SC-M-69-129
May 1969

PLANETARY QUARANTINE

DESIGN REQUIREMENTS FOR LAMINAR AIRFLOW CLEAN ROOMS AND DEVICES

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ABSTRACT

This document explains the basic concept of laminar airflow and the control of airborne contamination by this method. It defines the basic design criteria which are essential for the maximum performance of the various types of laminar airflow facilities which are described and illustrated. An appendix provides a list of items useful in preparing a comprehensive clean room specification.

*This work was supported by the United States Atomic Energy Commission.

PREFACE

This document provides design considerations and requirements for the basic types of laminar airflow facilities. In presenting the current state of the art in laminar airflow facility design, this report contains updated and revised information from (and supersedes) the following publications:

> Basic Design Requirements for Laminar Air Flow Dust Control Devices; W. J. Whitfield, SC-R-64-145, May 1964.
>
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Information from other publications, technical papers, and laboratory research related to the laminar airflow concept was also used in an effort to provide more comprehensive coverage of the subject.

The information contained herein is furnished for guidance in the design and construction of laminar airflow facilities. It explains the basic concept of laminar airflow and the control of airborne contamination by this method. Further, it describes and illustrates the various types of clean rooms and benches that employ laminar airflow, without attempting to depict all of the commercial models currently available.

The basic design criteria which are essential to the maximum performance of laminar airflow facilities are presented. The Appendix provides a list of items which may be useful in preparing a comprehensive clean room specification.

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The basic design criteria which are essential to the maximum performance of laminar airflow facilities are presented. The Appendix provides a list of items which may be useful in preparing a comprehensive clean room specification.

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SECTION 1

PRINCIPLES OF CONTAMINATION CONTROL

A clean room or other clean air devices are usually a major segment of any contamination control program with regard to cost and the degree of control provided. Determining the extent of airborne contamination and selecting clean air facilities that will efficiently provide the necessary controls requires a comprehensive knowledge of the functions and capabilities of the various types of clean air rooms and devices.

The relationship of clean air facilities to the overall contamination control program is illustrated by a basic model of contamination control. This model, shown in Figure 1, provides a simplified description of the field of contamination with the fundamental forms of contaminants and affected environments. The model shows that any or all of the contaminants may occur in any of the environments, which means that a direct relationship can exist between any specific contaminant and environment. The relationship may be further illustrated by expanding the model to provide details in a specific area of the discipline.

