technical considerations. This chapter will deal with these considerations by analyzing three parts.

1. Technical consideration.
2. Attitudinal factors.
3. Clothing.

3.2 Technical Considerations

The management starts with the proper layout of the facility, specifically the management of the circulation. Present cleanroom technology uses either full laminar flow or clean tunnel-bay systems. In the full laminar flow design, the entire facility is divided into clean modules, each module combines HEPA filtered ceilings wih grated floors. This concept is for full flexibility in the equipment size and layout. An exception to this would be the wall location for the return air. But you pay for this flexibility, the tunnel approach handles traffic flow in a highly efficient manner. The main artery, or tunnel, connecting the modules is the location of the densest traffic flow. This system does not have the open space for flexibilty, but by not using the entire space there is a cost savings. (see chapter 4, section 3, "Flexibility")

In either case, the overall cleanroom plan must manage the movement of personnel. At the point of entry into a intergrated circuit manufacturing facility the person should immediatly start mentally and physically work to create a clean atmosphere. Street shoes should immediately be removed and or be covered by special slippers. As one proceeds through the facility, further levels of cleanliness should immediately become evident.

Floors, even in the reception type areas should be exceptionally clean. The level of cleanliness should actually increase as one approaches the actual fabrication area. These environments should take on a hospital-like appearance. Even locations relatively far from the fabrication area, like the floors and walls should be finished with a cleanroom type appearance as stated in chapter one. (1.3, section 11)

Besides always being constantly cleaned, the main circulation floors should be covered with what is called a dust collecting rug or mat. The cleaning of these areas should be done with the use of lint free brooms, and vacuum cleaners with a good filtering system, and plastic bags to contain swept up debris.

The manner in which personnel enter and exit the fabrication areas should provide a further measure of cleanliness. Essentially, all the people who enter into the fabrication area should pass through several staging areas.

There will be four stages used in this example. These areas are the different levels that should be achieved to meet a level of utmost cleanliness. The first area should be a location where employees and visitors would remove their jackets along with the slippers that were issued upon arrival to the facility.

The next stage would develop through a pass through air -locked set of doors into a second area where cleanroom clothes are put on (slippers would remain on.) A third area would be a relatively large laminar flow area, equipped with a metal grating floor and HEPA filter ceiling. In this area, personnel would put on their second pair of slippers and wash their hands. These areas could be equipped with what are called electronic eyes which would allow the people to wash and dry their hands without touching any surface. . A fourth and final stage would consist of a air wash tunnel. This will last approximately 30 seconds. A general consensous about air showers is that their function is more for pyschological reasons than actual performance.

At this point people would enter the fabrication area. What is important here was the thought process people would go through to mentally concentrate on reducing the contamination spread.

The next point to manage would be the traffic movement. Movement of workers within the cleanroom create air currents that interfere with proper laminar flow. Cleanrooms that are short of a perfect laminar flow are going to have pockets of less clean air and locations of settled particulates.

Unnecessary movement in the cleanroom will stir up these problem areas and could allow contamination to be placed upon the product being manufactured. Traffic should be limited as much as possible for peak performance.

Visqueen or plexiglass shields can help in isolating critical areas from air movement caused by the movement of personnel through critical area. Intercoms, and also pass-throughs are helpful in maintaining low traffic levels. Any pass-through should be accompanied by a intercom system to prevent the use of the pass- through for purposes of conversation.

Another item to manage is the proper handling of the clean room product. Operators in the cleanroom must realize the importance of protecting the product at all times from contamination, and must know how to do this. Cleanroom guidelines must be established and followed. Current personnel should be retrained; incoming personnel and visitors should not be admitted until they have a clear understanding of these guidelines. Everyone connected with the cleanroom facility should know and follow the guidelines.

A final note on some specific issues that should be implemented in the management of cleanroom operation:

1. Ordinary paper should not be used in a clean room of less than class 10,000 rating.
2. No food, gum, candy, or smoking material should be allowed in the cleanroom.
3. The use of cosmetics, rubber bands, and plastic gloves should be prohibited in the cleanroom.
4. If a vacuum cleaner is to be used in maintenance, make sure it is properl filtered.
5. Materials entering the cleanroom should be either double bagged or wiped down with diluted alcohol.
6. Avoid turning laminar flow hoods off, even during brief shutdowns (absence of movement will allow contamination to settle.)

7. Do not allow employees to sit on work surfaces or stand on any furniture.
8. Segregate coats and sweaters from cleanroom garments.
9. Leave all personnel items outside the cleanroom area.
10. Vent all locker storage with laminar flow.

3.3 Attitudinal Factors

Product effectiveness in the cleanroom ultimately depends on the users. In many cleanrooms the personnel fall into three categories: production (operators), personnel dedicated to mainteanc,technicians and engineers. The hierarchy is engineers followed by technicians, and than operators. Also in many cleanrooms this is the same as the technical hierarchy.

In the environment of a cleanroom facility with everyone wearing white, and working in such a sterile atmosphere there is a sense of anonymity resulting in this necessity of wearing cleanroom garments. In many cleanroom facilities there is a assembly line atmosphere which after a while creates a task identity and significance problem.

This sameness of environment and task can result in an attitude problem. This is even compromised by training programs of personnel that is primarily prescriptive (do this; don't do that) instead of educating operators. A final point in this area, is that "Cleanrooms, perhaps more than any other manufacturing setting ever, provide little opportunity for operators to guage the quality or progress of their work. Both the product and the problems that affect it are well below the visual threshold. Operators are left to follow procedures designed to ensure proper manufacturing processing, but this situation means that the work is more ritualized than it is product-focused. In effect, operators are working in an infomational void." (15. Northcraft, 1986.) This sense of anonymity also can develop into a sense of frustration, or a non-commitment to work attitude in this working environment.

In conclusion, to promote a positive attitude in the cleanroom environment to increase the performance of personnel, a number of steps should be taken. Among those:

1. Thorough and proper training. The personnel should be knowledgeable in the whole design process. Not in just their task, but also what everyone else does. A good way would be to rotate people to eventually have them work on all the different tasks. This will make personnel understand the whole picture, and better understand what each position is contributing.

That goes for operators, technicians, and to a point engineers knowing each others job. This will in affect develop a repect for each others task as well.

2. Develop ways of communicating with each other. One way is by the use of an inter-com system. Another is to develop predictable work schedules for personnel so that everyone knows each others schedule. This would help in not disrupting workers.

3. Room finishes: Cleanrooms have the same problem that is apparent in operating rooms and similar rooms in hospitals. What hospitals are doing now, and what cleanroom facilities should do now is to create more of an exciting space visually.

This is done in hospitals now by the use of color, and wall murals. Another area that needs to be looked in cleanrooms is the floors. For vertical laminar flow, the use of floor grating is effective for laminar flow. But walking on this grating all day can be very uncomfortable on the feet. What some Japanese facility designers have done was benefiscial. "Japanese facility designers recognized that walking on grating all day long would most likely become fatiguing. Thus, they replaced gratings with solid flooring on major traffic paths in sections of the fabrication area where ultimate cleanliness was not mandated.

It soon became evident however, that flooring made up entirely of steel grating would have psychological as well as functional drawbacks. One Japanese manufacturer solved this problem by placing prefilters directly under gratings."
(16. Edmark, 1984.)

As cleanrooms become more sophiscated the products will become smaller, and the equipment will be doing more of the work load. This will make the personnel even more alienated. And unless the personnel can develop an attitude of say, a craftsman, or someone that feels he or she is really contributing by being managed as such, maximum productivety will not be achieved.

3.4 Clothing

As mentioned in section 3.1, personnel in the cleanroom are the biggest potential contamination contributor in the clean room. Because of this factor the managing of the proper attire is mandatory in a cleanroom. "Full smocks (i.e., bunny suits and jump suits) are standard issue in all fabrication areas, and considerable attention is devoted to the tailoring of these smocks." (17. Edmark,1984.) Clean room clothing is not a requirement to protect the personnel. It's only function is to protect the environment of the work piece.

Personnel shed large amounts of skin flakes all the time. " The skin and hair constantly shed tiny flakes, composed mostly of the protein keratin surrounded by what is left of the membrane of the dead cell. Moisture droplets are ejected with every exhalation, blink of the eye, sneeze, cough, and even every word spoken. The clothes we wear also shed tiny particles. " (18. Waring, 1984.)

"To make matters worse, people use such products as body powders, cosmetics, powdery deodorant sprays, and hair sprays, all of which eventually ends up as air borne contamination. These products contain an amazing variety of compounds and metals, including iron zinc, and titanium compounds, mica dust, carbon black, and numerous organics. Even the best cleanroom garment available is not capable of containing all of the human generated contamination." (19. Northgate, 1986.)

The cleanroom clothing must be made of a fabric and designed into a series of garments which in combination will restrict the passage of particulates either through the garment itself or by -passing closures. Cleanroom clothing must:

1. Be low-linting in design.

2. Inhibit the build-up of static charges. "A human when wearing cleanroom clothing will generate static triboelectric means by which the rubbing of, say , the sleeves against the body, the body against a plastic chair or bench may build a charge of up tox 25,000 volts." (20. Waring, 1984.)

3. Withstand the processing for bacterial destruction when being cleaned.

4. Fully tailored.

5. Adhere to a strict cleaning cycle.

6. Be comfortable to wear, this is important because discomfort equates to an agitation that creates contamination.

With personnel spending so much time in these "bunny suits", it is important to design theses outfits as to not feel too confined while wearing them. Having the proper attire, and feeling comfortable in them is an important issue. But also, managing strict guidelines by always being properly dresses, properly cleaned, and not having too many people at one time walking through the clean room will help in the contamination control. (See Figure 3.)

figure 3 Cleanroom Clothing (Full Smock, Bunny Suit)

Chapter 4 Energy Efficiency And Cost Savings In Cleanroom Design

4.1 Introduction

During the research process, the need for energy and cost saving measures was always present. With the costs of cleanrooms being "$350-750 dollars per net square foot," (21. Maini, 1986.) methods were being compiled whether it was by reading about cleanrooms, talking to people working in cleanrooms, or walking through cleanrooms themselves on ways of savings in energy or costs. This list of methods will always be imcomplete for there will always be something that was either missed, or has not been discovered yet. The intention here is to compile all the information gathered and list them in this chapter. These energy, and cost saving methods will be primarily involved in the design aspects as it pertains to intergrated circuit facilities.

4.2 Methods For Energy Efficiency And Cost Savings

This section which is structured to discuss ways of energy and cost savings in cleanroom design for microelectronics facilities is divided into twelve seperate areas for savings in energy and costs.

These are:

1. **Feasibility Studies**
2. **Site Considerations**
3. **Flexibility**
4. **Vibration and Noise**
5. **Water (Purity and Waste)**
6. **Protective Transfer Systems**
7. **Clean Room Monitors and Sensors**
8. **Energy Conservation in Minimizing Cooling Load**
9. **Fans**
10. **Humidity**
11. **Lighting**
12. **Testing**

1. Feasibilty Studies

With the cost of microelectronic facilities being so high, it is important to develop a feasibilty study before the actual design phase to determine an accurate assessment of the facilities needs. This involves developing a well defined program. This will also have implications on such items as site selection, facility size and function. Developing a well defined program for the facility will help in determining such things as what class of cleanliness will be needed.

This is an important cost consideration. Knowing this important item will result in not over designing the mechanical systems which will add high high costs which are not needed as well as other increases in the overall costs of the facility. Along with this, a well defined feasibility study will help in developing a more clear construction schedule which will also help in generating a more accurate preliminary cost estimate. "Microelectronics facility spaces can vary in cost from $125 per square foot for class 100,0000 to $750 per square foot for class 10." (22. Maini, 1986.)

2. Site Consideration

This is a very important aspect because of its large implications on the overall facility with the location of the various building services needed to operate the facility. Among these services which need to have easy access to the site are the accessibility of water, and the required amounts of electrical power and clean air. The on-site water is used to rinse the process components. "The initial purity of this local water source can affect the ultimate cost of the sophisticated water polishing systems." (23. Maini, 1986.)

Electrical power is a necessary source and the need for back-up emergency power for possible power outage is mandatory. Large quantities of fresh air are needed to supply the extensive exhausting systems that are used in the cleanroom operation.

Having a site in an open area can be important especially if the facility is a production facility for integrated circuits which may use high concentrations of particular chemicals. If these facilities are located next to an area of heavy concentrations of people, than odor absorption equipment may be needed which in turn can be costly. Possible site locations in areas of wide climatic variation will require more costly heating and ventilating systems because of the strict controls for humidity, and temperature that are required at the wafer fabrication areas.

Other factors to consider on the site plan for semiconductor facilities is providing enough area for bulk storage of the many gases needed in the manufacturing process. A site location that does not accomodate for all of these items will prove to be potentially very costly.

3. Flexibility

The cleanrooms in the microelectronics facility can vary in function depending on the process being done. This involves the use of different kinds of equipment. Also, room for possible expansion should also be planned. With these considerations, it is important to develop a facility which is flexible for change. Flexible in the movability of its wall components and room layouts, and flexible for expansion of the mechanical, and electrical services, as well as other services that are used in microelectronic facilities like increased water capacity for increasing processes.

The use of modular building systems constructed using the materials, and finishes as discussed in chapter one will provide for the most efficient change, cost-wise in the microelectronic facility.

The cleanroom design solution must respond to the need for non-disruptive change (flexibility), easy maintenance or cleaning on a periodic basis, non-shedding construction materials, and ease in providing services for equipment through walls and contamination control. Ceiling space costs can be substantially reduced if HEPA filters are not used in the entire ceiling space. Only the areas that need cleanroom control require HEPA filters.

Having the flexibility in the ceiling for HEPA filters only where needed for laminar flow (spot laminar flow) saves on cost by minimizing fan horsepower too.

4. Vibration and Noise

The production of semiconductor microchips requires a location where vibration is kept to a minimum. With the size of these chips decreasing, and the smaller line widths used in the new high density products, the effects of vibrations in the facility can be damaging to the product and cause an increase in the defects which will not be cost effective. This can also become an annoyance to the people working in the facility. High noise levels can also vibrate and effect the performance of sensitive equipment.

A vibration free facility is unrealistic, but special structural design can help in the vibration control. This is done by utilizing structural systems with stiffness and mass. The most common system for these requirements is the concrete waffle slab. This system maximizes the stiffness with its ribbed construction while also using more concrete in volume than concrete slabs. This system also allows a suffienct depth to dampen the vibrations caused by pedestrian traffic (Footfall). This is one of the most important vibration sources to consider.

Another form of vibration is caused by the mechanical equipment. These items should have spring isolators, inertia blocks, and flexible connections on the ductwork.

(See Figure 4.)

Vibration and sound are related. Vibration can cause sound, so placement of equipment (boilers, chillers, etc.) must be strategically located. There is also some equipment used in the fabrication of semiconductor microchips that have very stringent environmental vibration limits. The final product may depend on the reliability of the wafer manufacturing equipments vibration isolation system. One way is to provide a concrete slab on which the machine is mounted on, and than which is physically seperated from the remainder of the building's concrete floor.

Pneumatic isolators which are devices that rely on compressed air to support a load can also be used on the equipment, and also on the column support for the building. (See Figure 5.)

Finally, vibrations reaching vibration-sensitive equipment can be minimized by using a three-stop approach to isolate vibrations.

1. **Source**
2. **Path**
3. **Receiver**

1. Source control is applying vibration isolation to the mechanical equipment or any other source of vibration.

2. Path control typically takes two forms. First, the distance between vibration sources (mechanical equipment, etc.) and any equipment that might be adversely affected by the vibration sources should be maximized. Increasing the path length will reduce the level of ground-transmitted vibration that reaches the vibration-sesitive equipment. The second important aspect of path control measure is to make sure that no direct transmission paths (from source to receiver) are present in the foundation or structure of the building that houses the complete system.

3. Receiver control is attained by using a properly designed passive vibration isolation system under any vibration-sensitive equipment. (24. Burggraaf, 1986.)

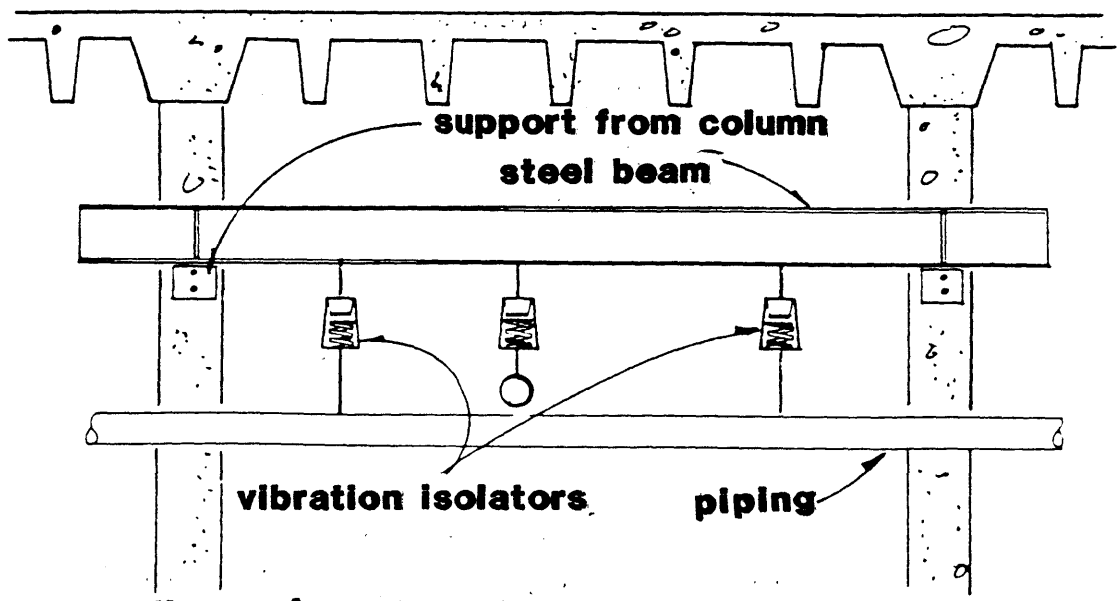


figure 4 Vibration Isolators

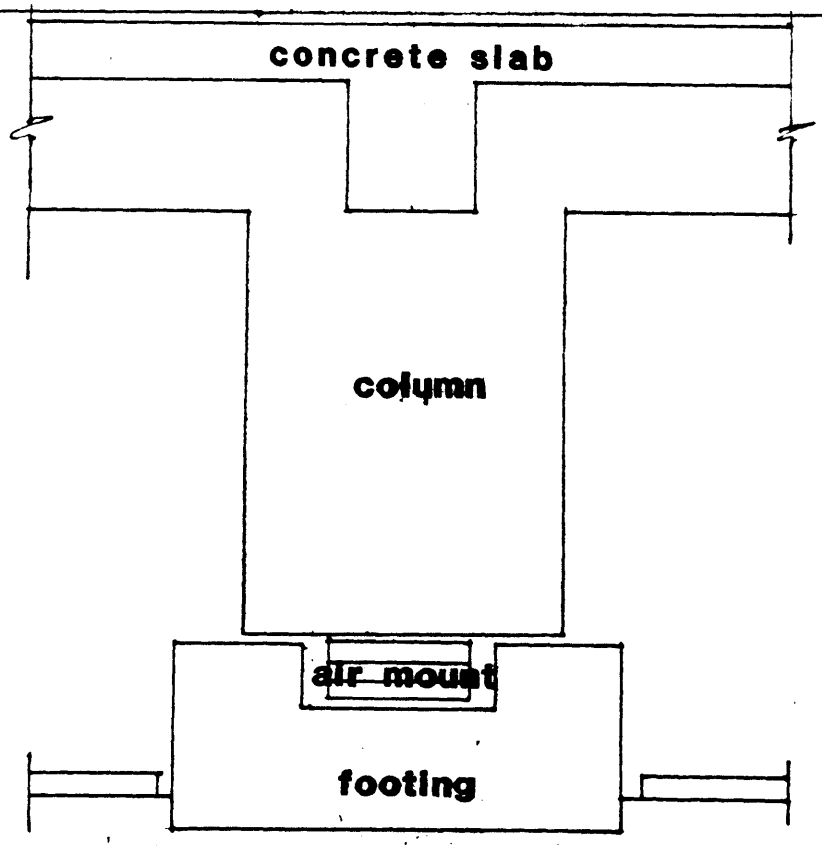


figure 5 Pneumatic Isolators

5. Water

An important part of the intergrated circuit manufactufing process is the use of ultra-clean water to wash the product at various stages of development. A major source of contamination in the integrated circuit fabrication is using process water that is not of the high purity level.

Water for microelectronics use may be purified by distillation, membrane filtration, absorption and deionization. (See 1.2 for definitions.)

Future demands for pure water will only increase. "recent forecasts indicate that production demands for pure water will increase at a 20-30% annual growth rate." (25. Clifford, 1986.) With this aspect, available water supplies may decrease in both quanity and quality.

To provide cost efficiency, two things should happen:

1. Fabrication processes should be designed to conserve the use as well as assist its re-use of water. This includes the waste water. The water that is not re-used should be neutralized to a point that it can be discharged to a local sewage system.

   If some water cannot be neutralized to a satisfactory point, than it should be collected in a dedicated waste piping system for off-site disposal.

2. Reliable test methods for water purification should be enforced. This is important for safety reasons, and product purity.

6. Protective Transfer Systems

When examining ways to cut costs in cleanroom design, a major area to do this is the reduction in the size of the laminar cleanroom. This can be done effectively by leaving out the laminar portion in areas where transport of the wafers is done. Instead of providing laminar flow, applying protective handling tunnels and box systems will cut down on the costs of the cleanroom.

Comparing the costs of the laminar cleanroom (class 1, and class 10) at $201 per square foot with the cost of a service aisles ($19.30 per square foot, one can easily see the savings involved. (26. Burnett,1986.)