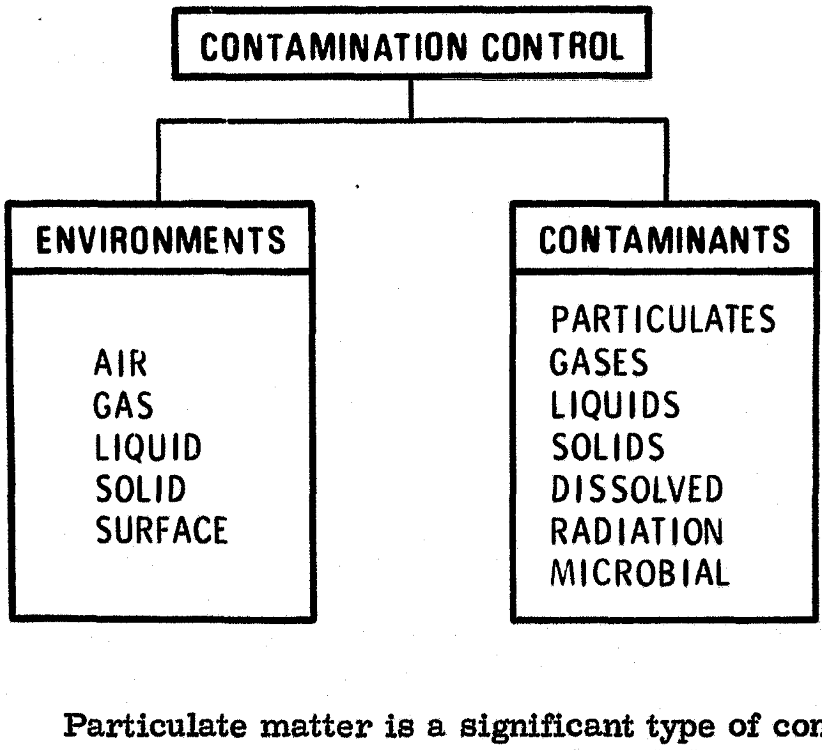

Figure 1. Basic Model

Particulate matter is a significant type of contamination and a variety of the sources and forms with some examples of the environments in which they may be found are shown in Figure 2. A further expansion of this chart is shown in Figure 3, which now includes methods of detecting and measuring and some methods for control. More specific detail may be developed in any particular area; however, these illustrations show the extensiveness of the field of contamination control.

TYPICAL SOURCES AND CONTAMINANTS	CONTAMINANT TYPE	CATEGORIES OF AFFECTED ENVIRONMENTS	
		GENERAL	SPECIFIC EXAMPLES
PEOPLE: BACTERIA AND VIRUS EPIDERMAL SCALE HAIR COSMETICS CIGARETTE SMOKE, ETC. CLOTHING: FIBERS AND LINT INDUSTRIAL PROCESSES: SMOKE FUMES FLUE DUST SOLDER AND WELD SPATTER MACHINING CHIPS AND BURRS SAND, ETC. PRODUCT: WEAR PARTICLES MATERIAL SHEDDING CORROSION PRODUCTS, ETC. EARTH: DIRT SAND, ETC. PLANTS: POLLEN	PARTICULATE	AIR	LABORATORIES FABRICATION AREAS ASSEMBLY AREAS
		GASES	FLUID SYSTEMS INERT GASES FILL GASES
		LIQUIDS	FUELS SOLVENTS HYDRAULIC FLUIDS COOLANTS LUBRICANTS
		SOLIDS	METALS PLASTICS GLASS EXPLOSIVES FUELS
		SURFACES	ELECTRICAL CONTACTS FILTERS FABRICS MECHANICAL PARTS TUBING

Figure 2. Particulates--sources and affected environments

TYPICAL SOURCES & CONTAMINANTS	CONTAMINANT TYPE	ENVIRONMENTS AFFECTED	EXAMPLES OF ENVIRONMENTS	METHODS OF DETECTING CONTAMINANTS	METHODS OF CONTAMINATION CONTROL
PEOPLE EPIDERMAL SCALE HAIR COSMETICS CIGARETTE SMOKE, ETC.	PARTICULATE	AIR	LABORATORIES FABRICATION AREAS ASSEMBLY AREAS	(1) MEMBRANE FILTER & MICROSCOPE (2) LIGHT SCATTERING REF: ASTM F25 ASTM F50	(1) FILTRATION (2) ELECTROSTATIC PRECIPITATION (3) ABSORPTION IN LIQUID (4) ADHESION
CLOTHING FIBERS & LINT		GASES	FLUID SYSTEMS INERT GASES FILL GASES	(1) MEMBRANE FILTER	
INDUSTRIAL PROCESSES SMOKE FUMES FLUE DUST SOLDER & WELD SPATTER MACHINING CHIPS & BURRS, ETC.		LIQUIDS	FUELS SOLVENTS HYDRAULIC FLUIDS COOLANTS LUBRICANTS	(1) MEMBRANE FILTER & MICROSCOPE (2) LIGHT SCATTERING (3) LIGHT ABSORPTION (4) SILTING INDEX	(1) FILTRATION (2) DISTILLATION (3) CENTRIFUGE SEPARATION (4) SETTLING (5) PRECIPITATION FILTRATION
PRODUCT WEAR PARTICLES MATERIAL SHEDDING CORROSION PRODUCTS, ETC.		SOLIDS	METALS PLASTICS GLASS EXPLOSIVES FUELS	(1) CHEMICAL ANALYSIS (2) MASS & EMISSION SPECTROGRAPHY (3) X-RAY (4) ULTRASONIC TESTING	(1) PREVENTATIVE MEASURES IN PROCESSING AT MILL OR FOUNDRY
EARTH DIRT SAND ETC.		SURFACES	ELECTRICAL CONTACTS FILTERS FABRICS MECHANICAL PARTS TUBING	(1) DIRECT: a) VISUAL / MICROSCOPE b) ULTRAVIOLET (2) INDIRECT: a) GAS FLUSH b) LIQUID FLUSH	(1) MECHANICAL SCRUB OR ABRASION (2) CHEMICAL CLEANING (3) VAPOR DECREASE (4) WASH OR RINSE (5) ULTRASONIC CLEAN (6) VACUUM OR BLOW OFF