The laminar flow cleanrooms and the protective wafer transfer systems, called tunnel clean concept are used to cut down on the amount of microcontamination that reaches the wafer surface, thereby increasing the overall production yield. A protective wafer transfer should be measured in order to determine the systems performance in improving control of the defects per square centimeter. This measurement should be done under conditions that are realistic.

7. Clean Room Monitors and Sensors

Maintaining a cleanroom at a constant set of values (temperature, humidity, etc.) requires constant checking of this system. A good way to do this is to install a monitor system in the intergrated circuit facility. This would include automated detection of temperature, humidity, air flow velocity, air borne impurities, and the static pressure drop across the HEPA filters. (note: humidity sensoring will be further discussed in this chapter under the heading, 11. Humidity ".)

Table 1 briefly outlines the monitoring systems and technology which are most common in intergrated circuit clean rooms. This table describes what method is used, and by what type of monitor and technology that is used to count the particulate present, and its minimum size in microns.

Table 1

Monitoring Technology (27. Tolliver,1984.)

Type of Monitor	Technology Used	Lowest Sensitivity Level (Microns)
Surface	White Light	0.50
Surface	Laser	0.30
Aerosol	White Light	0.30
Aerosol	Laser	0.10
Aerosol	Condensation	0.01
Liquid	White Light	0.50
Liquid	Laser	0.40
liquid	Ultrasonic	1.00

Airborne particle monitoring systems are the most common type of particle monitors found in cleanrooms.

Sensor manufacture's literature and specifications should be carefully reviewed. The cost and inconvenience of sensor recalibration and replacement for maintaining the required tolerance must also be considered. Cutting down on defects by monitoring the cleanroom will provide for a more cost effective facility.

8. Energy Conservation In Minimizing Cooling Loads

The energy that is required for the environmental control in a clean -room is high. This energy consumption is related to cooling, fans, humidification, and reheat. Cooling energy is significant and 85% (28. Brown,1986.) of the total cooling capacity will be required to :

1. Condition make-up air
2. Remove process heat
3. Remove fan heat

By minimizing cooling energy, this provides a good opportunity for energy consveration. Possibilities for this inclide :

1. Heat recovery in make-up air.
2. Highest possible water temperature.
3. Lowest cooling tower temperature.

The temperature for the make-up air that is required to provide for dehumidification in most cleanrooms will need to provide water temperature in the 38-42 degrees fahrenheit range.

when evaporative cooling is used for make-up air, there are many hours per year when the outside air, while cooled to the required wet-bulb, is cooled to only 50-60 degrees fahrenheit. Since the chilled water for the recirculation air cooling and precooling of make-up air can be accomplished with 50-60 degrees fahrenheit water, the use of a dual temperature chilled water system is possible.

Energy consumption can be reduced for the make-up air cooling by using outside air and pre-cool it by indirect evaporation. This can be accompolished by using a "finned -tube heat exchanger piped either to a cooling tower or some other independent evaporative heat exchanger." (29. Brown, 1986.) Another method of make-up air precooling is accompolished by heat recovery, utilizing exhaust air. If a high percentage of exhaust air is scrubbed , a heat exchanger downstream of the scrubber can offer a good potential for additional energy recovery." (30. Brown, 1986.)

By operating the chiller with the lowest possible condenser water temperature will save in the power that would have been needed to run the fan to lower the temperature. This can be done by using low input power chillers by increasing the heat exchange surface area over long operating hours.

9. Fans

Laminar flow clean air systems operate by moving a large quanity of air through High Efficiency Particulate Air Filters (HEPA). The idea here is to reduce the electrical consumption but not compromise on performance standards of fans. This power is reduced by using less fans but larger ones. Fan energy becomes more significant as the cleanliness class improves. Laminar flow clean air systems are large volume, low static pressure systems. "The most efficient fan for this requirement is the low speed, forward curved blade, squirrel cage type." (31. Marsh, 1981.) Larger fans are more efficient than smaller ones of the same type. Motors for fans have different efficiency factors. This is formulated by output horsepower divided by the input wattage. The efficiency range can range anywhere from 60 to 85%. For an energy efficient system, the efficiency factor should be at least 75%. (32. Marsh, 1981.) Because of this, a high voltage three phase motor is not necessarily as efficient as a lower one.

The location of the central fan system is more efficient the closer it is located to the source. The increase in distance causes friction losses in the connecting distance.
In laminar systems the use of different fan speeds is benefiscial, especially during non-production hours. By being able to cut down on fan speed when the facility is not in production cuts down on the energy being used.

The laws of fluid dynamics state that whenever eddying or turbulant flow is present, there is a greater loss in overall pressure than in a smooth flow. An abrupt change requires more energy to conform than a gradual change. Design wise , having a laminar flow of minimum air change can be more energy efficient. (See Figure 6.)

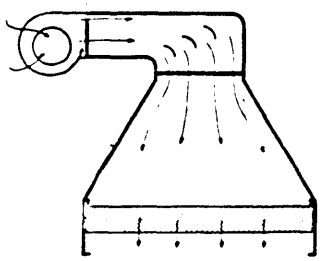


figure 6

10. Humidity

Relative humidity is defined as the amount of water vapor in a gaseous atmosphere. Too much water vapor in the cleanroom can transport contaminants to the product or create oxidizing conditions, while too low a humidity level can cause static electricity problems. Every process has an optimum humidity level, and achieving the proper level can result in cost savings.

For proper design, the selection of monitors, and sensors for measuring and controlling humidity require careful thought so that unnecessary costs can be avoided. First, the humidity level and tolerance for the particular process should be determined. Second, the number of sensors needed and then placement in the room should be established. As mentioned before in the section of this chapter entitled "Cleanroom monitors and Sensors," the manufacturers literature and specifications should be carefully reviewed. Also, the cost and inconvenience of sensor recalibration and replacement for maintaining the required tolerance must also be considered.

In summary the thorough planning before purchasing a humidity sensor, and the placement of these in the cleanroom facility will be a savings both in money and time.

11. Lighting

Having the right amount of footcandles in the clean room is important, as was stated in chapter one. But leaving the lights on all the time cuts down on the overall efficiency. Keeping the lights on converts the energy from the lights into heat which adds to the airconditioning load. Keeping the lights on when not needed also increases the maintenance cost by replacement cost, and the maintenance cost of replacing there lamps.

An energy efficient method to use would be a programmable control system which can be readily applied to lighting loads with a payable period of less than one year. (See Table 2)

Table 2
Lighting Costs (33. Schneider, 1984.)

Operation Mode	Hours of use	Light cost * ($)	A/C cost* ($)	Total cost* ($)	Savings (%)
Continuous	8760	3504	1191	4695	0
No Weekends	5640	2256	767	3023	37
One Shift	2008	803	273	1076	77
Two Shift	4016	1606	546	2152	54
Three Shift	6024	2409	819	3228	31

(*annual cost) see next page for basis.

basis: (1) Analysis for 1000 sq. ft.

(2) 4 watts/sq. ft. lighting level

(3) cost of power is $.10 per kwh.

(4) Airconditioning EER = 10 BTU/watt

12. Testing

Over the years there has been two basic types of tests for cleanroom systems to properly evaluate a cleanroom facility :

1. **initial performance tests**
2. **operational monitoring.**

The initial performance tests may result in corrections of problems within the cleanroom facility before personnel occupy the space

A cleanroom facility cannot be fully evaluated until it has performed while the facility is in operation. In laminar flow cleanrooms it is important to sample the work areas. This sampling should be done with a light scattering photometer, providing a high rate of samples (34. Cambridge Filter, 1986.)

Average velocity readings throughout the cleanrooms should be taken with what is called a hot wire anemometer to determine velocity gradients and air patterns. Several readings should be taken to give an average of each filter in the bank of filters of a laminar flow cleanroom. With the needs of class 10, and class 1 rooms to be certified, revisions are still being made.

Organizations have developed methods for the testing of cleanroom performance. Along with the Federal Standard 209B, which is now being revised there is one published by the Institute of Environmental Sciences which is entitled CS-6T. This is also in the process of being revised and is entitled, RP-006-84T. These particular tests have not been adopted by the Federal Standards but until they are, it makes for good planning to adopt these tests for a more efficient overall operation.

These test areas are: **(RP-006-84T)**

1. HEPA filter Leaks
2. Temperature Gradients
3. Humidity Gradients
4. Parallelism
5. Particle Count
6. Vibration Level
7. Uniformity
8. Recovery
9. Induction
10. Pressurization
11. Lighting Level
12. Noise Level

Chapter 5 Vertical Laminar Flow (Research)

5.1 Introduction

Part II of this thesis is to develop a better insight with vertical laminar flow as it pertains to cleanroom design. This insight will answer performance questions on its design, and offer an improvement in the efficiency of the cleanroom design in regards to the vertical laminar flow. There are cleanroom designs which also function using horizontal laminar flow, and diagonal flow design. The majority of cleanrooms use either vertical, or horizontal flow design.

The concern here is with the vertical flow aspect because of its heavy use and also this design offers the most flexibility (See Figure 7.) An advantage of the vertical laminar flow is the isolation of individual operations using laminar flow. Also, this flow generates the shortest distance from possible contamination areas to removal from the room. The biggest disadvantage of this form is the cost.

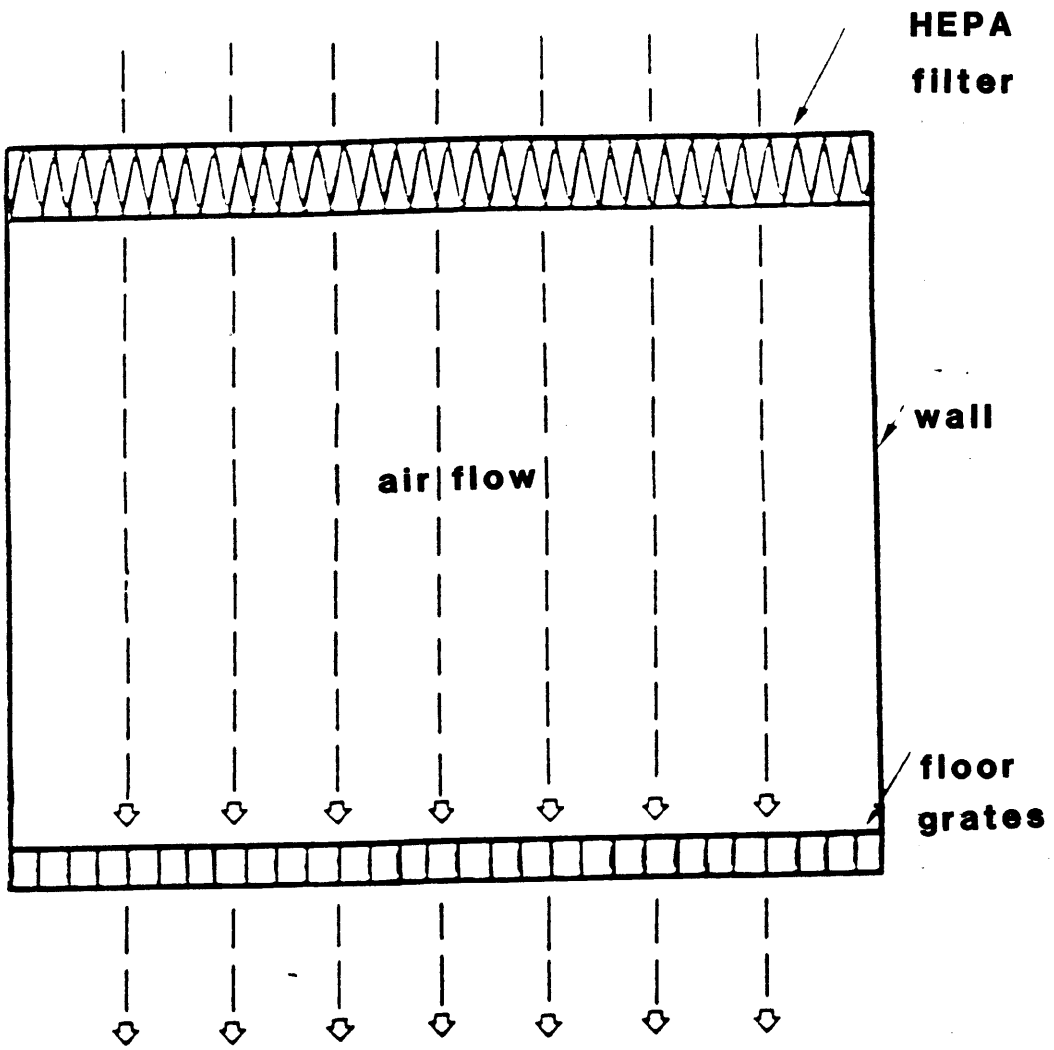


figure 7 Vertical Laminar Air Flow

5.2 Laminar Flow (Vertical)

Laminar flow is the flow of a fluid (air) at very low velocities, moving along smooth paths in layers with one layer moving smoothly over an adjacent layer (sometimes called "streamline", or viscous flow) with no eddies or swirls. A viscous flow is characterized by viscosity, which is the property of a fluid (air) that resists relative motion of adjacent fluid layers. In true laminar flow, the action of viscosity cancels out any turbulent tendencies.

Laminar flow cleanroom air systems operate by moving a large volume of air through High Efficiency Particulate Air Filters (HEPA), and then quickly through the entire area that is to be protected. This large volume of air is designed to make a single pass through the clean area to remove all the airborne contamination and is then recirculated back through the HEPA filters before making another pass. As velocity increases, eddies or swirls form and this type of flow is called "turbulent". Turbulent flow is a condition of flow which exists when the velocity exceeds a critical value. Laminar and turbulent flow each have their own laws of resistance to motion which applies to all fluids. This nature of flow whether it is laminar or turbulent, and its relative position along a scale indicating its turbulent to laminar tendencies are indicated by what is called, the Reynolds number. The nature of a given flow can be characterized by this Reynolds number. C.Reynolds, in 1833 analyzed basic fluid flow charateristics through experiments using the principle of "Dynamic Similarity" (36. Leary, 1951. page 28.)

This dynamic similarity is attained in two or more conditions of flow if a dimensionless parameter called the Reynolds Number is the same in both cases. (See Figure 8.)

This Reynolds number is defined as:

Rd = p ud /u1

p = fluid density U1 = fluid viscosity
u = fluid velocity

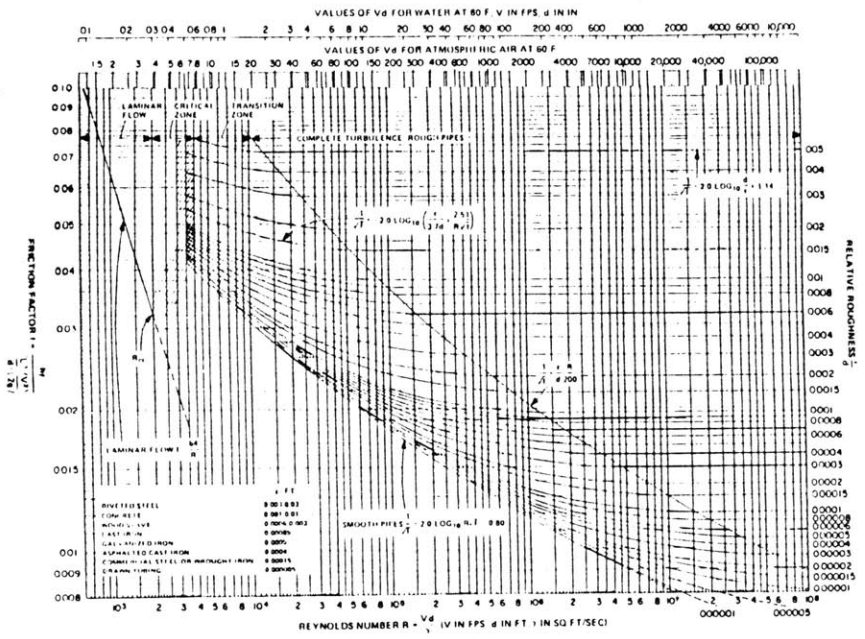


figure 8

Friction factor vs. Reynolds number showing laminar flow

5.3 Research Model

5.31 Design

This research model is designed to assimilate a vertical laminar air flow cleanroom. (explained in chapter one.) As mentioned before, The vertical laminar air flow cleanroom as presented here represents a large percentage of the type used in intergrated circuit facilities.

This model operates in a laminar flow by using air supplied through the top and streamlines through the ceiling perforated panel. The air moves through the cleanroom space vertically and exhausts through the perforated flooring panels and exits out the adjusted sliding doors which are located on all four sides of the model.

This cleanroom model is designed to move the air through the space in a vertical manner. It was felt that by using two perforated flooring screens, 4 inches on center, and a prefilter placed on top of the floor grating, this would structure the air movement in a more linear pattern. Cleanroom air exhaust locations are either at wall locations,or through floor gratings in the typical intergrated circuit facility. For a more laminar flow, it is recognized that exhausting through the floor is more effective for laminar flow. The design of this model is patterned after this. The scale is one quarter of full scale, so the floor to ceiling height is 8'-0".

The research being done in this model will deal with laminar flow and not with particulate control. Because of this, the use of High Efficiency particulate Air Filters (HEPA) will not be needed as is required in all cleanrooms. (See Figure 9)

5.32 Model

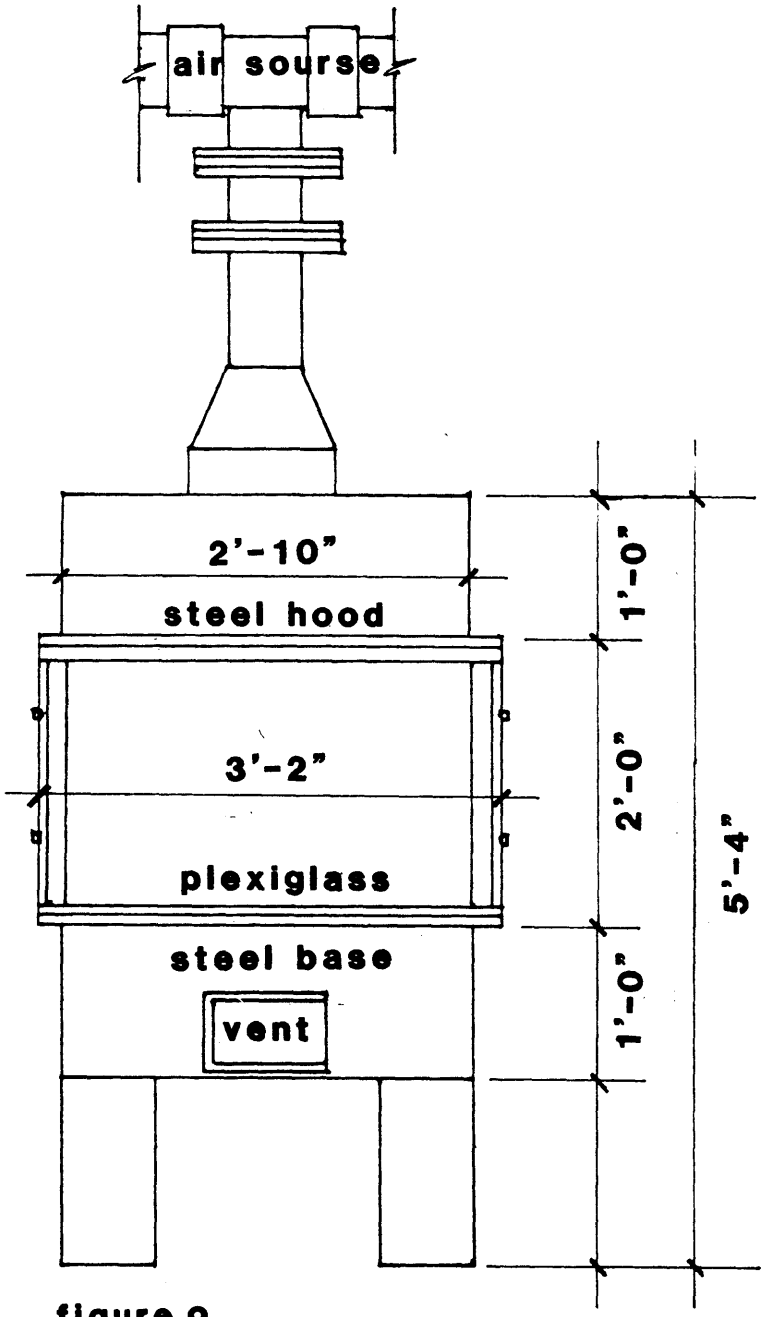
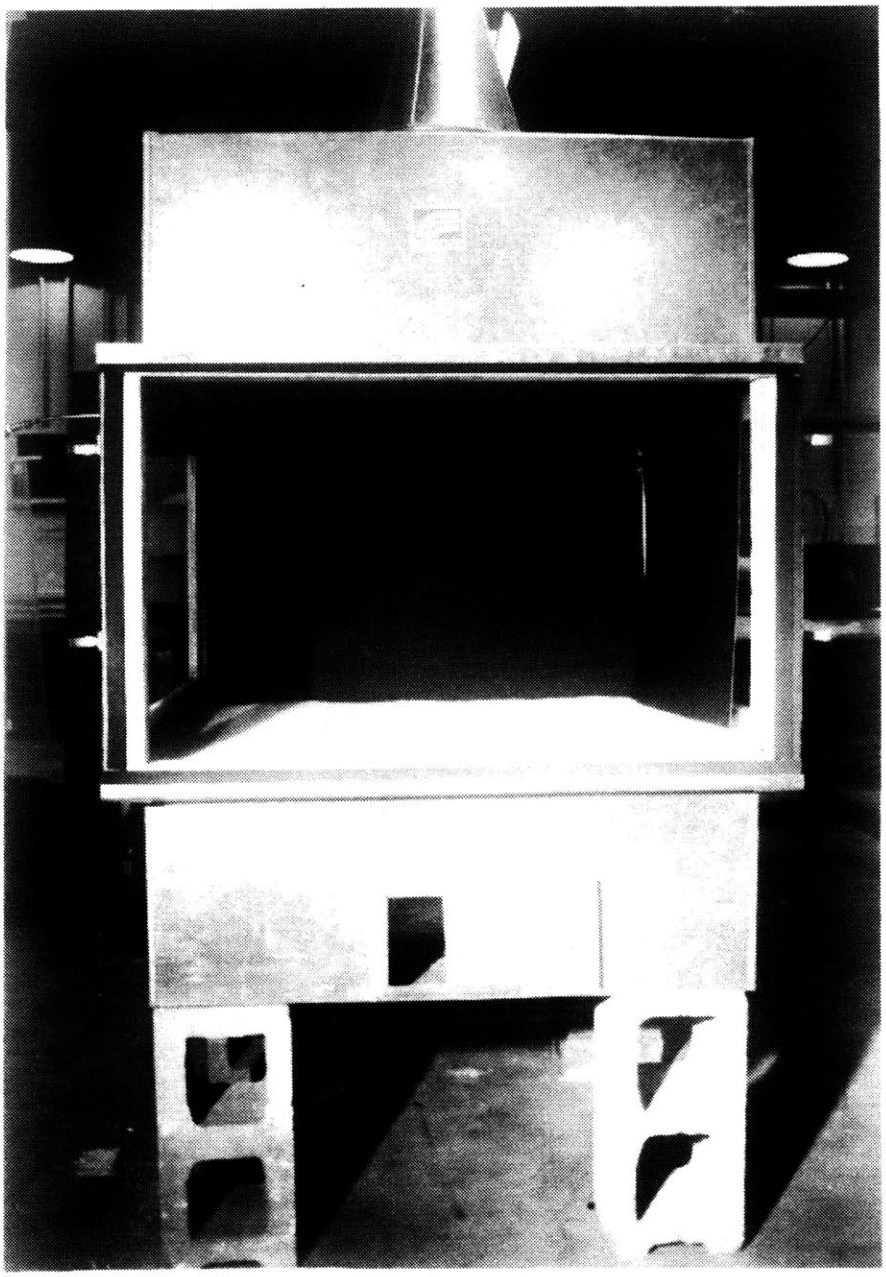


figure 9

Research Model



Photograph 1

Research Model

5.4 Research

The main function of a cleanroom is to control or limit airborne particles. In laminar flow cleanrooms, airborne particles are carried from the room by what is called "unidirectional" (straightlines) air-flow. Ideally, air flow in laminar flow rooms move through the room in these straight lines without major disturbances. Particles released in the room will be carried out very quickly with the laminar flow.

5.41 Research Agenda:

This research is intended to show the relationship of people and other objects in a cleanroom environment that is operated by using a vertical air flow to clean the room of contaminates that are generated from the people, and equipment, etc. The reason for this is to point out the limitations of this type of system.

A. Research Questions:

1. Does the vertical 'streamline' air flow (laminar flow) as defined by Federal Government Standard 209B (see appendix) adequately eliminate the particulates that cause defects on chips being produced in a cleanroom?

2. Is the location of personnel in the cleanroom effective for vertical air flow design ?

3. When personnel are working in a cleanroom, they are almost always working with some form of equipment. For an effective use of verical air flow, how should personnel best position themselves in relation to their equipment ?

4. How are turbulence and eddys formed in cleanrooms? What are some of the methods that may be used to prevent this from happening?

B. Alternate method for more effective vertical laminar flow in the cleanroom environment.

5.5 Discussion On Research Process

The research was developed by first testing the model. The model was tested to determine how uniform the air velocity was coming through the ceiling. This was performed by using an IBM PC-AT computer with a "Based Data Acquistion System". Attached to this unit was a anemometer and a hot film sensor probe which was placed inside the model while the system was running. An advantage of using a hot film sensor probe is that it has the ability to measure low velocities like those in cleanrooms. A hot film sensor probe is essentially a conducting film on a ceramic substrate. The program for this was entitled "Uncle Scope". (developed at MIT)

With this system running, and with the film sensor at a fixed position, the "Uncle Scope' program was able to give out 1,024 readings, every 20 seconds on the monitor. Every 20 seconds there were 3 velocity figures given.

1. minimum velocity.
2. maximum velocity.
3. average velocity.

These field measurements gave an overall series of numbers. These numbers were the velocity readings. The closer the numbers were to each other the more uniform the air flow was. The intent of this model is to provide a uniform flow. This is what is achieved in a typical cleanroom. The sensor was placed randomly all through the model at a working height of 42". (See chapter 1.3 , fundamental issue number 5 entitled "Lighting".

The difference of reading the voltage point output of the anemometer between the lowest point and the highest point was .13 volts. For this research the velocity across the ceiling of the model was judged uniform.

As mentioned earlier the model was designed at 1/4 full scale. This cleanroom space has a floor to floor height of 8'-0". The human figure in this room is 6'-4", and the table is 42" above the finished floor.

To visually see the air current, two methods were used.

1. **video tape** attached to thread spanning across the ceiling.
2. **smoke sticks** attached to ceiling above figure.

1. video tape: The video tape was used to observe the air movement. This tape was attached to a thread that was placed across the ceiling of the model. The video tape hung down individually next to the figure and table in different lengths to conform to the shapes. This video tape stopped just short of touching the floor. The placement of this tape hung freely and did not touch the figure or the table that would have consequently influenced the movement of the video tape.

The vertical air flow was turned on, and the movement of the air was depicted by the movement of the tape. (the more 'streamline' the air flow, the less the tape would move.)

The tape when placed in the room with the system on , visually moved slightly. After running the system several times, over a period that involved several days it was observed that

A. The video tape moved slightly. This movement was in the form of a "wiggle".

B. The video tape moved the most by the floor. This movement started to appear approximately 1-2" from the floor.

C. The video tape seemed to curve towards the figures face, especially when the figures head was crouching over the table, similar in nature to an operator working on processing equipment in a cleanroom. The video tape was a preliminary study for the smoke sticks.

2.* smoke sticks: The smoke sticks were used to detect air currents for visual study. Each smoke stick provided a continuous 10 minute smoke with each one giving the effect of 2 ciggerates smoking simultaneously.

The smoke sticks were attached to the ceiling above the figure. When the air system was turned on, the smoke moved in a 'streamline' fashion down the front of the figure and working area. This action shows how the vertical air flow "washes" the area of contamination and, in this case, exits through the floor. without this process, contaminates would otherwise settle on the chip being processed, and cause a defect to occur on the chip.

As indicated by the pictures the laminar air current in the room was affected by the precence of furniture, and people. (See Photographs 2-11.)

* Note: The smoke sticks were provided by "Airchain Products", located in Metuchen, New Jersey.

5.51 Response to Research Questions. (5.41 Research)

1. Does the vertical 'streamline' air flow (laminar flow) as defined by Federal Government Standard 209B (see appendix) adequately eliminate the particulates that cause defects in chips being produced in a cleanroom ?

According to Federal Standard 209B , section 20.3; (see appendix) "For the purpose of this standard, laminar airflow is defined as air flow in which the entire body of air within a confined area essentially moves with uniform velocity along parallel flow lines."

From a technical point of view, the use of the expression "laminar flow", to desribe this concept is incorrect. The meaning actually intended is stable parallel flow with small-scale turbulence only, superimposed on the main air flow.

Through this research and by photographing the results, the inclusion of furniture, and people cause obstructions in the vertical parallel air flow. This obstruction forms turbulence and this action causes problems because this air flow recirculates and will be remixed back into the air flow system.

The problem with this is that particulates that are in this location will be recirculated causing more possible defects on the chips being manufactured. There is not total vertical laminar flow when people, and equipment are placed in a cleanroom.

The design concept of the vertical laminar flow cleanroom is to reduce the small scale turbulence to the point where it is acceptable and to prevent the development of large scale turbulence resulting from objects placed in the flow field, movement of people, thermal sources, etc.

Rapid recovery from air disturbances, such as personnel motion, is also an important requirement.

Users of the vertical laminar air flow, and horizontal laminar air flow must recognize these principles and seek to achieve the best possible arrangements of equipment, personnel and movement to maximize the effectiveness of these systems.

2. Question: Is the location of personnel in the cleanroom effective for the vertical laminar flow design?

By looking at photographs 4,& 5, all personnel that are located in the cleanroom will cause the vertical laminar flow at their location to become turbulent because people obstruct this vertical laminar flow. For effective use of vertical laminar flow in the cleanroom, the location of people should be away from the product manufacturing location.

3. Question: When personnel are working in a cleanroom, they are almost always working with some form of equipment. For an effective use of vertical air flow, how should personnel best position themselves in relation to their equipment?

People provide the highest percentage of contamination in the cleanroom. **(continued on next page.)**

With the air flow coming down from the ceiling, this flow will then either strike the equipment than the people, in that order or vice versa.

When the people are struck first by the vertical air flow, the potential for defects on the chip are more likely. The better relationship is when the equipment is affected by the vertical flow before the people.

4. Question: How are turbulence and eddy's formed in the cleanroom? What are ways that can be used to prevent this from happening in the cleanroom .

Turbulent flow is an irregular flow, and eddy's are air flow that are running contrary to the main flow. These are caused by the presence of personnel and equipment in the cleanroom that disrupt the streamline air flow by blocking this continous flow.

Methods that can be used to prevent turbulence, and eddys from forming are:

1. **Prohibit people from occupying cleanrooms.**
2. **Minimum movement by people, equipment, etc.in the cleanroom.**
3. **Minimum surfaces perpendicular to the air flow.**
4. **Maintaining a velocity of air under a 2000 Reynolds number.**

B. Alternate solutions for more effective vertical laminar flow in the cleanroom environments.

Along with the prevention techniques that were presented in question 4 on part "A", (Research Questions) what has evolved from this research is a method for more effective control of the vertical laminar air flow. The presence of people in the cleanroom will cause obstructions in the vertical laminar flow. Until people are totally alleviated, which will not happen for some time, there must be methods developed for more effective use of the vertical laminar flow. One method that has developed from this research is the addition of another smaller air source which is directed at the personnel working in the cleanroom. (See Photographs 10, &11) As shown in the picture, turbulence and eddys form around people. This is especially true at the upper body and when these operators are leaning over while working. What has been established is that as the persons head becomes more perpendicular with the vertical laminar air flow, the larger the turbulence and the eddys that are formed.

By injecting another smaller air flow (smaller source, lower velocity) that is positioned slightly above and directed towards the operators upper body and head , and also the area of the chip processing, the more the particulates coming from the person will be directed away from the work area, and consequently fewer possible defects on the chips will occur. This is a method for working with the problem of people being present.
(See Figure 10.)

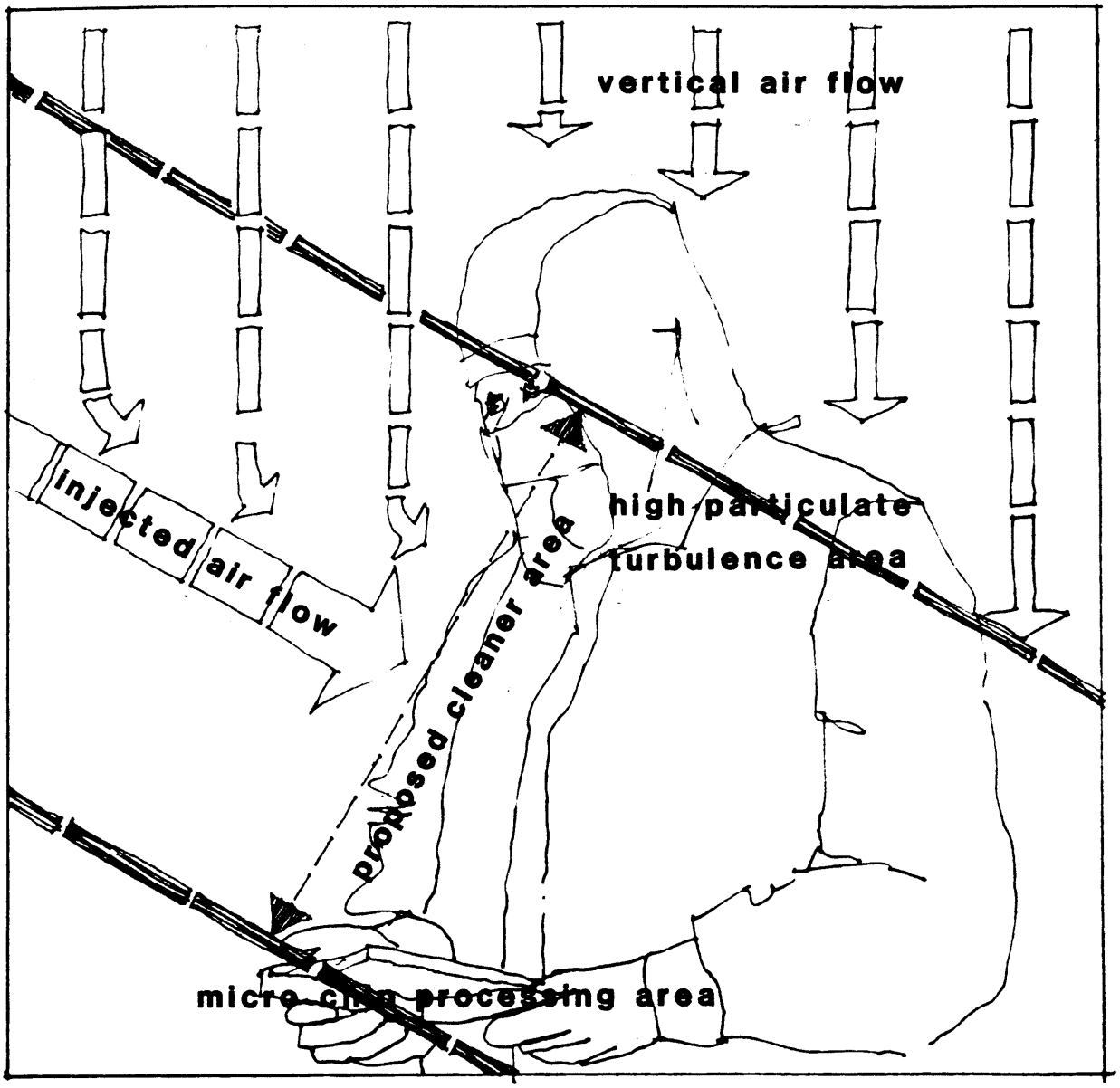
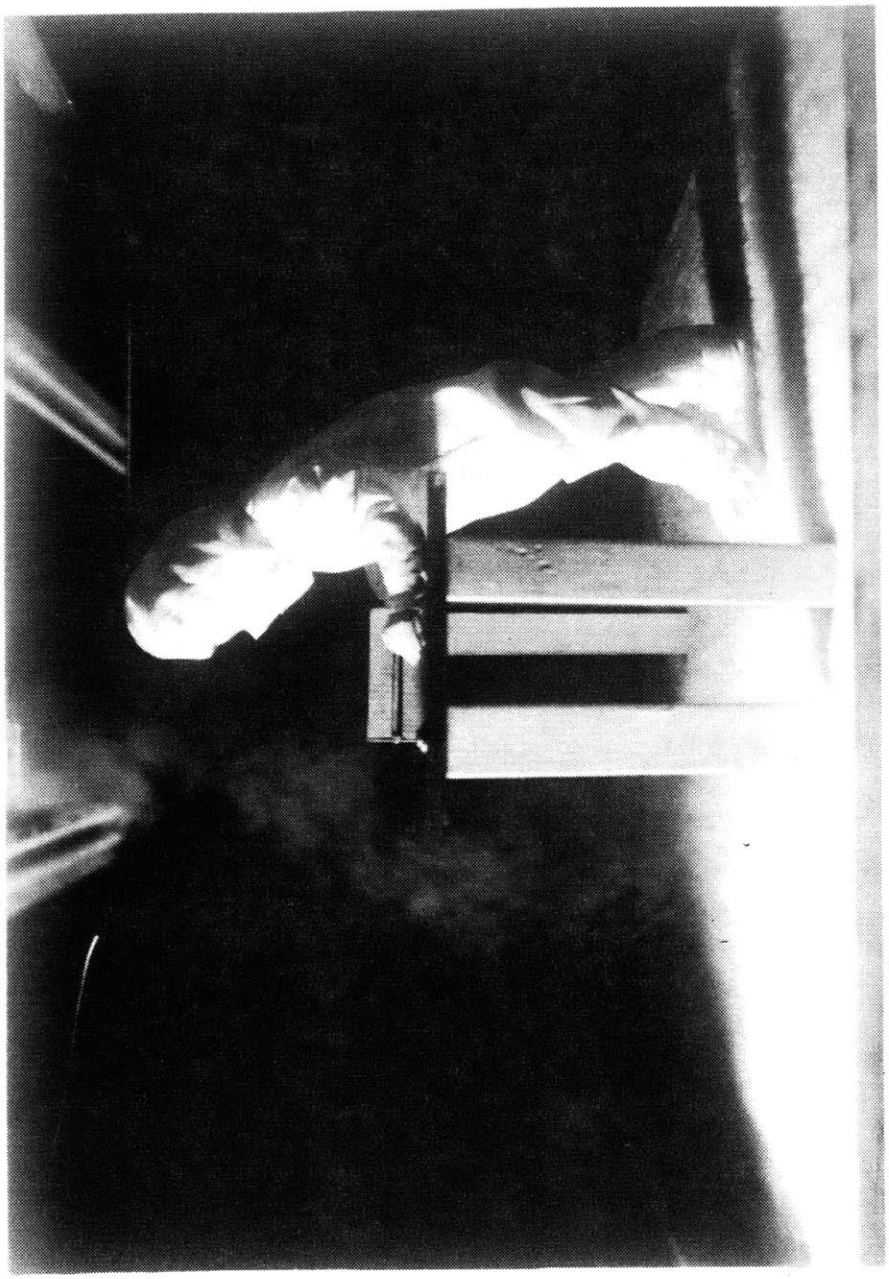


figure 10

Showing proposed method for more efficient operation of vertical air flow

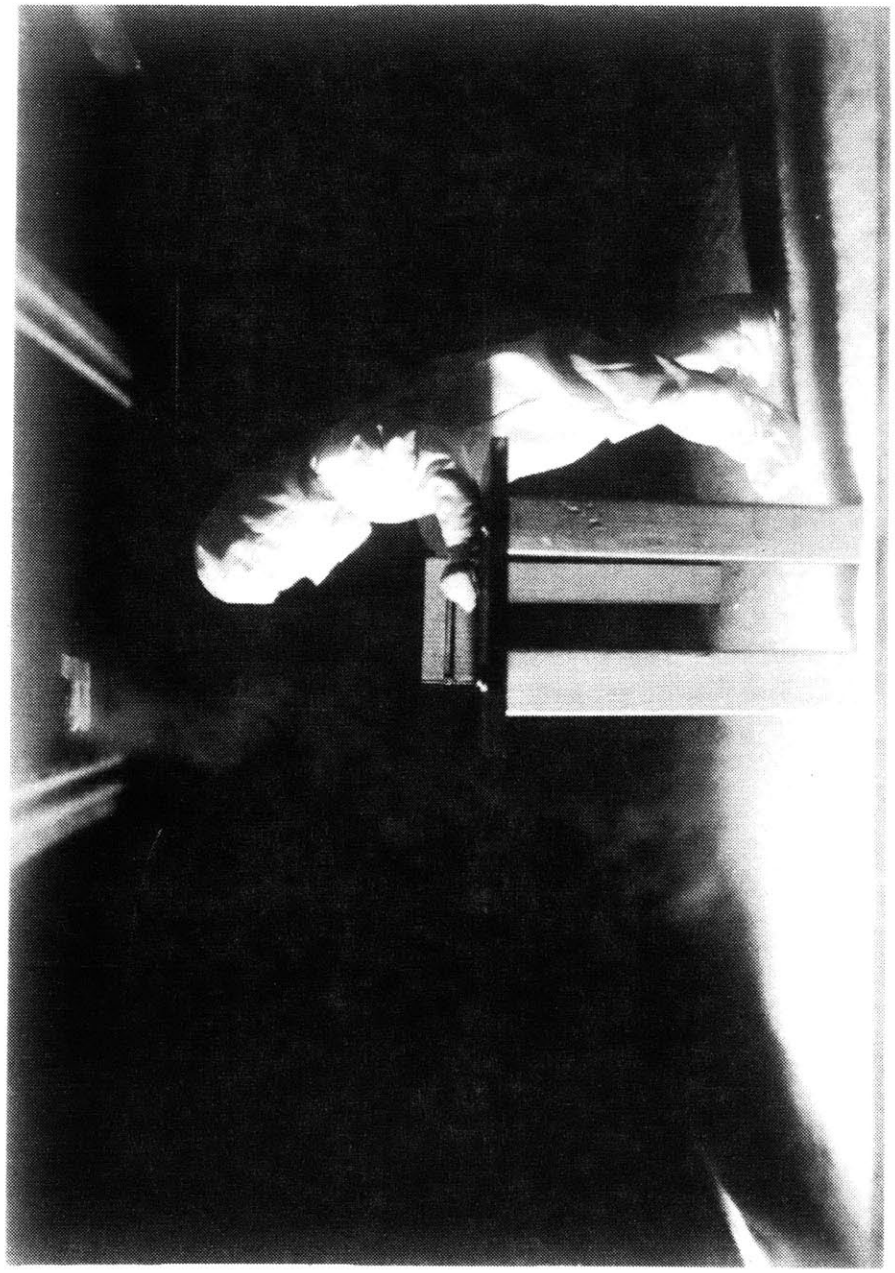
5.52 Research Photographs

Photograph 2
Vertical laminar flow.