Figure 3. Particulates--expanded chart

The contamination of a product or part, how to clean it, and how to keep it clean are some of the common thoughts related to the practical application of contamination control. In turn, the environments and the types of contaminants that are involved must be considered when determining what control measures, if any, are required to protect a product from contamination. Some of the sources and methods by which contaminants are deposited on a product are illustrated in Figure 4. Air is one of the principal environments affecting the sources of contamination and contributes both directly and indirectly to the accumulation on the product. With particulates being a significant form of contamination, it is then apparent that airborne particulate matter is a major consideration in contamination control.

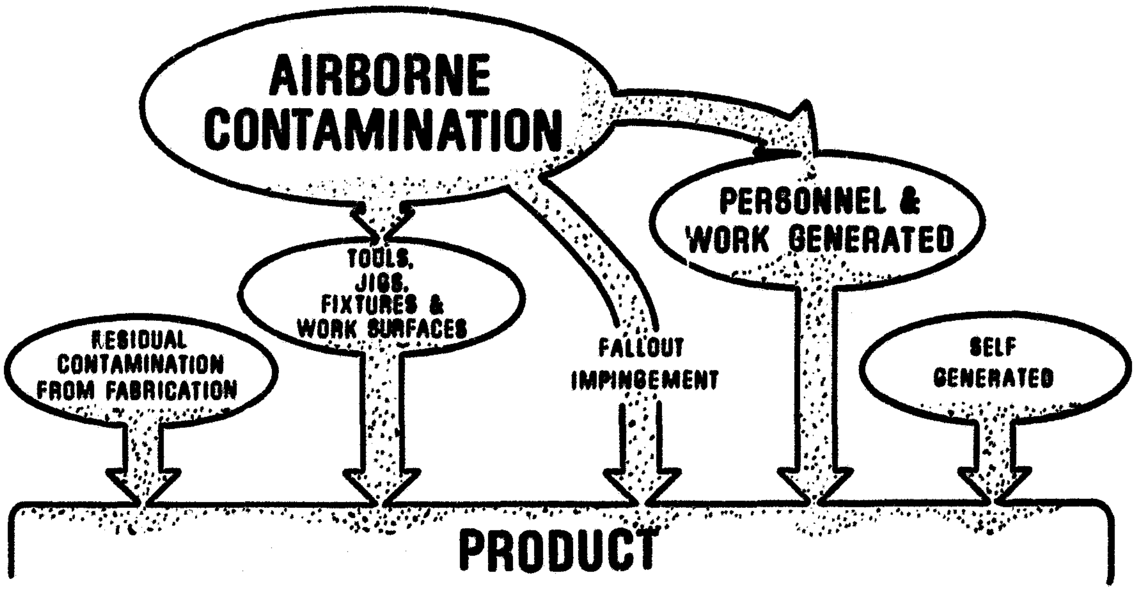

Figure 4. Sources of accumulated contamination

SECTION 2

Principles of Laminar Airflow Devices

The principal function of clean rooms and other clean air devices is to control airborne particulates by preventing or limiting airborne particles from entering an area or enclosure. This may be accomplished by passing all the air through a highly efficient filter system. Maintaining a high level of air cleanliness attained by filtration is dependent on the airflow characteristics and the activities performed within the enclosure. Providing a unidirectional airflow through the enclosure is an effective means of removing generated airborne particles and preventing a buildup of contaminants in the laminar airflow device.