Photograph 3

Note obstruction of air flow at edge of table.



Photograph 4

Note air flow moving towards operators face and processing area.

Photograph 5

Note turbulence and eddy's forming by operators chin, and edge of table.

Photograph 6
note injection of additional air by copper tube upper left side.(injection just starting

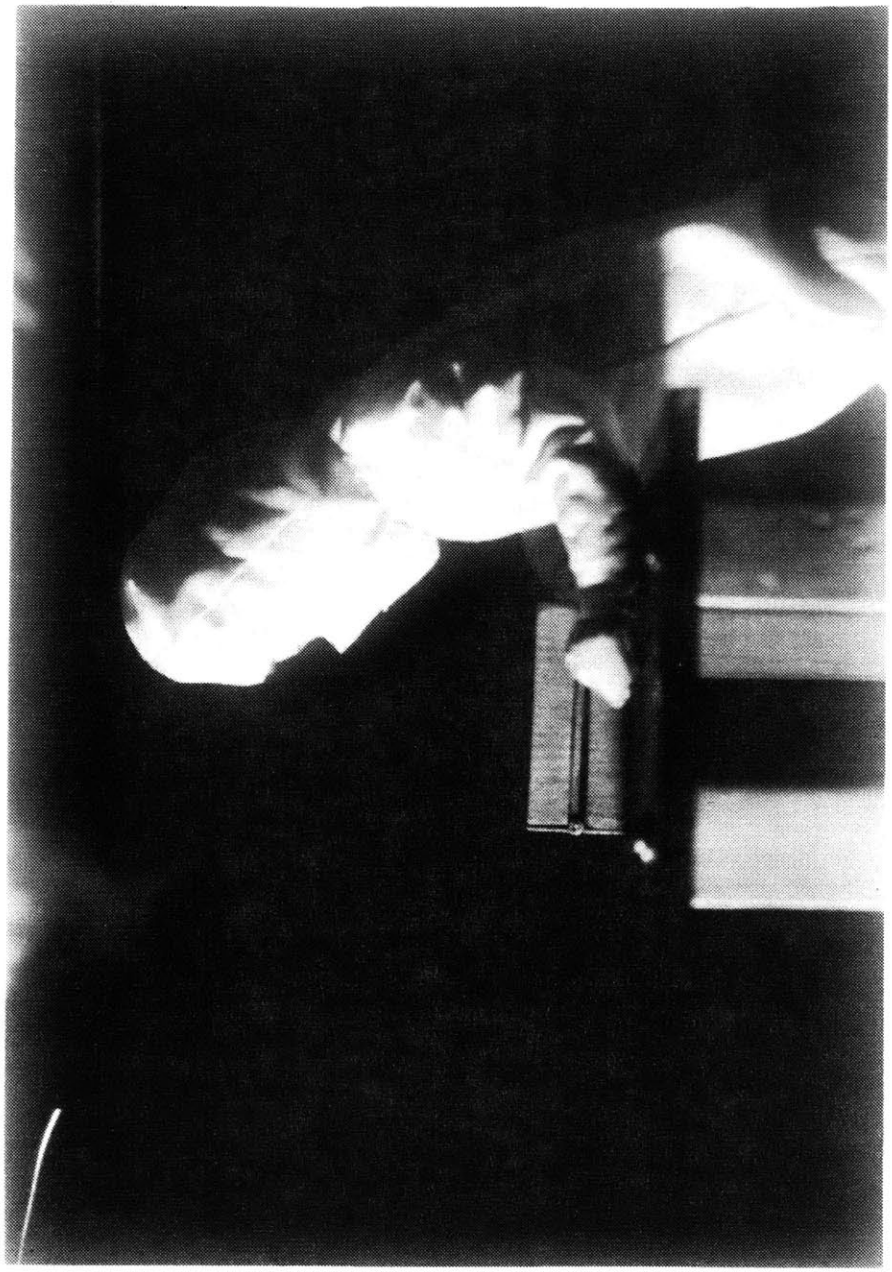
Photograph 7
Additional air being injected by tube located upper left. Notice air being washed by operators chin.

Photograph 8
Close up showing turbulence forming under operators chin. (additional air not injected at this point)

Photograph 9

Close up showing turbulence forming by operators chin and on top of processing area. (additional air not injected at this time)

Photograph 10
Additional air being injected by copper tube.
Note air moving away from processing area.



Photograph 11
Close up of air being injected in front of operator and processing area

5.6 Related Studies / Future Considerations

There has been other research through the years on laminar air flow since its conception in cleanroom design which occured in 1962.

With what is described as laminar flow has been the various velocities of air movement to give an overall efficient operation in conjunction with dispersion of particulates. This has been accepted to be between 90-120 feet per minute. A velocity in this range appears to be a reasonable value for well designed unidirectional flow systems to achieve minimum dispersion and rapid recovery downstream from flow disturbances. Though the research here has been focused on vertical air flow, the relationship of air flow and particular control is unseperable, among the many studies that have been done in this area are:

1. The relationship of air patterns and particulate movement.
2. Using plastic curtains around personnel to cut down on contamination.
3. Studies on air flow velocity in relation to particulate count.
4. Movment away from self-contained hoods that provide localized laminar flow (too much noise and vibration.)

In planning for the future, the use of robotics, and other forms of automation should be included. Automated guided vehicles are currently being used today, though largely for material transfer. (37. Zygmont, 1986.) By reducing human handling, and presence, the contamination level in cleanrooms will decrease. The semiconductor industry in the United States is at an important stage now because of pressures from overseas manufacturers. This is not from lack of new technology, rather from less than efficient use of existing technology.

Chapter 6 Conclusion To Thesis

Manufacturing efficiency has become a key success factor within the integrated circuit industry worldwide. The on going drive to increase the number of circuit functions per device by shrinking its size and expanding die sizes has made today's devices more vulnerable to all types of submicron contamination. This has made it necessary to reduce and maintain defect densities as close as possible to zero.

The main emphasis in this thesis has been two-fold.

1. Address the problem in prevention of contamination by using efficiency in energy and costs.
2. Research the vertical laminar air flow that is used in cleanroom contamination control.

What has resulted from this is:
Part I: Good initial planning that is focused on the effective use of energy and cost will create a better cleanroom solution initially, and in its future operation.

Part II (Research): Vertical air flow as described in the Federal Standard 209B can be made to operate more effectively with less potential defects on the chip being processed by injecting into the design process, an additional source of air wash, which is directed at the personnel's upper body, head, and work area. Also, the use of vertical air flow throughout the cleanroom may not be mandatory.

At this point, additional research could coincide with this study, which would focus in on the effects of the actual particulates. This could be addressed by how these particulates respond to this air movement.

APPENDIX: FEDERAL STANDARD NUMBER 209B

FEDERAL STANDARD

CLEAN ROOM AND WORK STATION REQUIREMENTS, CONTROLLED ENVIRONMENT

This amendment, which forms a part of Federal Standard No. 209B, dated April 24, 1973, was approved by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies.

PAGE 1

Contents, after paragraph 5.1.1 add: Paragraph 5.1.1.1 Class 1000 (35).

PAGE 3

Paragraph 5.1: Delete sentences three and four and add as follows:

Particle counts are to be taken at specified intervals during work activity periods at a location which will yield the particle count of the air as it approaches the work location. The preferred location for the particle count is at work level height with the sampling probe pointed into the airstream. Other classifications (i.e. 500, 5000, 80,000 etc.) may be used for particle count levels where special conditions dictate their use.

PAGE 4

Table I, Air Cleanliness Classes: Delete and substitute:

TABLE I

AIR CLEANLINESS CLASSES

Class English System (metric system)	Maximum number particles per cubic foot (per liter)* 0.5 micron and larger	Maximum number of particles per cubic foot per liter)* 5.0 microns and larger
100 (3.5)*	100 (3.5)*	Less than 10 (0.35)* See note.
1000 (35)*	1000 (35)*	Less than 10 (0.35)* See note.
10,000 (350)*	10,000 (350)*	65 (2.3)*
100,000 (3500)*	100,000 (3500)*	700 (25)*

*Metric system
NOTE: Counts below 10(0.35) particles per cubic foot (liter) are unreliable except when a large number of samplings are taken.

PAGE 4

After paragraph 5.1.1 Class 100 (3.5) add as follows:

5.1.1.1 Class 1000 (35). Particle count not to exceed a total of 1,000 particles per cubic foot (35 particles per liter) of a size 0.5 micron and larger (see 5.2).

FSC 6636

PAGE 5

Table II, Particle size distribution curves, add a straight line denoting Class 1,000 (35) as follows:

A line originating at an ordinate value of 1,000 (35), bearing parallel to the three established class lines on Table II, and terminating at an abscissa value of 12. The line shall be solid above the ordinate value of 10 (.35) and dotted below it. The line shall be labelled Class 1000 (35).

PAGE 20

Paragraph 60.1.1 Nonlaminar flow clean rooms: Delete paragraph and substitute:

60.1.1 Nonlaminar flow clean rooms. Airborne particle counts should be taken at specified intervals at representative locations throughout the work activity area. The preferred location for the particle count is at work level height with the sampling probe pointed into the airstream.

PAGE 25

After subparagraph 6. add the following:

7. MIL-C-4566, Calibration System Requirements, (5)
8. MIL-Q-9858, Quality Program Requirements, (5)
9. MIL-I-4520, Inspection System Requirements, (5)

After footnote (4) add the following:

(5) Copies of Military Specifications, Standards, drawings and publications required by contractors in connection with specific procurements should be obtained from the procuring activity or as directed by the contracting officer.

PAGE 26

Addendum to Table III, Facility Guidelines for Air Cleanliness Classes as follows:

TABLE III

FACILITY GUIDELINES FOR AIR CLEARLINESS CLASSES

Laminar Air flow Vertical Flow room Vertical flow curtain unit Vertical flow bench	Entire work area meets requirements at normal working height locations.
Cross flow room Tunnel room Wall-to-floor room Cross flow bench	First work locations meet requirements.
Nonlaminar Air flow Conventional clean room	Will not meet requirements under operating conditions.

Fed. Std. No. 209B
April 24, 1973
SUPERSEDING
Fed. Std. No. 209A
August 10, 1966

FEDERAL STANDARD

CLEAN ROOM AND WORK STATION REQUIREMENTS, CONTROLLED ENVIRONMENT

This standard was approved by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies.

FOREWORD

Within recent years, the application of clean room technology has spread from manufacturing to such other fields as aerospace, bioscience, pharmaceuticals, medicine, computing, and food processing. This expansion of the technology brought increased experience and knowledge not only in the diversified requirements for air cleanliness, but also in the methods which must be employed to meet these requirements.

Since the necessity for control of airborne particulates has been demonstrated in many governmental activities, the need for standardization has been recognized. Accordingly, this document provides standardization of definitions and air cleanliness classes for clean rooms and clean work stations.

Orders for this publication are to be placed with General Services Administration, acting as an agent for the Superintendent of Documents. Single copies of this standard are available at the GSA Business Service Centers in Boston, New York, Atlanta, Chicago, Kans City, MO, Fort Worth, Denver, San Francisco, Los Angeles, and Seattle, WA. Additional copies may be purchased for 45 cents each from the General Services Administration, Specifications Activity, Printed Materials Supply Division, Building 197, Naval Weapons Plant, Washington, DC 20407.

CONTENTS

CONTENTS (cont.)

APPENDIX

APPENDIX (cont.)

APPENDIX (cont.)

APPENDIX (cont.)

1. SCOPE AND OBJECTIVE

1.1 Scope. This document establishes standard classes of environmental air control within clean rooms and clean work stations.

1.2 Objective. The objective of this standard is to prescribe air cleanliness classes and certain other environmental air conditions required for achieving and maintaining the levels of environmental cleanliness specified in the product specifications.

2. REFERENCED DOCUMENTS

2.1 Documents. The following documents, of the issues in effect on the data of invitation for bids, form a part of this standard to the extent specified herein.

Nongovernmental:

American Society for Testing and Materials (ASTM) Standards:

F 25 - Method for Sizing and Counting Airborne Particulate Contamination in Clean Rooms and Other Dust-Controlled Areas Designed for Electronic and Similar Applications.

F 50 - Method of Test for Continuous Counting and Sizing of Airborne Particles in Dust Controlled Areas by the Light-Scattering Principle (for Electronic and Similar Applications).

(Application for copies should be addressed to the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa., 19103.)

Society of Automotive Engineers (SAE), Inc. Standards:

SAE-ARP-743 - Procedure for the Determination of Particulate Contamination of Air in Dust Controlled Spaces by the Particle Count Method.

(Application for copies should be addressed to the Society of Automotive Engineers, Inc., 2 Pennsylvania Plaza, New York, New York 10001.)

3. DEFINITIONS

3.1 Clean room. A clean room is an enclosed area employing control over the particulate matter in air with temperature, humidity, and pressure control, as require

To meet the requirements of a "clean room" as defined by this standard, all clean rooms must not exceed a particulate count as specified in the air cleanliness class of 5.1.3.

3.2 Clean work station. A clean work station is a work bench or similar working enclosure characterized by having its own filtered air or gas supply.

3.3 Particle size. Particle size is expressed as the apparent maximum linear dimension or diameter of the particle. (Note: While measurements from light scattering equipment may vary some from maximum linear dimension, this variation is not usually considered significant for normal clean room monitoring requirements.)

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

4. GENERAL REQUIREMENTS

4.1 Clean room or clean work station area. These areas are to be operated with emphasis on minimizing airborne particle contamination to levels within the limitations indicated in 5.1.

4.2 Equipment calibration. All equipment used to control, monitor, and record clean room and work station conditions shall be calibrated as specified.[1]

4.3 Environmental control. Environmental conditions such as temperature, humidity, pressure differential, and airborne particle count shall be controlled, recorded, and records reviewed as specified.[1]

4.4 Clean room air pressure. All clean rooms shall maintain a pressure above that of surrounding areas to assure that all leakage shall be outward.

4.5 Air change rate or airflow. Either the air change rate or the airflow velocity shall be specified.[1]

4.6 Temperature range. The temperature range shall be established as demanded by the product and in consideration of the personnel occupying the area.

[1] When the terms "as specified" or "shall be specified" are used without further reference, the degree of control needed to meet product requirements will be specified by the user or contracting agency.

4.7 Humidity range. The relative humidity range shall be 40 percent ±5 percent at the temperature/humidity control point, unless otherwise specified. Reasonable allowance should be made for instrument and system tolerances when specifying relative humidity requirements.

4.8 Audio noise level. The allowable audio level shall be specified and should conform to local health codes and the Occupational Safety and Health Act of 1970 unless otherwise excepted.

4.9 Vibration. The amount and character of allowable vibration shall be specified.

4.10 Microbial contamination. The allowable airborne microbial contamination shall be controlled to the level as specified in an applicable process or product specification. It must be recognized that airborne microorganisms are particulate in nature and that they are included in the total particulate count of air cleanliness classes per 5.1.

4.11 Other environmental factors. Due consideration should be given to other environmental factors such as light level, electromagnetic radiation, ionizing radiation, radioactive particles and particularly gases and vapors such as mercury and cleaning solvent vapors. Adverse environmental conditions such as the presence of hazardous materials are mentioned only to alert the user to the need for adequate controls and may involve considerations beyond the scope of this Standard.

5. DETAILED REQUIREMENTS

5.1 Air cleanliness classes. The three classes defined by this standard are shown in Table I. Classifications are based on particle count with a maximum allowable number of particles per unit volume 0.5 micron and larger or 5.0 microns and larger. Particle counts are to be taken during work activity periods and at a locatio which will yield the particle count of the air as it approaches the work location. Other classifications (i.e., 1000, 5000, 80,000 etc.) may be used for particle count levels where special conditions dictate their use. Such classes will be defined by th intercept point on the 0.5 micron line in Table II with a curve parallel to the three established curves.

TABLE I

AIR CLEANLINESS CLASSES

Maximum number of particles per cu ft (per liter)* 0.5 micron and larger	Class English system (metric system)*	Maximum number of particles per cu ft (per liter)* 5.0 microns and larger
100 (3.5)*	100 (3.5)*	See note at the bottom of Table II
10,000 (350)*	10,000 (350)*	65 (2.3)*
100,000 (3500)*	100,000 (3500)*	700 (25)*

*Metric system

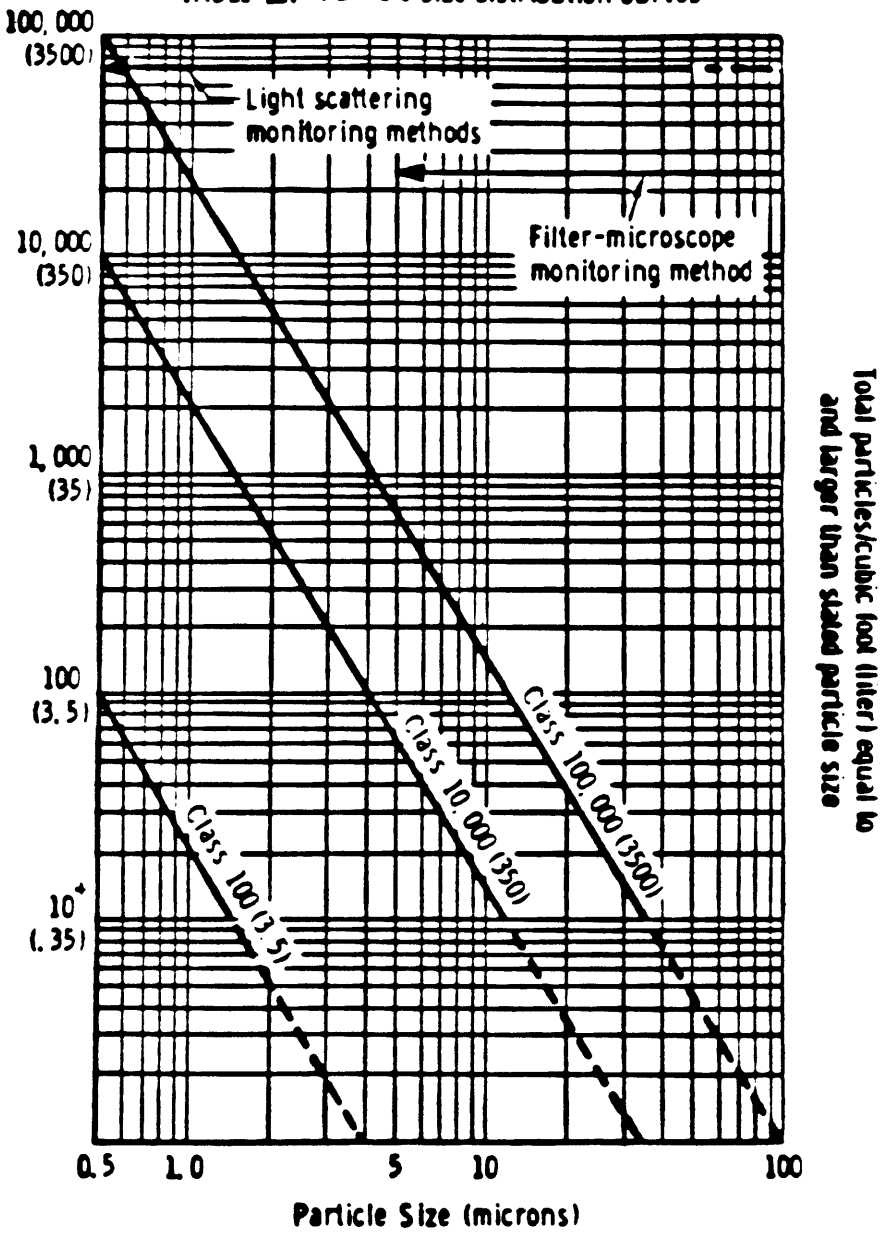
5.1.1 Class 100 (3.5). Particle count not to exceed a total of 100 particles per cubic foot (3.5 particles per liter) of a size 0.5 micron and larger. (See 5.2.)

5.1.2 Class 10,000 (350). Particle count not to exceed a total of 10,000 particles per cubic foot (350 particles per liter) of a size 0.5 micron and larger or 65 particles per cubic foot (2.3 particles per liter) of a size 5.0 microns and larger. (See 5.2.)

5.1.3 Class 100,000 (3500). Particle count not to exceed a total of 100,000 particles per cubic foot (3500 particles per liter) of a size 0.5 micron and larger, or 700 particles per cubic foot (25 particles per liter) of a size 5.0 microns and larger. (See 5.2.)

5.1.4 Statistical average particle size distribution. In Table II the three classes of clean rooms and work stations are depicted by the statistical average particle size distribution curves. While the definitions for these classes are taken from these curves, it should be recognized that single sample distributions may deviate from these curves because of local or temporary conditions.

TABLE II. Particle size distribution curves



*Counts below 10 (0.35) particles per cubic foot (liter) are unreliable except when a large number of samplings is taken.

5.2 Airborne particle monitoring.

5.2.1 Particle counting methods. For proof of meeting the requirements of the class of clean room or clean work station, one or more of the following particle counting methods shall be employed on the site of use:

(a) For particle sizes 0.5 micron and larger, equipment employing light scattering principles shall be used, as specified in ASTM F 50.

(b) For particle sizes 5.0 microns and larger, microscopic counting of particles collected on a membrane filter, through which a sample of air has been drawn, may be used, as specified in ASTM F 25 and SAE-ARP-743.

(c) Other monitoring methods and equipment may be used only if demonstrated to be of accuracy and repeatability equal to those methods listed in 5.2.1(a) or 5.2.1(b).

5.2.2 Monitoring techniques. Appropriate equipment shall be selected and monitoring routines established to measure air cleanliness levels under normal use conditions so that conformance to the specified air cleanliness class may be determined.

Manual microscopic methods are adequate for monitoring air in the classes 10,000 to 100,000 range. When monitoring air below the class 10,000 level, so few 5.0-microns and larger particles will be present that the manual method may not detect enough of these size particles to produce a statistically valid determination; therefore, air monitoring in the range below 10,000 can be done only with light scattering equipment.

6. CHANGES

When a Federal agency considers that this standard does not provide for its essential needs, written request for changing or adding to the standard, supported by adequate justification, shall be sent to the administration. This justification shall explain wherein the standard does not provide for essential needs. The request shall be sent in duplicate to the General Services Administration, Federal Supply Service, Standardization Division, Washington, D.C., 20406. The administration will determine the appropriate action to be taken and will notify the agency.

7. CONFLICT WITH REFERENCED SPECIFICATIONS

Where the requirements stated in this standard conflict with any requirement in a referenced specification, the requirements of this standard shall apply. The nature of conflict between the standard and the referenced specification shall be submitted in duplicate to the General Services Administration, Federal Supply Service, Standardization Division, Washington, D.C., 20406.

FEDERAL AGENCY INTERESTS:

Department of Defense, Office of the Assistant Secretary of Defense, (Installations and Logistics)

Army
Navy
Air Force

National Aeronautics and Space Administration

General Services Administration

Department of Health, Education, and Welfare

Department of Commerce

Federal Aviation Agency

Atomic Energy Commission

APPENDIX

NONMANDATORY SUPPLEMENTAL GUIDANCE INFORMATION

FOREWORD

The purpose of this supplement is to provide guidance in the preparation of documents related to the design, acquisition, testing, operation, and maintenance of clean rooms and clean work stations. This appendix is provided for information only and, as stated under Authority on the title page of this standard, adherence to its provisions is not mandatory in determining compliance to this standard.

Two distinct approaches to the design and operation of such clean rooms are presently utilized, both of which are covered in this document. One approach, sometimes called a conventional clean room, but referred to here as nonlaminar flow, makes use of highly filtered and conditioned air brought into the area through individual diffusers located in the ceiling, and exhausted through return air ducts located near the floor around the periphery of the room. Emphasis is placed on limiting the amount of contamination introduced into the air in the room by closely controlling the personnel, operations, and materials inside the facility. Personnel are required to wear low particle shedding type garments and all material must be cleaned before being introduced into the area. Accumulated contamination should be removed through adequate maintenance and janitorial service. Normally, critical operations would not be performed in a nonlaminar flow room.

The other approach utilizes highly filtered and conditioned air brought into the room towards the work area through a filter bank comprising an entire wall or ceiling of the room, and exhausted through the entire opposite surface facing the air inlet filter bank. The air is moved through the room in a laminar flow fashion, thus making only a single pass through any given area of the room. This laminar flow air movement carries out of the room any airborne contamination released by personnel and equipment, or generated by operations in the room. Contamination generated in localized areas of the room may be isolated from other areas by the striations of the

laminar airflow. Emphasis is placed on performing critical work in the undisturbed flow of clean air from the filter bank. Personnel restrictions and operational limitations are normally much less than those imposed in a nonlaminar flow room.

While both of these approaches represent acceptable methods of airborne particulate control for certain applications, they differ greatly in many respects and particularly in the degree of control they can provide.

10. REFERENCED DOCUMENTS

10.1 Specifications and standards. The following document (MIL-F-51068) of the issue in effect on the date of invitation for bids, forms a part of this standard to the extent specified herein.

Military Specification:

MIL-F-51068--Filter, Particulate, High-Efficiency, Fire Resistant.
(Copies of Military Specifications and Standards required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

10.2 Other publications. The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

Governmental:

TID-7023--High Efficiency Particulate Air Filter Units (HEPA).

(Application for copies should be addressed to the U.S. Atomic Energy Commission, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.)

American National Standards Institute (ANSI) Inc.:

Z9.2 - The Design and Operation of Local Exhaust Systems.

(Application for copies should be addressed to the American National Standards Institute, Inc., 1430 Broadway, New York, New York 10018.)

American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc.
ASHRAE Guide and Data Books.

(Application for copies should be addressed to the American Society of Heating, Refrigeration and Air Conditioning Engineers, United Engineering Center, 345 E. 47th St., New York, New York 10017.)

20. GLOSSARY

20.1 Nonlaminar flow clean room. A room supplied with filtered air with no specified requirement for uniform airflow patterns or uniform air velocity.

20.2 Nonlaminar flow clean work station. A work station characterized by nonuniform air patterns and velocities. This includes work stations which have constricted air exhaust or ports.

20.3 Laminar airflow. For the purpose of this standard, laminar airflow is defined as airflow in which the entire body of air within a confined area essentially moves with uniform velocity along parallel flow lines.

20.4 Laminar airflow clean room. A room in which the laminar airflow characteristics predominate throughout the entire airspace, with a minimum of eddies.

20.5 Laminar airflow clean work station. A work station in which the laminar airflow characteristics predominate throughout the entire airspace, with a minimum of eddies.

20.6 High efficiency particulate air (HEPA) filter. A filter as specified in MIL-F-51068 with a minimum efficiency of 99.97 percent as determined by test. The test can be by the homogeneous dioctylphthalate (DOP) method or other equally sensitive method at an airflow of 100 percent of the rated flow capacity for all size filters and at 20 percent of the rated airflow for sizes 4, 5 and 6.

20.7 Prefilters. A filter to trap gross particulates located upstream from and with lower collection efficiency than the HEPA filter. The efficiency of initial prefilters is usually in the 20-30 percent range by the NBS Discoloration (Dust Spot) Test, while intermediate prefilters usually have a collection efficiency of 80-90 percent by the same test.

20.8 First air. The air which issues directly from the HEPA filter.

20.9 First work location. The work location nearest the downstream side of the HEPA filters in a laminar airflow device.

30. ENVIRONMENTAL CONDITIONS

30.1 Airborne particulate contamination. As dictated by work locations, airborne particulate contamination should be measured at locations of interest in the clean room or clean work station by the methods specified in 5.2.

30.2 Recommended temperature range. Temperature in the clean room area should be maintained around a nominal temperature of 72°F (22.2°C), with the range to be specified by the user. Exceptions are those laboratories or work areas for which other temperatures may be necessary for control of stability of items being

fabricated or tested, in which case the nominal temperature and range should be specified. For example, the temperature variation at the control point may range from plus or minus 0.25°F (± 0.14°C) in the most critical operations to as much as plus or minus 5.0°F (± 2.8°C).

30.3 Relative humidity range. Relative humidity should be controlled in the clean room area. Choice of range should be based primarily upon product requirements. Two general problem areas should be recognized: (a) Rusting of parts can occur and become a serious problem at relative humidities above 50 percent. Hygroscopic particles that collect on surfaces can adsorb enough moisture from the air to become starting points for corrosion pits and will adhere to surfaces more tenaciously than particles in low humidity environments. (b) Electrical static charges on dielectric materials or parts can cause problems due to particle attraction at low relative humidities.

30.4 Make-up air. Make-up air volume supplied to the clean room area should meet American Society of Heating, Refrigeration and Air Conditioning Engineers Guide, using agency or local building code requirements. Make-up air should be prefiltered to at least the same degree as recirculated air. In rooms utilizing a relatively low volume of recirculated air, make-up should normally be specified as a percentage of the incoming air into the room; e.g., 5-20 percent fresh air make-up. In rooms utilizing a high volume of recirculated air, make-up air should normally be specified as a given volume per minute; e.g., 30 cubic feet per minute per person. When vented hoods are used for vapor control, make-up air volume should be greater than that of the exhausted air in order to maintain a positive pressure in the room.

When a large percentage of make-up air is required, air-to-air rotary heat exchangers or run-around systems should be considered to reduce the air conditioning load (i.e., heating or cooling).

30.5 Pressure. The minimum positive pressure differential between the room and any adjacent area of less clean requirements should be 0.05 inch of water, with all entryways closed. When the entryways are open, the blower capacity should be adequate to maintain an outward flow of air to minimize contamination migrating into the room.

30.6 Noise. Clean room noise should be controlled to levels which permit necessary communication, meet operational or product requirements and which are within

the range of personnel comfort and safety. Sound level meters which comply with ANSI Standard S1.4 set on the A scale slow response are generally acceptable for measuring broad band noise. Excessive low frequency or pure tone noise may necessitate the use of other scale readings or an octave band analysis.

40. DESIGN INFORMATION

40.1 Nonlaminar flow clean room. (See Figure 6)

40.1.1 Clean room shell. Clean room shell, floor, walls, and ceiling should be designed and constructed with materials and in such a manner as to eliminate air leaks into or from the room. The walls and ceiling material should be low shedding and easy to clean. The floor covering should be low particle shedding and sufficiently durable to withstand wear imposed by traffic and clean room operations.

40.1.2 Entryways. Entryways, doors, and pass-throughs should be of correct size to permit personnel and required equipment access to the clean room. These entryways should be the air lock type and should provide air seals sufficient to allow pressurization of the clean room. The room should be designed such that only one door or entryway may be opened at one time, except under emergency conditions.

40.1.3 Anterooms. Anterooms should be provided as needed for clean room personnel clothing change area, clothing storage, wash-up facilities, air showers, toilet facilities, and other equipment for personnel clean room entry requirements. Anterooms may also be provided, as needed, to house parts cleaning and other room support equipment.

40.1.4 Air supply and filtration equipment. Air supply and filtration equipment should have adequate capacity to filter all recirculated and make-up air entering the room. A three-minute room air change is usually considered to be minimum for rooms 8 to 12 feet (2.438 to 3.658 meters) high. Equipment should be provided to supply fresh, or make-up air, as required.

Access should be provided for changing and testing the filters and for cleaning the ducts leading to and from the filters.

40.1.5 Air-conditioning equipment. Air-conditioning equipment for prefiltering, cooling, heating, humidification, and dehumidification of the clean room air should be provided, as required.

40.1.6 Clean room furniture. Clean room furniture should meet clean room operational needs and should be constructed of low particle shedding materials.

40.1.7 Clean room lighting equipment. Clean room lighting equipment should be provided to meet work requirements within the clean room. Shadowless, uniform lighting at intensity levels of 100 to 150 foot-candles (1076 to 1615 lux) at work position is satisfactory for most clean rooms. Ceiling light fixtures should be flush mounted and sealed to prevent air leaks.

40.1.8 Fire protection. Clean room fire protection should be consistent with product and local requirements and with National Fire Protection Association standards for anticipated occupancy and use. Smoke detection units should be installed in the downstream end of the clean room to automatically shut off blower motors in case of fire. A conveniently located remote blower switch should also be provided to shut off blower motors in emergencies.

40.2 Laminar flow rooms.

40.2.1 Clean room shell. For economy of operation, laminar airflow rooms should have floor, walls, and ceiling assembled in such a manner so as to inhibit the leaking of any air into or from the room. The materials for walls and ceiling should be low shedding, and the finish should be readily cleanable. Floor covering should have low shedding characteristics and should be able to withstand wear imposed by personnel and operations within the room.

40.2.2 Entryways. Entryways, doors, and pass-throughs should be of sufficient size to permit entrance and exit of personnel and required equipment. These openings should provide an air seal, when closed, to allow pressurization of the area. The use of air lock and air shower type facilities is not generally required.

40.2.3 Anterooms. Anterooms should be provided as needed for storage of personnel clothing, lunches and personal belongings, washing and toilet facilities, and cleaning equipment.

40.2.4 Air-conditioning equipment. Air-conditioning equipment for prefiltering, cooling, heating, humidification, and dehumidification of the clean room air supply should be provided, as required. In a large recirculating system, consideration should be given to air tempering equipment and a bypass arrangement to minimize required refrigeration capacity.

40.2.5 Clean room furnishings. The furniture and equipment which will be used in the clean room should be constructed of low particle shedding and low static generating materials.

40.2.6 Clean room lighting equipment. Shadowless, uniform lighting at intensity levels satisfactory at normal working levels should be designated as required. Ceiling lighting fixtures may be suspended into the clean room to eliminate the necessity for sealing, but such fixtures should be as streamlined as possible. If the ceiling height is exceptionally low, it would be proper to employ flush mounted and sealed fixtures.

40.2.7 Laminar flow rooms. Several configurations are feasible with laminar airflow, some of which are:

40.2.7.1 Wall-to-floor airflow. As displayed in Figure 1, this design is adaptable to a wide choice of sizes inasmuch as the length is limited only by the space available.

40.2.7.2 Ceiling-to-floor airflow. This vertical downflow design usually has the capability of providing the greatest control for the entire clean working environment because airborne contamination generated by personnal or a specific operation is immediately carried down and out of the room. This design (Figure 2) may be varied such that the blowers and HEPA filters are remotely located and the filtered air is ducted to the top of the room and enters the room through a diffusion ceiling arrangment such that the airflow meets the provisions of 20.3. This variation may reduc cost, the area of filter bank required, noise, and vibration, but it may also requir greater motor/blower capacity and greater attention to leak proof duct joints.

40.2.7.3 Wall-to-wall airflow. The horizontal or crossflow rooms, as shown in Figure 3, represent the same basic design concept as the vertical downflow room but in a different configuration. While some degree of air cleanliness may be sacrificed toward the exhaust end, this design has the potential for a high degree of airborne particulate control. Since these rooms are normally longer than they ar wide and the filter bank occupies only one end of the room, a substantial cost savi can be realized over vertical flow rooms due to the reduction in HEPA filters, su porting structure, and air handling equipment.

40.2.7.4 Wall-to-open-end airflow. This design, commonly called a tunnel room, combines features of both the horizontal room and the downflow curtain unit. The filter bank is normally composed of prefabricated modules, each containing a motor/blower unit, prefilter, and HEPA filters. The rigid or flexible plastic ceiling and side walls are supported by a simple exterior wood, pipe or angle iron framework, while the end opposite the filter bank is open. Plastic material used in this application should be the self-extinguishing type. The tunnel room, as depicted in Figure 4, is the least costly type of room, can be disassembled and moved, and its effectiveness is comparable to the normal horizontal room.

40.2.7.5 Portable downflow curtained unit. This unit is similar to the vertical downflow room in concept, but incorporates several variations. The motor, blower, filter and plenum unit is mounted on an overhead framework supported by rigid metal legs. The filtered air flows in a downward motion and exits under the plastic curtain sidewalls which should be self-extinguishing material. Casters on the legs or sling attachment points on the framework provide some degree of portability, whereby the unit can be located over large items for which the operation to be performed requires a high degree of air cleanliness. (See Figure 5.) The width of these units should normally be limited to 10-12 feet (3.048-3.658 meters).

40.2.8 HEPA filter bank. The HEPA filter bank of laminar flow rooms should cover either one entire wall or the entire ceiling (Figures 2, 3, 4, and 5), except when diffusion ceiling or wall systems are used or when built-in benches are included at the incoming air end of the room (Figure 1). In the latter case, the wall filter bank may cover only the area extending from the bench work surface to the ceiling. Class 100 conditions should exist in the zone immediately downstream from the filter bank or the diffusion ceiling or wall.

40.2.9 Final filters. All final filters should be of the HEPA type. Specify HEPA filters free from pinhole or other leaks. DOP smoke penetration test ratings should include penetration, if any, through the filter gaskets.

40.2.10 Prefilters. Prefilters should be used to prolong the life of the HEPA filters. The anticipated airborne contamination level to which the prefilters might be subjected should govern the decision to use one or two sets of prefilters and the selection of prefilter efficiencies (see 20.7). Initial prefilters remove the gross

particulates and fibers whereas the intermediate prefilters are reasonably effective in removing smaller airborne particles. Prefilters should be checked periodically to determine whether they should be cleaned or replaced.

40.2.11 Air exit. The air exit from vertical and horizontal flow rooms (excluding vertical curtain units and tunnel rooms) should normally consist of an entire wall area or grating flow surface. While other air exit designs are used, any decrease in air exit area will reduce useable, highly controlled space. In these rooms, prefilters located behind the exit wall grills or grating floor will provide sufficient pressure drop across the exit area to help assure a uniform room airflow. Manually operated dampers in the air exhaust area may be required to maintain laminar flow characteristics.

40.2.12 Airflow velocity. Airflow velocity through the cross section of the room normally is maintained at 90 feet (~27.5 meters) per minute with a uniformity within plus or minus 20 percent throughout the undisturbed room. In certain applications where user requirements permit, airflow velocity in vertical laminar flow rooms may be reduced below the 90 fpm level. Any significant reduction in velocity can increase both the clean down time and the possibility of cross contamination between work locations.

40.2.13 Airflow patterns. The airflow should be undirectional throughout an undisturbed room. Equipment and work stations should be arranged so as to minimize turbulence.

40.3 Laminar flow clean work stations. Clean work stations defined by this document as the laminar flow type should meet the following: (See Figures 7, 8, and 9).

40.3.1 Containment surfaces. As applicable, side panels, tops and work surfaces of laminar flow work stations should be constructed in such a manner that they will provide a cross sectional area equal to and in the same configuration as the effective filter area. The effective filter area is defined as that area within the sealant of the external filter frame. There should be an air-tight seal at the juncture of the containment surfaces and the filter/bench frame to prevent ambient air from being drawn into the bench at this periphery. These containment surfaces are normally perpendicular to the filter face.

40.3.2 Final filters. Final filters should be of the HEPA type and should occupy the entire area of the rear or top surface of the enclosure.

40.3.3 Prefilters. Prefilters should be used to remove gross airborne particles and thereby prolong the life of the HEPA filter. Since work stations can be located in relatively dirty work areas, care should be exercised in selecting prefilters with an efficiency commensurate with anticipated contamination loading.

40.3.4 Air exit area. The area of air exit from the enclosure should be equal to the effective filter area in clean work stations.

40.3.5 Airflow velocity. Airflow velocity out of the air exit of an unobstructed work station should be maintained at 90 feet (27.5 meters) per minute average with a uniformity within plus or minus 20 percent across the entire area of the exit. Airflow velocity should not be measured closer than one inch to the internal containment surfaces.

40.3.6 Airflow patterns. Airflow patterns should be uniform with minimum turbulence in unobstructed areas of the enclosure. Outside air should not aspirate into the work areas along the containment surfaces.

50. PERFORMANCE TESTS

50.1 Laminar flow rooms. The following tests should be made on laminar flow rooms after installation and thereafter as specified:

50.1 (a) An in-place filter test should be made to determine whether the HEPA filter bank has any significant leaks. Tests should be made to determine leaks (1) in the filter media itself, (2) in the bond between the filter media and the interior of the filter frame, (3) between the filter frame gasket and the filter bank supporting frames, and (4) between the supporting frames and the walls or ceiling. Leak tests should be made by introducing a high concentration of smoke or fog[2] into the plenum upstream of the HEPA filters (concentration should be of the order of 10^4 particles above the minimum sensitivity of the photometer used as the detector; this normally

[2]For example, cold generated DOP fog. Ref: NRL 5929 "Studies of Portable Air-Operated Aerosol Generators," Echols and Young, National Technical Information Service, Springfield, Va., 22151.

will be on the order of 80 to 100 micrograms per liter). The entire downstream surface of the HEPA filter installation is then scanned with an aerosol photometer probe at a sampling rate of at least 1 cubic foot per minute. The probe should be sized to provide approximate iso-kinetic sampling and should be held 1 to 2 inches from the filter media and frame. (Thus for measuring laminar flow equipment having air velocities of from 70 fpm to 110 fpm, the probe opening should be sized from 1 to 1.5 square inches.) An aerosol photometer reading equivalent to 0.01 percent of the upstream smoke concentration is considered a significant leak and should be sealed.

50.1 (b) The performance test specified in 50.1 (a) may be modified provided the product or area requirement is such that a 99.97 percent filter efficiency is adequate and if it can be determined that the entire filter bank meets the requirements for HEPA filters. This provision applies only for vertical or horizontal laminar flow rooms where the air is recirculated.

50.1 (c) Airflow velocity should be measured through the cross section of the room and should conform to 40.2.12.

50.2 Nonlaminar flow rooms.

50.2 (a) The HEPA filter used in the incoming air ducts of nonlaminar flow rooms should be scanned per 50.1 (a).

50.2 (b) Tests should be made at the point(s) of air inlet to the room if the HEPA filter is not accessible and to check for aspiration of contamination from leaks in the incoming air ducts between the filters and air inlets.

50.3 Laminar flow clean work station.

50.3. (a) Tests for laminar flow clean work stations should be conducted as prescribed in 50.1 (a).

50.3 (b) Airflow velocity out of the air exit of an unobstructed clean work station should conform to 40.3.5.

50.4 Nonlaminar flow clean work station. The HEPA filter in the incoming air duct should be scanned per 50.1 (a) if it is readily accessible or by a method simila to that described in 50.2 (b).

60. MONITORING

60.1 Monitoring techniques. It is necessary to recognize that the differences between laminar and nonlaminar airflow devices as well as differences between vertical and horizontal laminar airflow, require different concepts of monitoring. For example, airborne contamination generated or reentrained in nonlaminar airflow devices tends to be dispersed over the entire work area, and is present in much greater concentrations than in laminar airflow devices. Therefore, since airborne particle counts are higher and may be fairly uniform throughout the work area, particle counters with a lower sampling rate (0.01, 0.1, 0.25 cfm) will usually give representative counts.

In laminar airflow devices, however, released airborne contamination tends to be carried by the airstream toward the air exit. Contamination levels will vary from virtually no particle count near the HEPA filters to a higher count downstream of the dirtiest activity. Due to the relatively low particle counts and the unidirectional movement of the particles, higher rate samplers (0.25, 1.0, 5.0 cfm) will more accurately reflect the existing particle count.

60.1.1 Nonlaminar flow clean rooms. Airborne particle counts should be taken at representative locations throughout the work activity area, at work level height, and at specified intervals.

60.1.2 Laminar flow clean rooms. Normally it can be determined that the contamination level of the first air in a laminar flow device is acceptable if the facility will pass the filter leak test and air velocity test described in 50.1.