Laminar airflow is defined as "airflow in which the entire body of air within a confined area moves with uniform velocity along parallel flow lines." A laminar airflow clean room or device is a dynamic facility in which the attainable cleanliness level depends on the performance and operation of its elements, rather than on the procedural and maintenance controls employed in nonlaminar-type facilities.

2.1 Basic Design Elements

The basic design requirements for a laminar airflow facility are as follows:

a. The airflow shall be uniform in velocity and direction throughout any given cross section of the enclosure.

b. All air entering the enclosure shall have passed through the high efficiency particulate air (HEPA) filter system (no leakage in or around the filter media).

An enclosure operating to meet these basic requirements will maintain the air throughout the enclosure at the same level of cleanliness at which it flows from the filter system, provided there is nothing already in or introduced into the enclosure that disrupts the airflow or introduces contaminants into the airstream. The HEPA filter is capable of capturing a minimum of 99.97 percent of all particles 0.3 micron and larger. This will provide air with a relatively low number of particles of any significant size.

Air cleanliness levels or classes are based on actual particle count with a maximum allowable number of particles per unit volume permissible over a given size. Classes of air cleanliness are further defined in Fed. Std. 209a, Paragraph 5. To obtain a reasonably true indication of the class or level of cleanliness, particle counts should be taken during normal operational activities and at or near critical locations and areas of interest where work is being performed.

The level of cleanliness attainable in any clean room or device will vary among the different types of facilities, the overall operating efficiency, and the type and amount of activity being performed in a facility. The approximate ranges of some types and combination of facilities are shown in Figure 5. The ability to upgrade the cleanliness level of a controlled area or room by the operation of clean benches in the area is also shown.

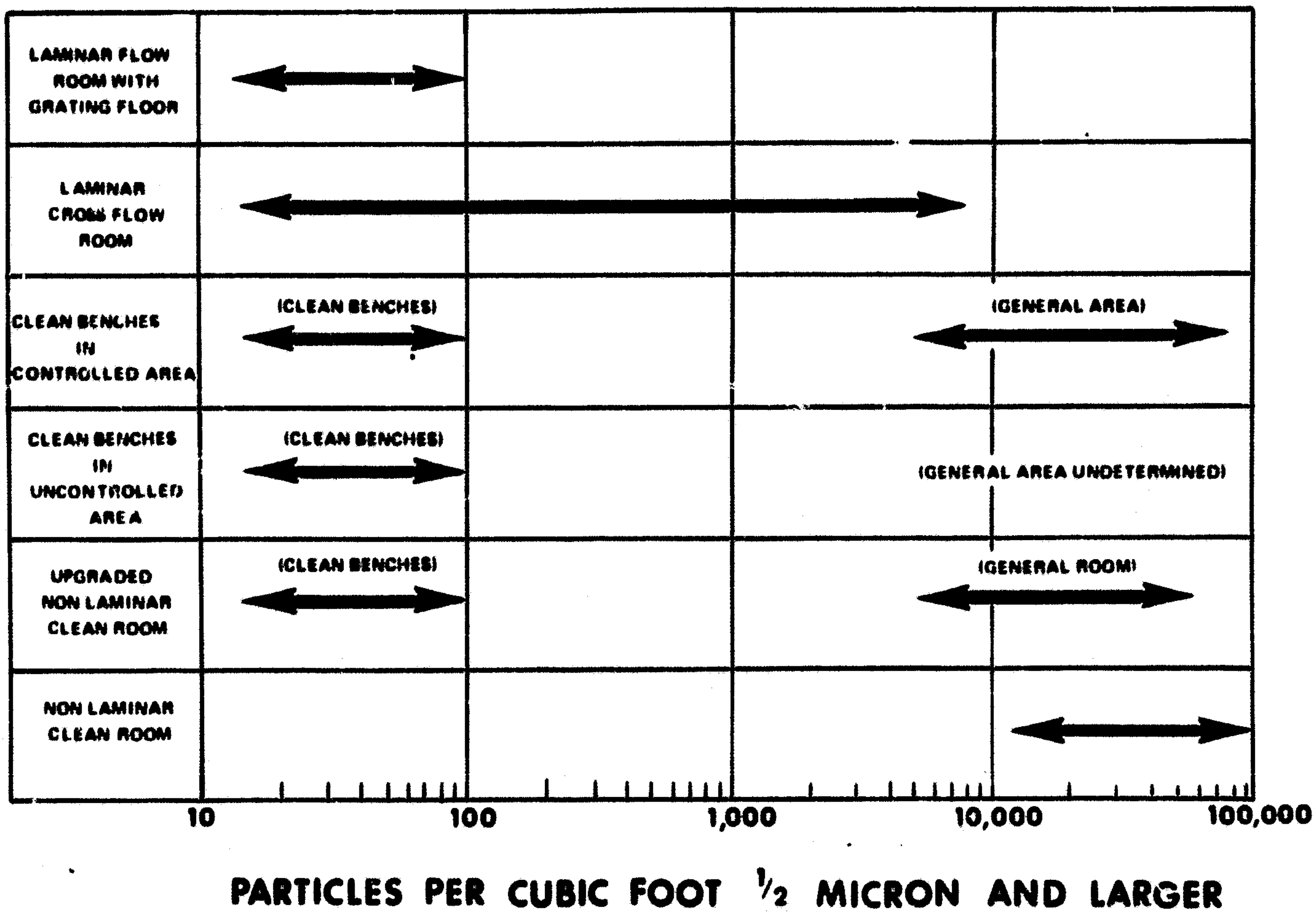

Figure 5. Range of cleanliness levels for clean rooms

The basic laminar airflow concept is employed in a number of different types of clean rooms and devices; the only significant variation is the direction of airflow. The basic concept of vertical laminar airflow (VLF) is shown in Figure 6, with the direction of airflow from top to bottom. In this type facility the air flows into the enclosure through the ceiling which is composed of HEPA filters and is exhausted from the enclosure through the floor grating. When Figure 6 is reoriented 90 degrees so the direction of airflow is from left to right or right to left, the same basic concept becomes horizontal laminar airflow (HLF). In this type facility, the air flows into the enclosure through one wall which is composed of HEPA filters and is exhausted through the opposite wall, which is open or louvered. One significant factor that will affect the movement of particles is the normal force of gravity which aids the airstream in the VLF and is perpendicular to the airstream in the HLF. For comparison, a nonlaminar-type room is shown in Figure 7 with the typical random airflow patterns that circulate particulate matter throughout the area.

Such variations and turbulences in the airflow provide a greater opportunity for airborne particulates to contaminate a product.