In a vertical laminar flow (VLF) room, the above facility performance check is usually more meaningful than an attempt to make particle counts where extremely few particles exist. If particle counts are desired for highly critical or unusual operations, care should be exercised that the particle counting instruments do not interfere with either the approaching clean air or the activity.

In a horizontal laminar flow (HLF) room, the contamination level of a work location will be influenced by the contamination produced at work locations preceding it in the airstream. A facility performance check will normally determine the acceptability of air cleanliness at the first work location downstream from the HEPA filters. The

particle count and airflow patterns should be monitored at subsequent downstream work locations periodically or after changes in operations or location of equipment.

60.1.3 Nonlaminar flow work stations. All work stations should be monitored at representative work locations at specified intervals.

60.1.4 Laminar flow clean work stations. All new work stations and work stations in which new HEPA filters have been installed should be monitored per 50.3 after being put into operation, following any relocation, and thereafter as stipulated in a specification. Periodic particle counts should be made at representative locations.

60.1.5 Changing HEPA filters. The methods used to determine when HEPA filters should be changed are:

(a) When the airflow drops below the minimum rate, and installing new prefilters does not increase the flow.

(b) When the static pressure drop across the filters exceeds the static capability of the blowers.

(c) When the filters develop uncorrectable leakage leading to consistently abnormal particle counts within the area.

Whenever HEPA filters are changed, a thorough leak check should be made (50.1).

70. OPERATIONAL GUIDES

70.1 General.

70.1 (a) All equipment should be cleaned by dusting, vacuuming, washing or other means best suited to the equipment involved before being brought into the area.

70.1 (b) Neither smoking nor eating should be permitted in the area.

70.1 (c) All personnel should wear lint free smocks or coveralls in the area.

70.1 (d) Head covers, covering all areas of head and facial hair, and other appar should be used as needed to contain loose bits of hair and skin flakes.

70.1 (e) Limit paper entering area. There are special nonshedding papers for necessary records or paperwork.

70.1 (f) Use only ballpoint pens for writing. Lead pencils and erasers should not permitted.

70.1 (g) Hand lotions, creams or soap containing lanolin to tighten skin particles should be used, as appropriate.

70.1 (h) Solvent contact with hands should be avoided, as many solvents remove natural skin oils causing excessive "skin peeling" or flaking.

70.1 (i) Fingernail polish should not be permitted in the area.

70.1 (j) Cosmetics and medication which may produce contamination should not be worn by any personnel. In particular, eye make-up, rouge, face powder, and hair spray should be avoided.

70.1 (k) Gloves, finger cots, tweezers, or other clean handling methods and equipment should be used while working with or handling sensitive parts, to avoid contamination of those parts by loose skin or natural skin oils.

70.1 (l) Exhaust systems for grinding, welding, soldering, machining, or other related operations should be installed in accordance with the Industrial Ventilation Manual, published by the American Conference of Governmental Industrial Hygienists and the ANSI Standard Z9.2, "The Design and Operation of Local Exhaust Systems."

70.2 Parts cleaning and handling. Before entry into the clean area, all parts, instruments, materials, etc., should be cleaned, as required, to prevent contamination of the room. To prevent direct transfer of contamination, constant surveillance of the established procedures for handling clean parts and assemblies is recommended.

70.2.1 Cleaning operations. Particular attention should be paid to cleaning operations that are performed in the room. Ultrasonic cleaners, spray rinses, etc., may release liquid droplets containing contaminants into the room air. The design of the cleaning equipment, and its location in the room, should be chosen to minimize this problem. Where practical, the contamination producing equipment or function should be located in adjoining areas, and, when completed, the work should be passed into the clean room without cross contamination.

70.2.2 Containers. Transport and storage containers should be made of low particle shedding materials. They should also have as rigorous a cleaning schedule as the parts. Care should be taken that containers used for transporting cleaned parts do not transfer contamination from surface to surface in the room.

70.2.3 Packaging. Film packaging materials should be cleaned before being brought into the clean room. Clean packaging operations should be performed at a location in the room which precludes cross contamination with other operations. The use of approved antistatic films will minimize the attraction and retention of airborne particles.

70.3 Nonlaminar flow room.

70.3 (a) Limit personnel access to the area to only those persons necessary for the area operation.

70.3 (b) Shoes should be covered, cleaned or changed before entering area.

70.3 (c) Use of compressed air or other high velocity gases for blow off or cleaning operations, except under exhaust hoods capable of carrying residue to exterior of clean room, should be avoided.

70.3 (d) Room maintenance should be restricted during normal operational periods to avoid generation of airborne particles. If a contamination producing emergency occurs or routine maintenance is required, normal work should be stopped until the room is cleaned.

70.3 (e) Janitorial service for a room should consist of a properly supervised, regularly scheduled cleaning program. Periodic or even continuous cleaning service may be needed to maintain an acceptable airborne particle count level.

70.3 (f) The use of laminar flow work stations within a nonlaminar flow room is recommended where feasible. This combination of facilities not only offers areas with a high degree of cleanliness at reasonable cost, but also upgrades the entire room by continuous refiltration of air through the HEPA filters in the work station(s)

70.3 (g) The airborne particulate level of a nonlaminar flow clean room is highly dependent on the amount of effort expended to control contamination. For example, a properly constructed room housing low particle generating operations in which strict personnel and janitorial controls are imposed may be able to meet Class 10,000 requirements. There is usually a point, however, beyond which the application of additional cleanliness measures will not produce significant improvement in the cleanliness level.

70.4 Laminar flow devices. Periodic checks should be made for proper operation of the device including proper airflow patterns, velocity, and uniformity; adequate lighting; properly sealed filters; and properly functioning prefilters. The blower system should be turned on at least 15 minutes before normal operations are started. During this clean-down period, fixtures and work surfaces should be cleaned.

70.4.1 Clean work station.

70.4.1 (a) The protective grille should be lightly vacuumed or wiped during the clean-down period noted in 70.4.

70.4.1 (b) Obstruction to the airflow should be kept to a minimum in the station, particularly upstream from the critical work.

70.4.1 (c) Care should be taken when locating work stations in an area to avoid air currents that could oppose work station airflow and could carry dust into the work station.

70.4.2 Crossflow and tunnel clean rooms.

70.4.2 (a) Operations should be graded according to cleanliness levels required for critical work. The most critical operations should be nearest the filter bank.

70.4.2 (b) Obstructions to the airflow should be kept to a minimum, particularly upstream from critical work.

70.4.2 (c) Furniture and equipment should be arranged so as to minimize turbulence.

80. FACILITY GUIDELINES FOR AIR CLEANLINESS CLASSES

80.1 General. There are usually several facility options available for achieving one of the standard air cleanliness classes. The selection of one or some combination of facilities should be based on the degree of air cleanliness needed, the amount and type of work to be accomplished, cost, and anticipated future needs.

Table III furnishes guidelines for selecting facilities for the various classes of air cleanliness. The information provided in Table III assumes that the HEPA filters used in the facilities listed have been properly installed and are free from significant

80.2 Types of facilities. Figures 1 through 9 represent basic types of clean room and clean work station designs. Many variations to these designs which may satisfy specific needs are commercially available. No attempt has been made to depict all possible variations.

90. ADDITIONAL REFERENCES

The following documents provide additional information on many of the subjects mentioned in this Standard. These documents are listed for information only.

1. Contamination Control Handbook,[1] NASA SP-5076, 1969.
2. Contamination Control Principles,[2] NASA SP-5045, 1967.
3. Sizing and Counting Particulate Contamination In and On Clean Room Garments,[3] ASTM F51-68, 1968.
4. Tentative Standard for HEPA Filters,[4] AACC CS-1T, 1968.
5. Tentative Standard for Laminar Flow Clean Air Devices,[4] AACC CS-2T, 1968.
6. Tentative Standard for Testing and Certification of Particulate Clean Rooms,[4] AACC CS-6T, 1970.

(1) National Technical Information Center, 5285 Port Royal Road, Springfield, Virginia 22151

(2) Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. 20402

(3) American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103

(4) American Association for Contamination Control, 6 Beacon Street, Boston, Massachusetts 02108

TABLE III

FACILITY GUIDELINES FOR AIR CLEANLINESS CLASSES

Type of Facility	Class 100	Class 10,000	Class 100,000
Laminar Airflow			
Vertical flow room Vertical flow curtain unit Vertical flow bench	Entire work area usually meets requirements at normal working height locations.	Entire area normally meets requirements.	Entire area meets requirements.
Crossflow room Tunnel room Wall-to-floor room Crossflow bench	First work locations normally meet requirements.	Entire work area normally meets requirements if particle generation, work locations and personnel are reasonably controlled.	Entire area normally meets requirements.
Nonlaminar Airflow			
Conventional clean room	Will not meet requirements under operation conditions.	In some cases, can be upgraded to meet requirements by placing laminar airflow devices (benches, modular units, tunnel rooms or downflow curtain units) within the room and continuously filtering the recirculated air. Personnel and operation restrictions and janitorial maintenance are also required.	Will usually meet requirements with strict observation of rules governing personnel, operations, garmenting, and janitorial procedures.