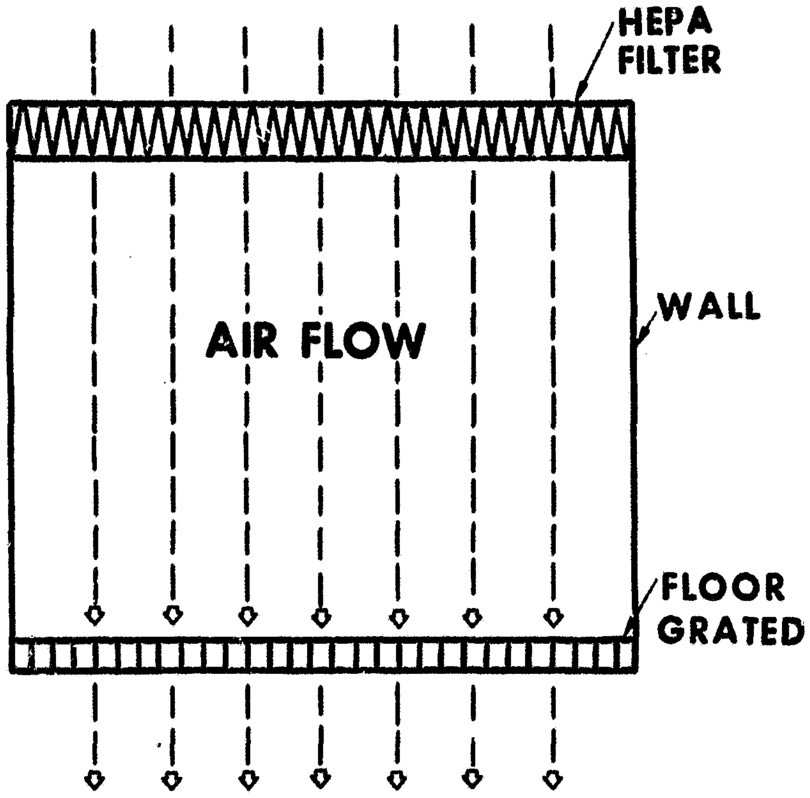

Figure 6. Basic laminar airflow concept

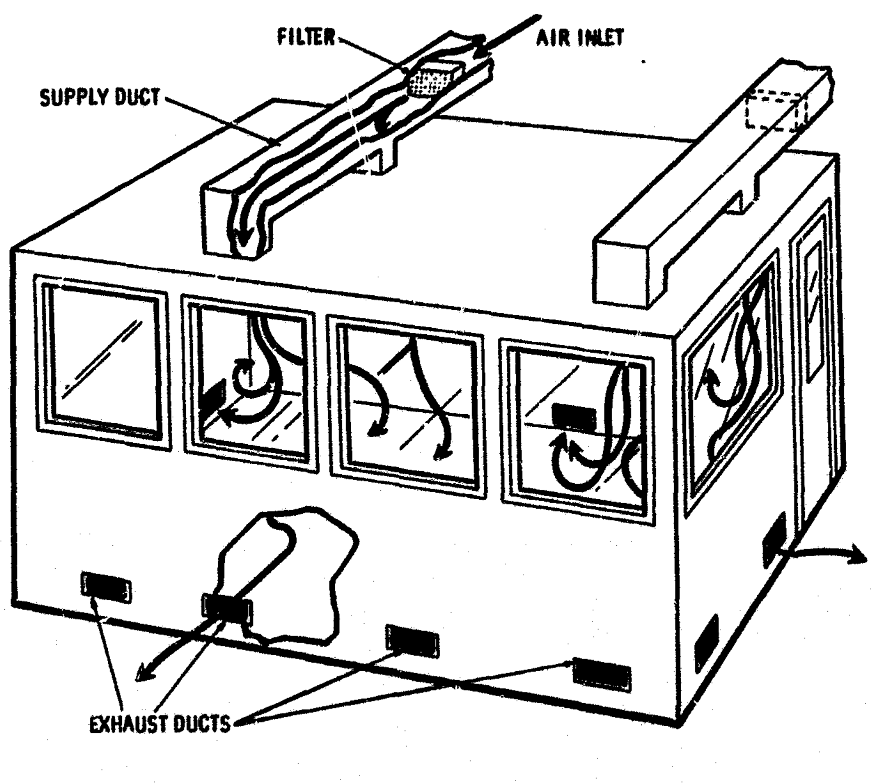

Figure 7. Nonlaminar airflow clean room

2.2 Other Elements of Control

Other conditions that may be controlled by a clean room or device are:

a. Other Types of Contaminants -- These are principally the gases which may be generated in the enclosure or introduced into the air-supply system and not removed by the HEPA-type filter. Controls may be incorporated in the air-supply system as required for the safety of personnel or to reduce effects on product.

b. Temperature -- This condition is normally controlled for personnel comfort but also may be specifically controlled to meet product requirements.

c. Humidity -- This is also a condition controlled to some extent for personnel comfort, but more specifically humidity is regulated to control the effects on product and tools and to limit problems caused by static electricity.

2.3 Functional Characteristics

The functional characteristics of the laminar airflow principle employed in clean rooms and devices may be summarized as follows:

a. Clean-down Capability -- The air velocities are sufficient to remove airborne contamination generated or carried into the facility. At an air velocity of 90 feet per minute, a vertical laminar airflow room with a 10-foot ceiling would undergo a complete change of air in less than 7 seconds.

b. Unidirectional Airflow Pattern -- Any particle capable of being airborne will be carried away from the product by the airstream because of the single direction of the airflow pattern. This lessens the opportunity for airborne particles to contaminate the product.

c. Reduced Janitorial Maintenance -- The ability of the facility to exhaust the airborne contamination produced within the installation precludes the need to continuously vacuum the area in an effort to maintain the desired air cleanliness levels.

d. Class 100 Available -- All laminar airflow facilities are fully capable of attaining a Class 100 condition, some types only in part depending on the operations. This class or better can be maintained with reasonable personnel direction and control of operations.

e. Better Control of Humidity and Temperature -- The volume of air introduced into the area is so much greater than in other types of environmentally controlled equipment that the absorption of heat, cold, moisture, or dryness is distributed over a greater volume of air, which greatly simplifies the maintenance of the desired levels. The recirculated portion of the air is also less costly to recondition because it has deviated from the norm much less than if it remained in the room for a longer period.

f. Reduced Garmenting Restrictions -- In a majority of circumstances, garmenting requirements may be met by a smock and head covering, due in large part to the capability of the laminar airflow to carry away particulate matter emitted by the worker. This represents a sizable savings in manhours consumed in the robing and disrobing several times each day when all-encompassing type garments are required. The additional freedom of movement also frequently manifests itself in improved output.

g. Reduces Critical Need for Airlocks, Air Showers, etc. -- Except in unusual cases (microbial or sterile conditions), air showers, double door airlocks, and large dressing rooms are not usually considered for a laminar airflow installation.

h. Increased Volume of Air Required -- The volume of air and the velocity at which it must be moved requires air-moving equipment and ductwork of larger size and capability than used for other type facilities.

SECTION 3

Basic Design Features for Laminar Airflow Facilities

A laminar airflow clean room or device that is operating efficiently and is performing within its specified control requirements is the result of careful planning with the application of good engineering design and judgment in all phases of construction. Certain features that have a major effect on performance must be given special consideration. Many of these features are common to all facilities that employ the laminar airflow concept and are described below. Those features that are unique to a particular type of room or device are described in the section for that type of laminar airflow facility.

3.1 Configuration of Enclosure

a. The internal surfaces of the walls must be parallel to the direction of airflow.

b. The cross-section area must be constant from the air supply end to the exhaust end of the enclosure. Any significant variation in this area violates the basic principle of laminar flow and results in nonuniform airflow.

c. The internal surfaces of all walls should have a minimum of ledges and offsets.

3.2 Materials for Inside Surfaces of Enclosure

a. The surface finish should meet the requirements of the work being performed. Where high-abrasion conditions exist, stainless steel may be needed. In most normal conditions, other lower cost materials with hard-gloss enamel or epoxy coatings are adequate.

b. All junctures and joints should be sealed to prevent air leakage.

c. Surface finish materials should be nonchalking, minimal shedding, and easily cleaned and maintained in good condition.