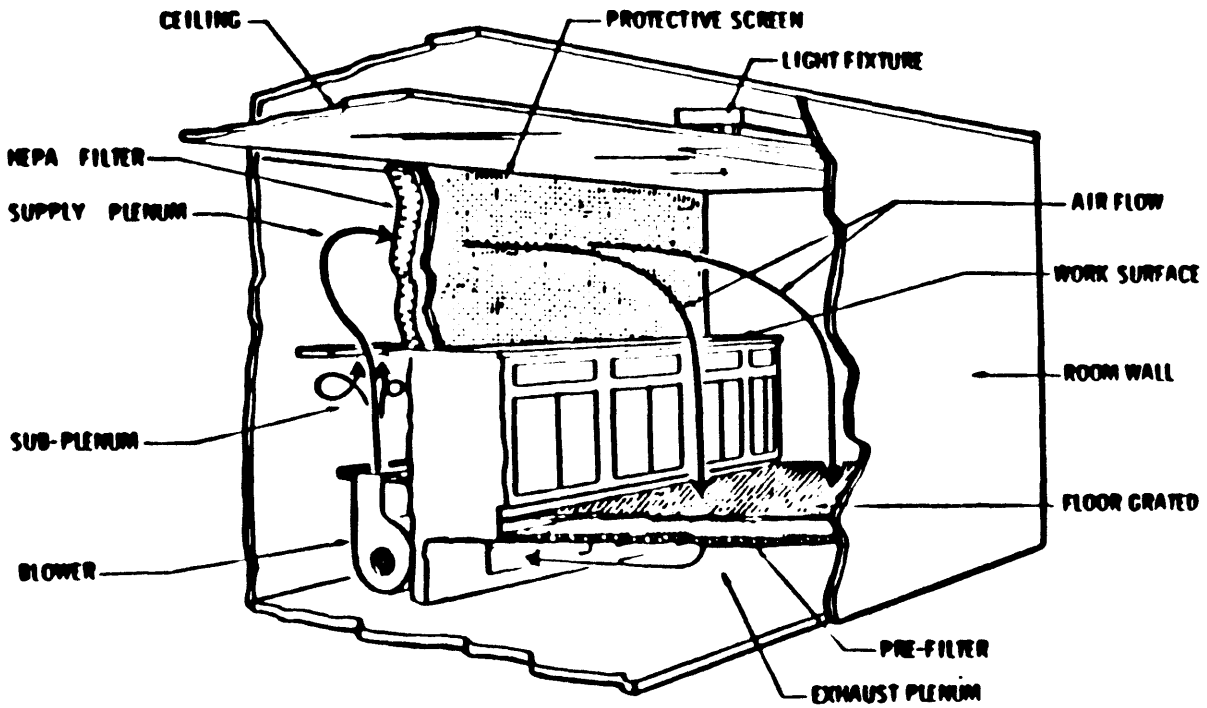


Figure 1. Wall-to-Floor Airflow Clean Room

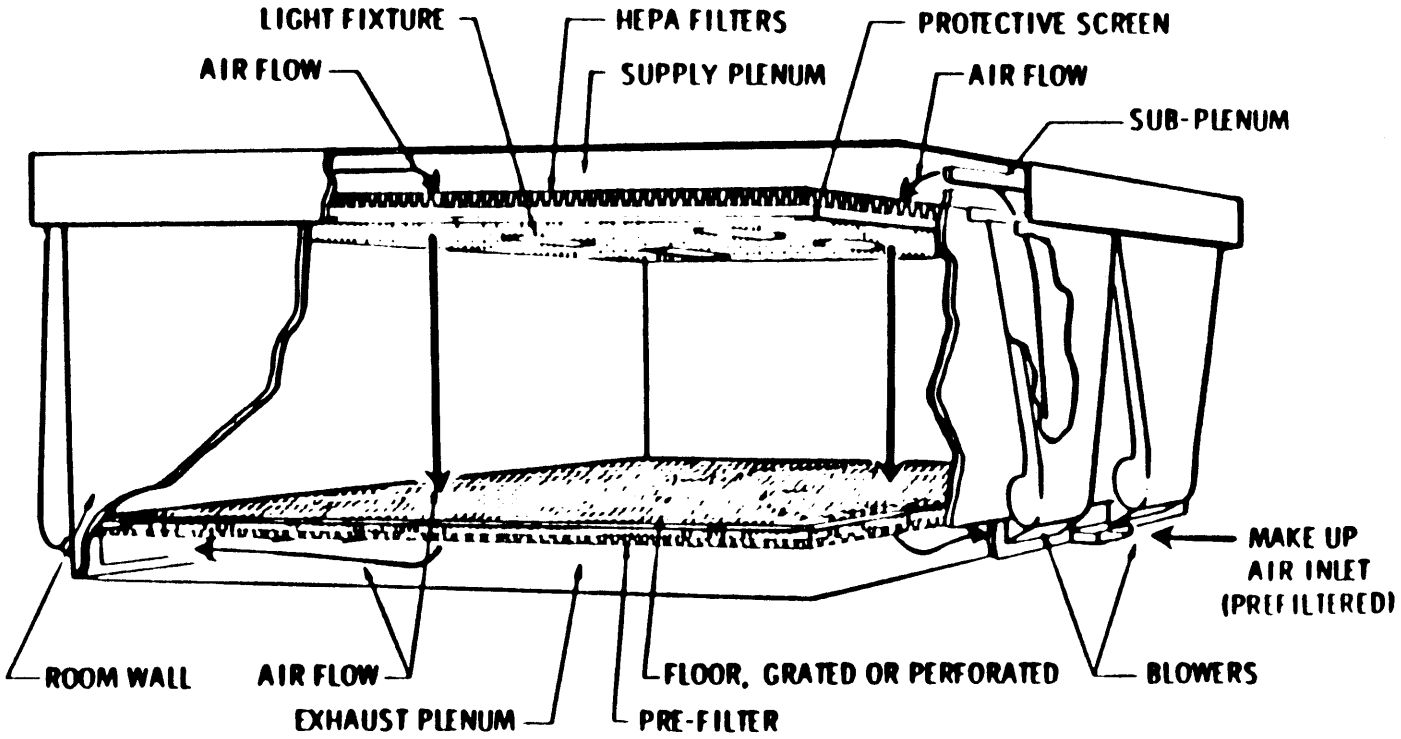


Figure 2. Ceiling-to-Floor Airflow Clean Room

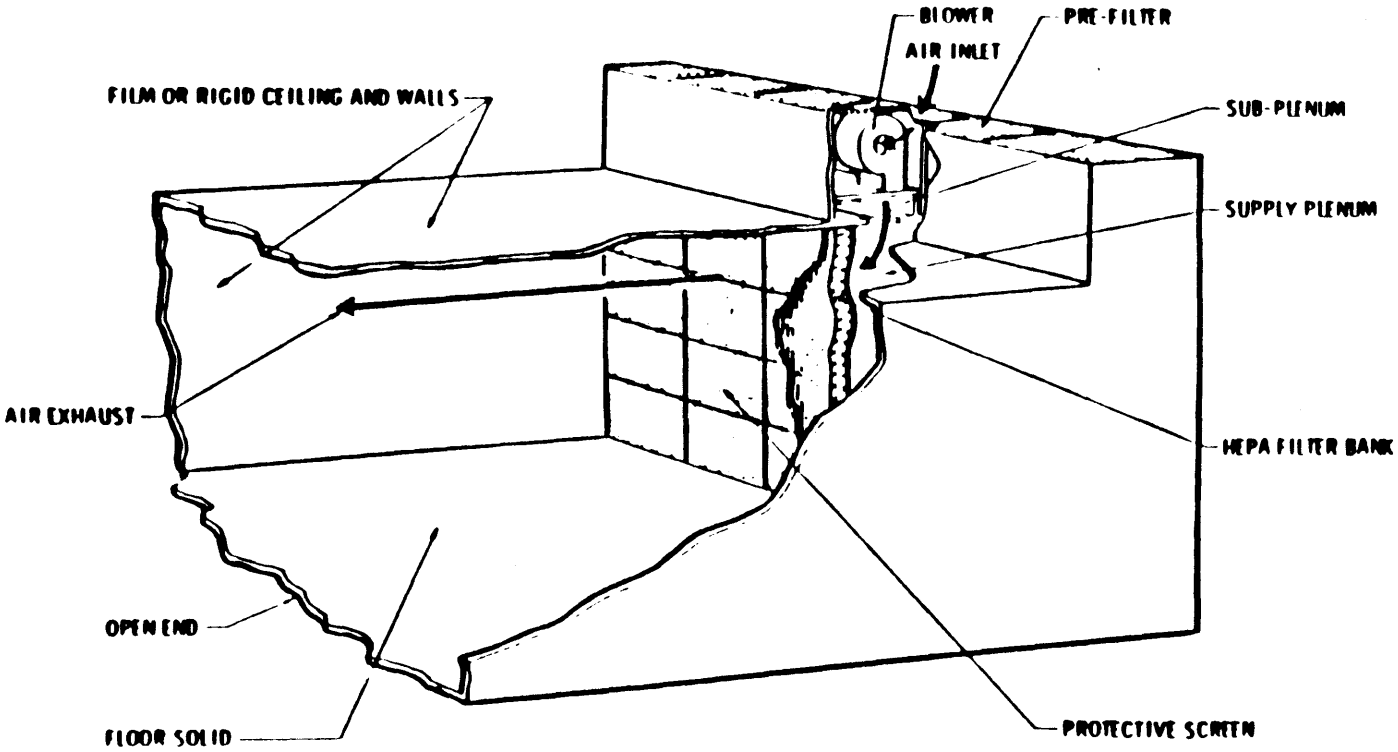


Figure 4. Wall-to-Open-End Airflow Clean Room

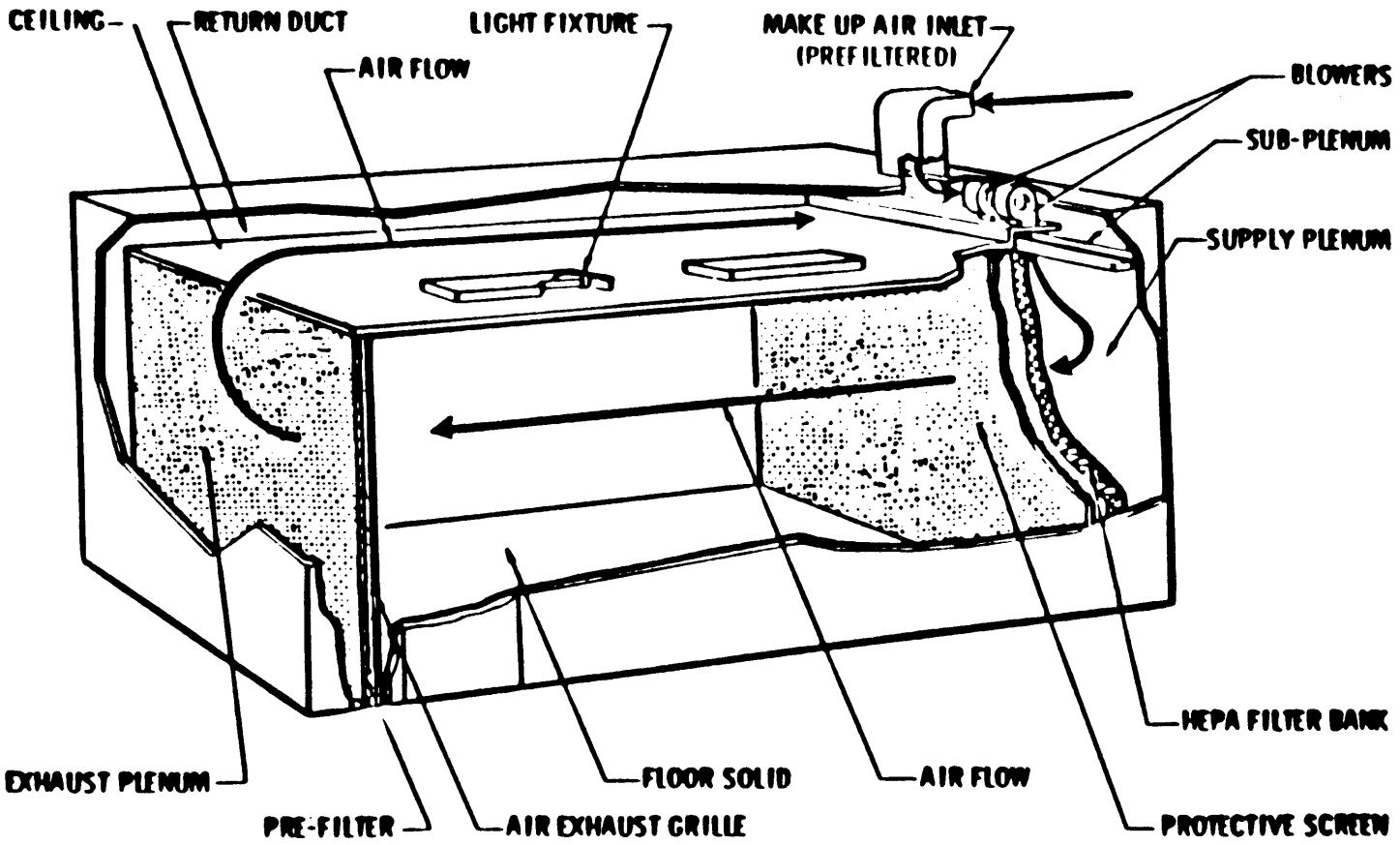


Figure 3. Wall-to-Wall Airflow Clean Room

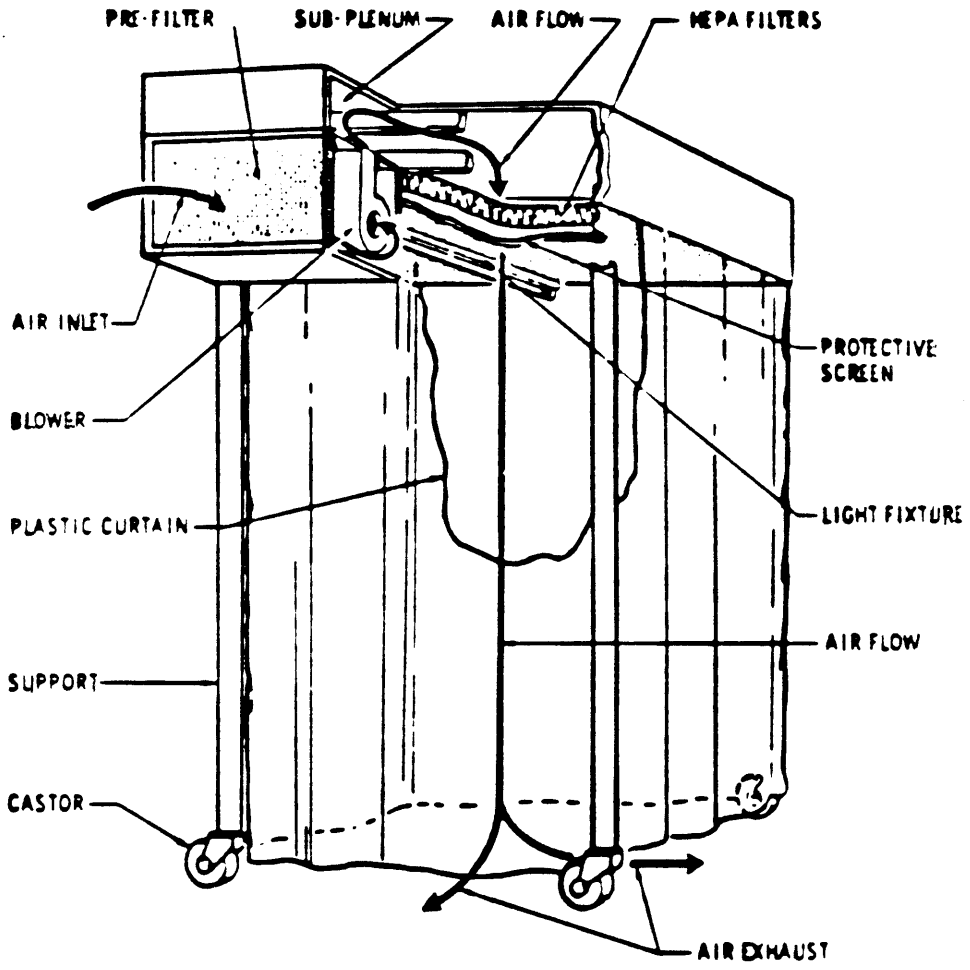


Figure 5. Portable Downflow Curtain Unit

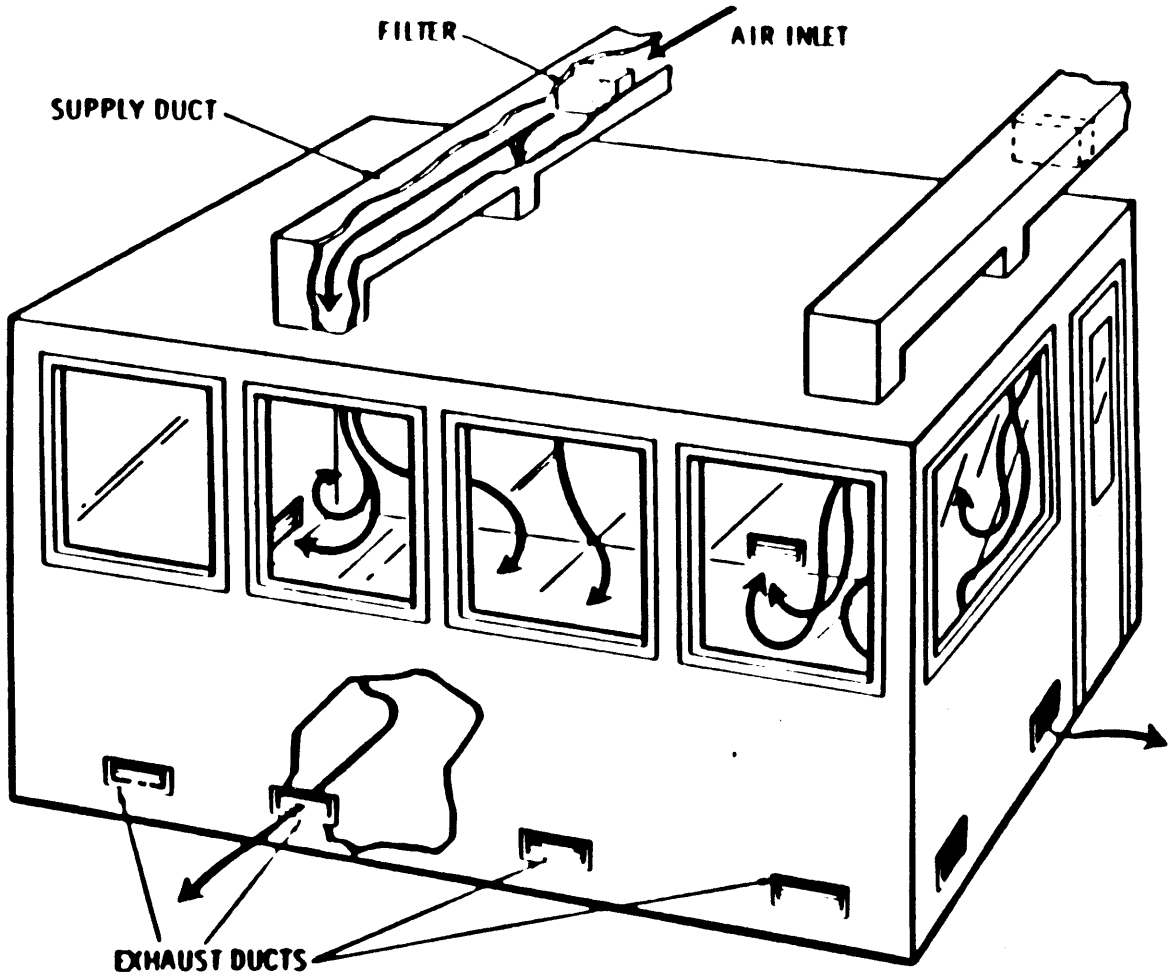


Figure 6. Nonlaminar Airflow Clean Room

Fed. Std. No. 209B

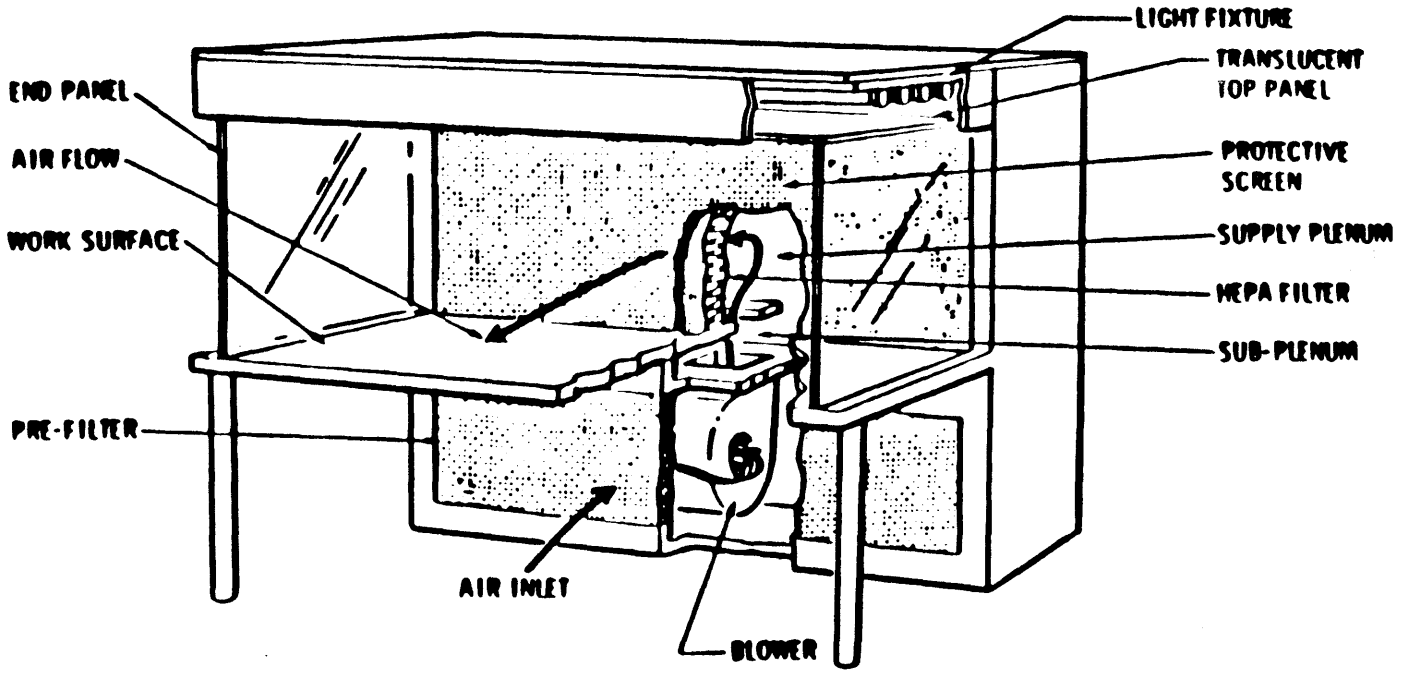


Figure 7. Horizontal Laminar Airflow Bench

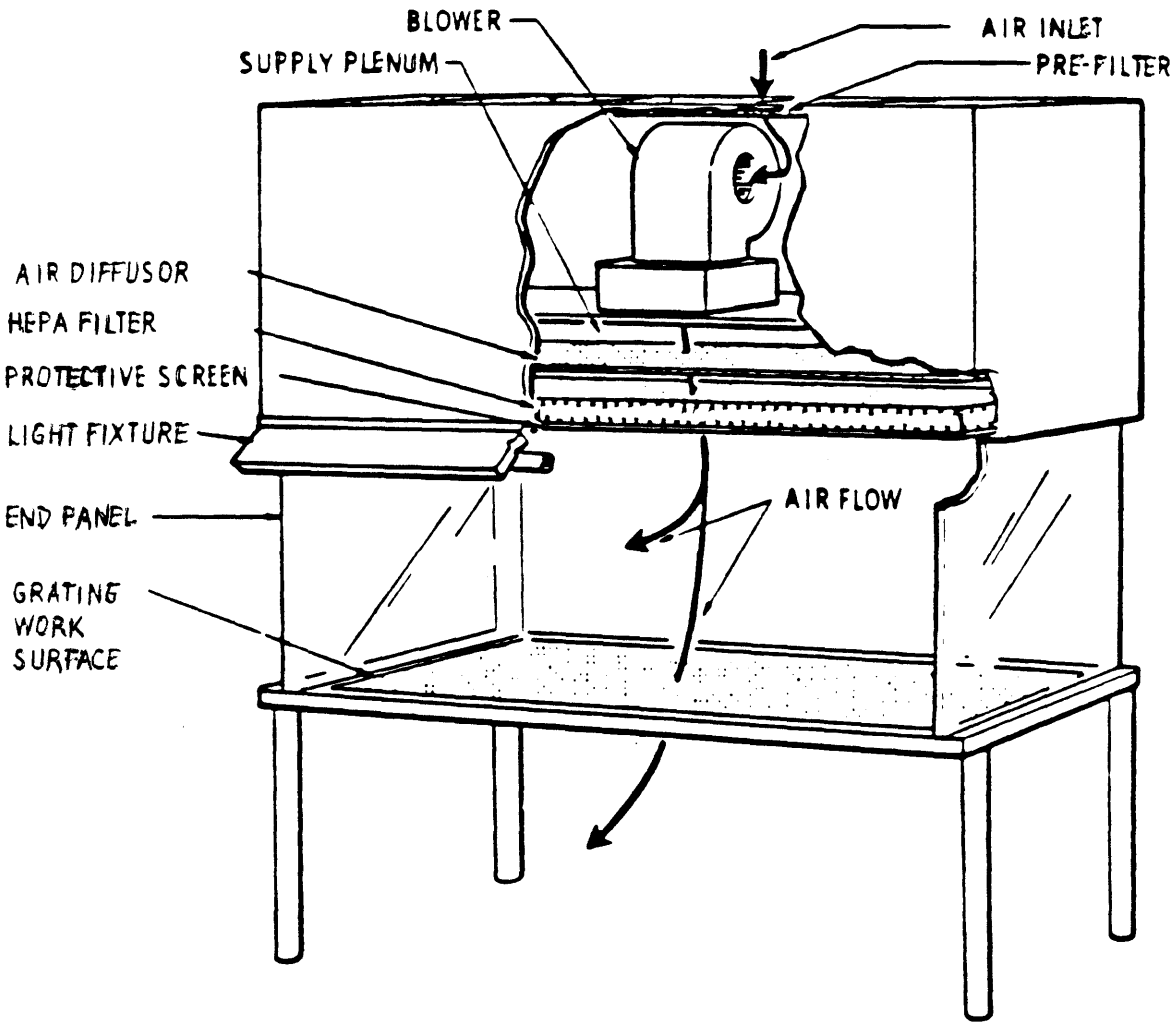


Figure 8. Vertical Laminar Airflow Bench

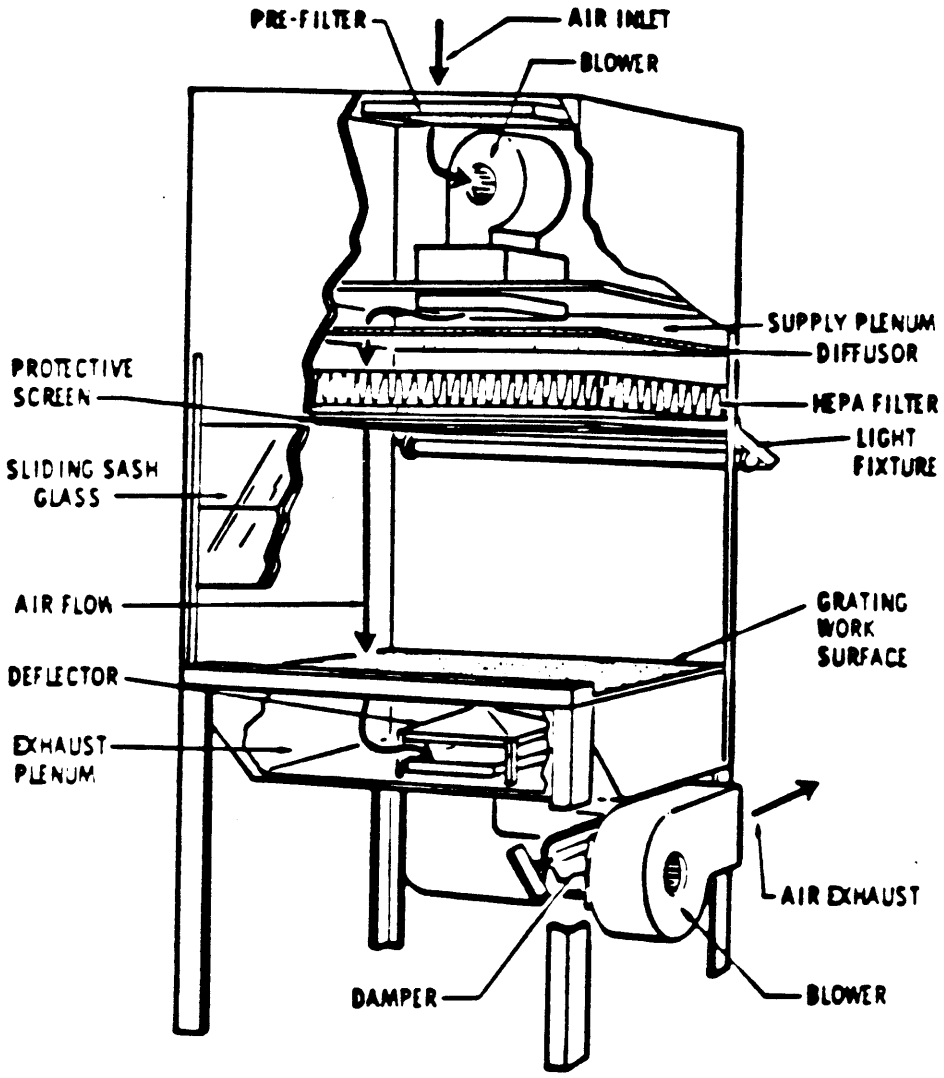


Figure 9. Balanced Vertical Airflow Exhaust Hood

The Proposed Revision of Federal Standard 209B

By: Robert D. Peck
Technical Editor

PREFACE

Probably no other document relating to contamination control has been so widely adopted and used as has Federal Standard 209 since its original publication in December of 1963. While it is nominally a U.S. government publication for the use of federal agencies, it has in fact been adopted by American industry and by most other countries with high-tech industry.

Federal Standard 209 originated from the Federal Government's recognition of the importance of contamination control to the success of the space program, particularly after the successful launch of Sputnik by Russia in 1957. The task of preparing a standard was given to the Sandia Corporation, a quasi-public organization of the Atomic Energy Commission. The first issue, FS209, was published in December of 1963. Subsequently, FS209A was published in August of 1966; FS209B in April of 1973; and Amendment #1 to 209B in May of 1976. None of these issues produced any significant changes from the original document.

Now, however, after four years of work by its RP50 Committee, the Institute of Environmental Sciences has submitted recommendations to the General Services Administration for substantial revisions which are designed to update the standard to the present state-of-the-art in cleanroom technology.

REVISION DEVELOPMENT

When the present IES Contamination Control Division's Standards and Practices Program was initiated in 1982, it was apparent that revision of FS209B should be a major effort. Discussions were initiated with the General Services Administration (GSA) of the U.S. government which culminated in the assignment by GSA to IES of the responsibility for proposing such a revision.

The reasons why revision of FS209B has been needed are numerous—as were the problems of revising it. Both reasons and problems derived from misunderstanding and misuse of the standard and from advances in contamination control technology during the more than 20 years since FS209 was first published. Among the questions raised were these:

a) FS209B is a government standard prepared for use by government agencies, and changeable only by governmental action and/or approval. Yet it has become a basic document, by reference, for industry and a significant source for contamination control documents in countries throughout the free world. How can industry and foreign interests be satisfied, while operating under Federal Government authority?

b) Can the confusion caused by the standard having "mandatory" and "nonmandatory" sections be clarified?

c) Can Classes 10 and 1 be included as industry indicates is now necessary?

d) Could such lower (numerically) classes, however, be defined in the same manner as Class 100 and greater?

e) While particle sizes for measurement in FS209B are 0.5 and 5.0 micrometer, now industry is concerned with smaller sizes, down to 0.1 micrometer. Can tests be made accurately at these sizes?

f) Do the class definitions apply to air only, or are they also applicable to cleanrooms, devices, areas, etc.?

g) Should the log/log tables be retained, since they do not relate to specific situations?

h) Does the general slope apply for classes below 100 and particle sizes smaller than 0.5 micrometer?

i) Should the standard be expanded to include classifications and tests for viable particles?

j) Are the methods specified for measurement (ASTM F25 and F50) still satisfactory?

k) Can the locations for taking particle counts be specified more precisely, and satisfactorily?

l) How can the present misuse of the standard for categorizing products as a class, or meeting a class, be prevented?

The initial effort by IES was to hold five general meetings (of up to 150 people) which anyone could attend, express their opinions, and disagree with others. Although these gatherings produced many valuable ideas, such large groups were too unwieldy to work out the specific requirements of a proposed revision. Thus, a working committee was formed (designated RP50), the membership of which included most of the outstanding authorities in contamination control—both young and old, male and female, suppliers and users. There was representation from government, industry, and universities; from manufacturers of particle counters, HEPA filters, laminar flow, and other devices, as well as from those who design, construct, and certify facilities. Members came from the aerospace, microelectronics, and pharmaceutical industries. It was a truly broad and balanced group.

Committee RP50 first met in Denver in February of 1984. Since then, it has met eight times, and several drafts have been prepared. Acceptance and inclusion of a proposed revision has required a two-thirds vote of committee members, and to obtain this, discussions were lengthy, heated, at times repetitious, but always progressive. The result is a compromise, naturally, and has the usual characteristics of a compromise—enormous improvement over the past, wide consideration of subject matter; current with the present state-of-the-art, but with work still to be done due to the inability to resolve some issues.

Whether the questions regarding FS209B have been satisfactorily answered by the proposed revision, time will best tell. That much has been done to find answers is evident from a study of the results of RP50's work. Here—not paragraph by paragraph, but by emphasizing the contents of the proposed revision—are those results.

TITLE CHANGE

Current 209B: "Clean Room and Work Station Requirements, Controlled Environment"

Proposed Revision: "Airborne Particulate Cleanliness Classes for Cleanrooms and Clean Zones"

A change in title may seem small, but actually it is important for the concepts and understandings it emphasizes, such as:

a) In 1963, the term "Controlled Environment" related almost

Keywords: standards, cleanroom, clean zone, cleanroom requirements, Federal Standard 209B, airborne particulate cleanliness classes

exclusively to cleanrooms and contamination control. Now it is used for all sorts of controls and all sorts of environmental factors.

b) The word "cleanroom" has been standardized as a single word rather than as two separate words, thus reflecting that a cleanroom is not just a clean room.

c) The term "Work Station" in 1963 encompassed the only configuration available other than a cleanroom. Now there are many, types of facilities, spaces, etc., which are designated generically as "clean zones".

d) Most important is the clarification of what FS209 has always been; that is, a definition of "airborne particulate cleanliness classes"; not a compilation of all the requirements for a controlled environment.

It is important to realize that these changes would be carried throughout the proposed document. No longer would there be separate mandatory and non-mandatory sections; no longer would there be specific requirements for temperature, relative humidity, airflow velocity, etc. While these, and other properties would be required to be stated for full description of a facility or for testing procedures, the actual values would be left to the very broad areas of application and technology to which contamination control now applies.

SCOPE CHANGE

Scope and Objective of Current 209B:

"This document establishes standard classes of *environmental air control* within clean rooms and clean work stations. The objective of this standard is to prescribe air cleanliness classes and *certain other environmental air conditions* required for achieving and maintaining the levels of environmental cleanliness specified in the product specifications." (Italics by this article's author.)

Scope of Proposed Revision:

"This document establishes standard classes of *air cleanliness for airborne particulate levels* in cleanrooms and clean zones. It *prescribes methods for class verification and monitoring* of air cleanliness. It also addresses certain other factors, *but only as they affect control of airborne particulate contamination.*" (Italics by this article's author.)

The current standard has always been confusing because of its statement of scope—which, as underlined above, indicated its coverage was broad and encompassed all environmental controls for clean rooms, whereas actually the standard has always been a classification system for particulate air cleanliness. In addition, a major consideration of the standard is not mentioned in the old Scope; namely, the methods of testing and determining the classes established.

These errors are corrected in the proposed new Scope, and the concentration of the document upon airborne particulate cleanliness is clearly delineated.

LIMITATIONS (A NEW SECTION IN THE PROPOSED REVISION)

"The requirements of this document do not apply to equipment or supplies for use within cleanrooms or clean zones. Except for size classification and population, this document is not intended to characterize the physical, chemical, radiological, or viable nature of airborne particulate contamination. No definitive relationship between airborne particulate cleanliness classifications and the level of viable airborne particles has been established. In addition to the need for a clean air supply monitored for total particulate contamination and meeting established limits, special requirements are necessary for monitoring and controlling microbial contamination."

The new GSA format for a Federal Standard (requiring a "Limitations" section) lent itself to the correction of what has become a major misuse of the standard; namely, the practice of designating *products* as meeting the requirements of FS209B. In this section of the proposed revision, it is specifically stated that the standard does not apply to equipment or supplies. It is hoped that manufacturers will stop this incorrect practice, and users will make the extra effort to evaluate whether products are usable in their cleanrooms, rather than just accepting the designation of meeting a class "per FS209B".

This section also makes clear that the standard does not encompass the physical, chemical, radiological, or viable nature of contamination. While FS209 has not been used as a means of classifying such contaminations (other than particulate), there were strong arguments made for broadening the revisions to include all types and manner of contaminants. The final decision was not to do so because of the great difference in contaminants, their effect and control, classification, test for compliance, etc. This is particularly true of classifications and methods of test for the viable nature of contaminants. Standards are needed for these other types of contamination, and IES, among other organizations, has groups working on such documents—but not as Federal Standards. A Federal Standard for classification of viable air cleanliness (or sterility) is unquestionably needed.

DEFINITIONS

Perhaps nowhere is the recognition of the advance of contamination control technology so evident as in the proposed revision of the Definitions section of 209B.

Of twelve definitions in the "Definitions" and "Glossary" sections of the present Standard, eight have been discarded completely; the other four were substantially changed in wording.

New definitions were added, among them:
- Airborne particulate cleanliness class
- As-built cleanroom
- At-rest cleanroom
- Operational cleanroom
- Unidirectional airflow
- Nonunidirectional airflow
- Condensation nucleus counter
- Optical particulate counter
- Particle concentration

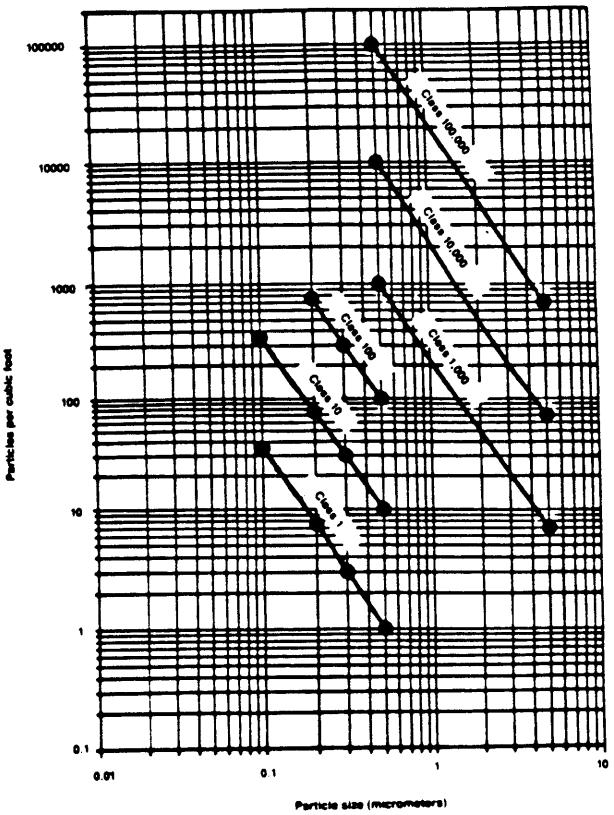


*Figure 1. Class Limits in Particles Per Cubic Foot of Size Equal to or Greater Than Particle Sizes Shown**

**The class limit particle concentrations shown on Table I and Figure 1 are defined for class purposes only and do not necessarily represent the size distribution to be found in any particular situation.*

DETERMINATION OF CLASSES

The principal purpose of FS209 has been, and is, to "establish classes for airborne particulate levels in cleanrooms and clean zones." The proposed revision accomplishes this through significant changes in the classes and in their determination.

Three of these changes are evident in Table I and Figure 1.

First, Class 10 and Class 1 have been added to the listed classes now in 209B.

Second, the particle sizes listed for measurement are increased by adding 0.1, 0.2, and 0.3 to the present 0.5 and 5.0

Third, an important statement has been added to both table and graph to emphasize that they are presented only for the purpose of defining classes and are not a representative size distribution relationship. This statement is a compromise between those committee members who wished to eliminate the log/log graph and those who felt strongly that it was a valuable part of the standard.

Table I. Class limits in particles per cubic foot of size equal to or greater than particle sizes shown.*

	Measured particle size (micrometers)				
Class	0.1	0.2	0.3	0.5	5.0
1	35	7.5	3	1	NA
10	350	75	30	10	NA
100	NA	750	300	100	NA
1000	NA	NA	NA	1000	7
10000	NA	NA	NA	10000	70
100000	NA	NA	NA	100000	700

(NA—not applicable)

**The class limit particle concentrations shown in Table I and Figure 1 are defined for class purposes only and do not necessarily represent the size distribution to be found in any particular situation.*

In addition to these changes in the table and graph, there are other important provisions.

a) The requirements for meeting a tabulated class would be changed in two very significant and new ways.

First, while the designation for a class is the number of particles listed for the class under the 0.5-micrometer size column, the class requirement would be met by measuring at any of the particle sizes listed in the table for that class. Thus, Class 100 is *labeled* from the limit of 100 particles permitted for the class (of 0.5 micrometer and greater size). However, Class 100 would be considered *met* if the particle concentration is *measured* for particles of 0.2, or 0.3 micrometer size, and the number of particles so measured falls below the number shown for the size in Table I (750 and 300 respectively for 0.2 and 0.3 size), and second, when a statistical analysis of the sampling locations is met. This provision is discussed later in this paper.

b) Provision is made for measurement at particle sizes other than those tabulated, provided that the particle count limit for the next larger particle size in Table I is not exceeded; counts may be interpolated between points, but may not be extrapolated beyond the end points of Table I.

c) Provision is also made for defining classes other than those tabulated in Table I. As is true in FS209B, these classes are defined by the intercept point on the 0.5-micrometer size line of the log/log graph (Figure 1).

d) The slopes in the log/log graph (Figure 1) have been adjusted to reflect the same particle size coverage for each class as is shown in Table I.

Running throughout the proposed new revision is the use of the phrase: "As Specified". The same phrase was incorporated into 209B, but was much less used. In the proposed revision, it indicates that the user or contracting agency shall specify the degree of control needed to meet requirements. Thus, requirements which vary from application to application (for example, temperature and relative humidity) are not specifically designated in the proposed revision, but the responsibility of the user to designate them is required.

VERIFICATION AND MONITORING

The procedures for determining if a cleanroom or clean zone meets a particular class are much clearer and far more extensive in the proposed revision than is true of the present 209B. Particularly, there are provisions for both "Verification" and "Monitoring". While the draft does not specifically define these terms, the intent is as follows:

a) *Verification:* to initially and periodically determine the airborne particulate cleanliness class by measurement of airborne particle concentration.

b) *Monitoring:* to determine if the airborne particulate cleanliness class is being maintained by measurement of airborne particle concentration after verification and during operations.

While Verification and Monitoring are separate sections in the proposed revision, the latter is treated only briefly, and the following details are from the section on Verification.

SAMPLING

In understanding the proposed new provisions for sampling, it is important first to recognize two new definitions, namely:

a) "*Unidirectional airflow (commonly known as laminar flow)* Air flowing in a single pass through a room or a clean zone in a parallel direction."

b) "*Non-unidirectional airflow (commonly known as turbulent flow)* Airflow which does not meet the definition of unidirectional airflow."

These definitions resulted from the realization that while in 1963 there were only the new "laminar flow" type of cleanroom, and the previous "conventional cleanroom", we now have "mixed flow", "vector flow", "nonlaminar flow", "flow control", "dilution control", etc. For sampling purposes first, and then for general categorization of airflows, it seemed clearest to simply distinguish flow in a single pass in a parallel direction from all other designations of airflow.

The sampling provisions of the proposed revision are based, therefore, upon these definitions. While this section of the draft is lengthy, it provides these points (realizing that a cleanroom is a specific instance of a clean zone):

a) Not less than two sample locations shall be taken for a clean zone.

b) At least one sample shall be taken at each sampling location; more than one may be taken at each location, and different numbers of samples may be taken at different locations.

c) The sample locations shall be uniformly spaced throughout the clean zone, except as limited by equipment.

d) For unidirectional airflow, the clean zone is identified by an entrance plane perpendicular to the airflow, and immediately upstream of the work activity area. The minimum number of sample locations shall be the lesser of (a) the area of the entrance plane (in square feet) divided by the square root of the airborne particulate cleanliness class designation, or (b) the area of the entrance plane (in square feet) divided by 25.

e) For non-unidirectional airflow, the number of sample locations shall be uniformly spaced horizontally, and as specified vertically, throughout the clean zone, except as limited by equipment within the clean zone. The number of sample locations shall be equal to the square feet of floor area of the clean zone divided by the square root of the airborne particulate cleanliness class designation.

f) A minimum volume of air per sample must be taken in accordance with Table II.

Table II. Minimum volume (in cubic feet) per sample for the air cleanliness class and measured particle size shown.

	Measured particle size (micrometers)				
Class	0.1	0.2	0.3	0.5	5.0
1	0.6	3.0	7.0	20.0	NA
10	0.1	0.3	0.7	2.0	NA
100	NA	0.1	0.1	0.2	NA
1000	NA	NA	NA	0.1	3.0
10000	NA	NA	NA	0.1	0.3
100000	NA	NA	NA	0.1	0.3

Sample Calculations

The data and calculations presented in the following paragraphs are intended to serve as a working example, illustrating the statistical procedures involved in determination of acceptance criteria for cleanrooms and clean zones. The data and calculations are based upon testing at 0.3 micrometer measured particle size; and for Class 10, with a class limit of 30 from Table I.

Tabulation of Particle Count Data

	Particle Counts					Total No. of	Total	Average Particle
Location	1	2	3	4	5	Samples	Count	Concentrations
A	15	NR	NR	NR	NR	1	15	15.00
B	33	24	9	15	NR	4	81	20.25
C	18	3	12	24	NR	4	57	14.25
D	39	18	9	33	6	5	105	21.00
E	0	27	6	0	NR	4	33	8.25

NR = No reading taken.

Mean of the Averages (M)

M = (15.00 + 20.25 + 14.25 + 21.00 + 8.25 = 78.75) ÷ 5 = 15.75

Standard Deviation (SD)

$$SD = \sqrt{\frac{(15.00-15.75)^2+(20.25-15.75)^2+(14.25-15.75)^2+(21.00-15.75)^2+(8.25-15.75)^2}{(5-1)}}$$

SD = 5.17

Standard Error (SE)

$SE = 5.17 \div \sqrt{5} = 2.31$

Upper 95% Confidence Limit (UCL)

For 5 locations, 95% UCL Factor = 2.1
UCL = (2.31 x 2.1) + 15.75 = 20.6

Conclusion

Since the upper 95% confidence limit is less than 30 and all location average particle concentrations were less than 30, the above example data meet the acceptance criteria for Class 10, although some of the individual particle counts were above 30.

Figure 2. Statistical Analysis

PARTICLE COUNTING METHODS

Counting particles 5 micrometer and larger: The membrane filter method is used, but the complete procedure is detailed in the proposed revision, rather than just referencing ASTM F25. It is based upon F25, but with elimination of those portions not current or not in conformance with other parts of FS209—such as relating to only 5 micrometers and larger, sampling locations, frequency, etc. Most significant, the aerosol monitor method and the laboratory open filter holder method are given equal choice and prominence.

Counting particles 0.1 micrometer and larger: Again, the complete procedure is detailed in the revision rather than simply referencing ASTM F50, but it essentially follows ASTM F50, F328, and F649, taking applicable sections from each; an optical counting instrument shall be used, it must count single particles, and it must be periodically calibrated and properly maintained.

In the "Definitions" section of the proposed revision, the definition of "Optical Particle Counter" is worded broadly enough to include laser particle counters, and a definition is included for the "Condensation Nucleus Counter". Footnotes to the paragraph on "Methods and Equipment for Measuring Airborne Particulate Concentration", combined with these definitions, permit the use of laser particle counters, condensation nucleus counters, and sedimentation methods, although there is no explanation, description, or requirements for doing so.

STATISTICAL REQUIREMENT

Completely new in this proposed revision of the Federal Standard are the requirements for statistical considerations in the determination of class, and of meeting a class.

The current FS209B has only a definition for particulate air cleanliness classes, without an explanation of how to apply such definition to a specific situation. Such an approach was reasonable since FS209B has been a definition of the cleanliness only of a cubic foot of air. When classification of spaces now is added, questions arise as to how many and where samples should be taken, and what results constitute passing; that is, must every sample be below the class limit, only a certain percentage, the average of the samples taken, the mean, or what? The "statistical analysis" and "interpretation of data" sections of the proposed revision help resolve these problems.

The first step would be to select: (a) the cleanliness class to be met; (b) the minimum particle size which you want to count; (c) the number of sampling locations required; (d) the number of samples to be taken at each location. All of these selections must be in accordance with the requirements under "Sampling", discussed above.

Sampling is then performed, the results collected, and the statistical interpretation of the data completed (see below). Based upon the results, the cleanliness class would be met—with a 95% confidence limit—if the number in Table I, for the class and particle size selected, is greater than:

a) The average particle count at each sampling location (regardless of the individual counts at that location), *and*

b) The mean of the averages of all sampling locations.

The specific procedure for the statistical interpretation of data is most easily understood by referring to Figure 2, which is similar to an example provided as an appendix in the proposed revision. With reference to this example, the procedure is as follows:

a) Determine:
   1) The cleanliness class to be met
   2) The minimum particle size which would be counted
   3) The number of sampling locations to be used
   4) The number of samples to be taken for each location

b) For each sampling location, total the *counts* for all samples at that location; divide by the *number* of samples at that location; and thus obtain an average count for each sampling location.

This number is termed the "Average Particle Concentration" for the sampling location. To meet the class requirement, all of these must be below the corresponding Table I figure.

c) Add the averages for each location, divide by the number of locations, and thus obtain what is termed the "Mean of the Averages".

d) For each sampling location, subtract the overall "Mean of the Averages" from the "Average Particle Concentration" for that sampling location. Square the resulting difference.

e) Add the results from (d) for all the sampling locations and divide by a number which is one less than the number of sampling locations.

f) Take the square root of the result obtained in (e). The result is the "Standard Deviation".

g) Divide the Standard Deviation by the square root of the number of sampling locations. The result is the "Standard Error".

h) Multiply the Standard Error by the 95% UCL Factor. The 95% UCL Factor is a number related to the number of sampling locations as follows:

No. of Locations	2	3	4	5-6	7-9	10-16	17-29	>29
95% UCL Factor	6.3	2.9	2.4	2.1	1.9	1.8	1.7	1.65

i) Add the product of the multiplication in (h) to the Mean of the Averages obtained in (c).

j) Compare the result to the number listed in Table I for the particle size measured and the class desired. If the result is less than that number, the test area is below the class limit and the class meets the statistical requirement.

APPENDICES

In the present FS209B, the appendix is an extensive compilation of all sorts of nonmandatory information regarding cleanrooms, how to operate and maintain them, and how to obtain the cleanliness required. When FS209 was written in 1963, much of the information was new and of value to persons just becoming acquainted with contamination control. Now, however, much of the present appendix has been outdated by the advances which have been, and continue to be, made in our industry. In addition to the resulting confusion is the fact that in many cases, inspectors have not honored the "nonmandatory" status of the appendix, even in cases where the provisions are obviously not practical or appropriate.

In the proposed revision, the appendices are limited to one detailing the requirements of the membrane filter method of sampling, one describing the same for the particle counter method, one providing an example of the use of the statistical interpretation of data, and one listing publications which are sources of information about cleanrooms and contamination control.

WORK REMAINING

From the foregoing discussion, it might appear that the proposed revision of 209B has resolved every outstanding issue to come before the RP50 working group. However, as with every standards document, the finished product is the result of numerous compromises, recognized omissions and still unresolved technical questions which need continuing study.

It can also be anticipated that the use of the proposed new document in the field will highlight some new and some possibly still existing technical deficiencies as well as both grammatical and interpretive weaknesses which should be addressed by the RP50 group in continuing studies leading to future revisions of the document.

The importance of contamination control as a major component of high technology industry and medicine, and, the rapidly changing state-of-the-art in particle management should provide sufficient pressure to ensure that FS209 does not again languish for thirteen years as it did prior to now. ■

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2. Peck, R. D., "History and Present Status of Contamination Control Standards," *Proceedings of 27th Annual Technical Meeting of the Institute of Environmental Sciences*, Los Angeles, California, May 7, 1981.
3. "209B Revision: Background and Update"; *Microcontamination* Volume 1, No. 1; June/July, 1983.
4. "Federal Standard 209B Revision: An Update"; *Pharmaceutical Manufacturing*; Volume 1, No. 4; June, 1984.
5. Proposed Federal Standard No. 209C, Proposed Draft No. 14 of April 1, 1986.

NOTE TO THE READER:

The Institute of Environmental Sciences emphasizes that the material presented herein has only been proposed for adoption by the General Services Administration (GSA). The final version will come from GSA; thus, the material in this article cannot be used in place of the current Federal Standard 209B.

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John A. McDonough, Mine Safety Appliances Company
Richard Beeson, Lockheed Missiles amd Space Company
William Brader, CUH2A
George H. Cadwell, Flanders Filters, Inc.
Frederick J. Carleton, Pfizer, Inc.
Douglas W. Cooper, IBM Watson Research Center
Warren Dexter, Environmental Air Control Inc.
Gabriel Danch, Environmental General Company
E. O. Dixon, Air Control, Inc.
Harold Fitch, IBM Corporation
James Flannery, ENV Services
Clifford Frith, Anatel Instrument Corporation
Fred Gerbig, Gerbig Engineering Company
Humphrey Gilbert, Consultant
Roger T. Goulet, Cambridge Filter Corporation
Robert I. Gross, Medical Repair Labs.
Patricia Keady, TSI, Inc.
J. Gordon King, Henningson, Durham and Richardson, Inc.
Alvin Lieberman, HIAC/ROYCO
Wendell J. Lough, Weber Technical Systems
R. Claude Marsh, CMCO International
Richard Matthews, Filtration Technology
Charles F. Mattina, Kimberly-Clark Corporation
Robert L. Mielke, Monsanto Research Corporation
Susan Morris, Merick, Sharp and Dohme
Stacey Nakamura, Johnson Space Center
Robert D. Peck, Controlled Environment Equipment Corporation
Stephen J. Pijar, HHS PHS FDA Center Radiological Health
Ludwig Pulaski, IBM Corporation
R. D. Rivers, American Air Filter
John H. Robertson, Upjohn Company
Ron Skowronski, Mine Safety Appliances Company
Robert L. Sorensen, U.S. FDA.
Brian Stembal, Travenol Laboratories
Konrad H. Stokes, University of Arizona
David C. Swinehart, Delco Electronics Division
Marvin Tillery, Los Alamos National Laboratories
Jeannie West, Climet Instrument Company
Richard A. Yeich, AT&T Technology Systems

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