3.3 Air-Supply Plenums

The air-supply plenum is the space directly behind or upstream of the HEPA filter. The plenum must be deep enough to assure equal distribution of air over the HEPA filter area. Unequal air distribution on the upstream side of the filters will prevent uniformity in the airflow velocity on the downstream side and result in nonuniform velocity and direction from the filter to the exhaust area.

a. Plenums with a width-to-depth ratio of approximately 4 to 1 are preferred where the air supply is provided along only one side of the plenum. This ratio may be increased to about 8 to 1 where the air supply is provided from two (opposing) sides of the plenum. Larger ratios have been used successfully, but carefully designed subplenums are needed to provide extremely uniform airflow to the main plenum.

b. Subplenums are used between the blower and supply plenum to aid in equalizing the distribution of air and reducing the velocities into the supply plenum. They also help to reduce the noise level generated by the blowers and high-velocity airflow.

c. Materials should have smooth nonshedding surfaces, and the area must be sealed airtight.

d. Provisions should be made for access into the plenum when entry is required for maintenance of filters, lights, and other utilities.

e. Nonshedding, noise absorbing liners should be used to reduce the noise level generated by the blowers.

3.4 Exhaust Plenums

Exhaust plenums are used only with the facilities that employ a recirculating air system and are usually under the floor or behind the exhaust wall.

a. The general design criteria should be essentially the same as for the supply plenum regarding width-to-depth ratios to provide a uniform flow of air to the return air ducts and to reduce noise.

b. Materials should be compatible with the environments to which they are exposed, particularly when the exhaust plenum is located under work areas where spillage or leakage of liquids may occur. Surfaces should be smooth, nonshedding, and easily cleaned.

c. Space and provisions should be provided for the prefilter medium and other restrictive elements that may be utilized to vary the resistance to the airflow to provide greater uniformity in direction and velocity within the enclosure.

d. Construction should provide airtight seals of all joints and junctures and include provisions for ready access to the plenum for cleaning, servicing and changing prefilters, and other maintenance functions.

3.5 Air-Moving Ducts

All air ducts should be of a size commensurate with the volume of air moved to avoid excessive air resistance and noise.

a. Internal surfaces should be smooth and constructed of nonshedding material.

b. Joints must be sealed airtight and have smooth internal surfaces.

c. Bends in ducts should have a radius sufficiently large to prevent the generation of heat and noise.

3.6 Air Blowers

The size and type of air-moving equipment required for a particular facility are generally determined by the following factors:

a. The total air resistance of the complete system (filters, ducts, plenums, and other restrictive elements) at the velocity and volume desired.

b. The range of pressures expected during the HEPA filter life, which should be considered for the compensating increase in airflow resistance.

c. Vibration and noise characteristics.

d. The space and location available for mounting.

3.7 Air Conditioning

The design of air conditioning for laminar airflow facilities is essentially the same as for any other type facility except for the following factors that should be considered:

a. The greater volume of air moved and the equipment employed require consideration of the mechanical heat load (work done on the air) as well as the heat generated by the driving motors.

b. The laminar flow, in effect, isolates the air layers and makes it necessary to inject an adequate volume of conditioned air into each blower to achieve and maintain the desired temperature and humidity conditions throughout the enclosure. This air mixing must be completed before the air enters the clean room.

3.8 HEPA Filters

Laminar airflow facilities that operate within the scope of Fed. Std. 209a require the high efficiency particulate air (HEPA) filter. This type filter consists of a dry-type media in a rigid frame with a particle collection efficiency of 99.97-percent minimum for 0.3-micron dioctylphthalate (DOP) particles and a maximum pressure drop of 1.0-inch water gage (clean filter) at rated airflow capacity. Other significant factors to be considered include the following:

a. The materials of construction should meet the humidity and fire-resistant requirements of the specific installation. The filter section shown in Figure 8 shows some of the construction details of this filter.

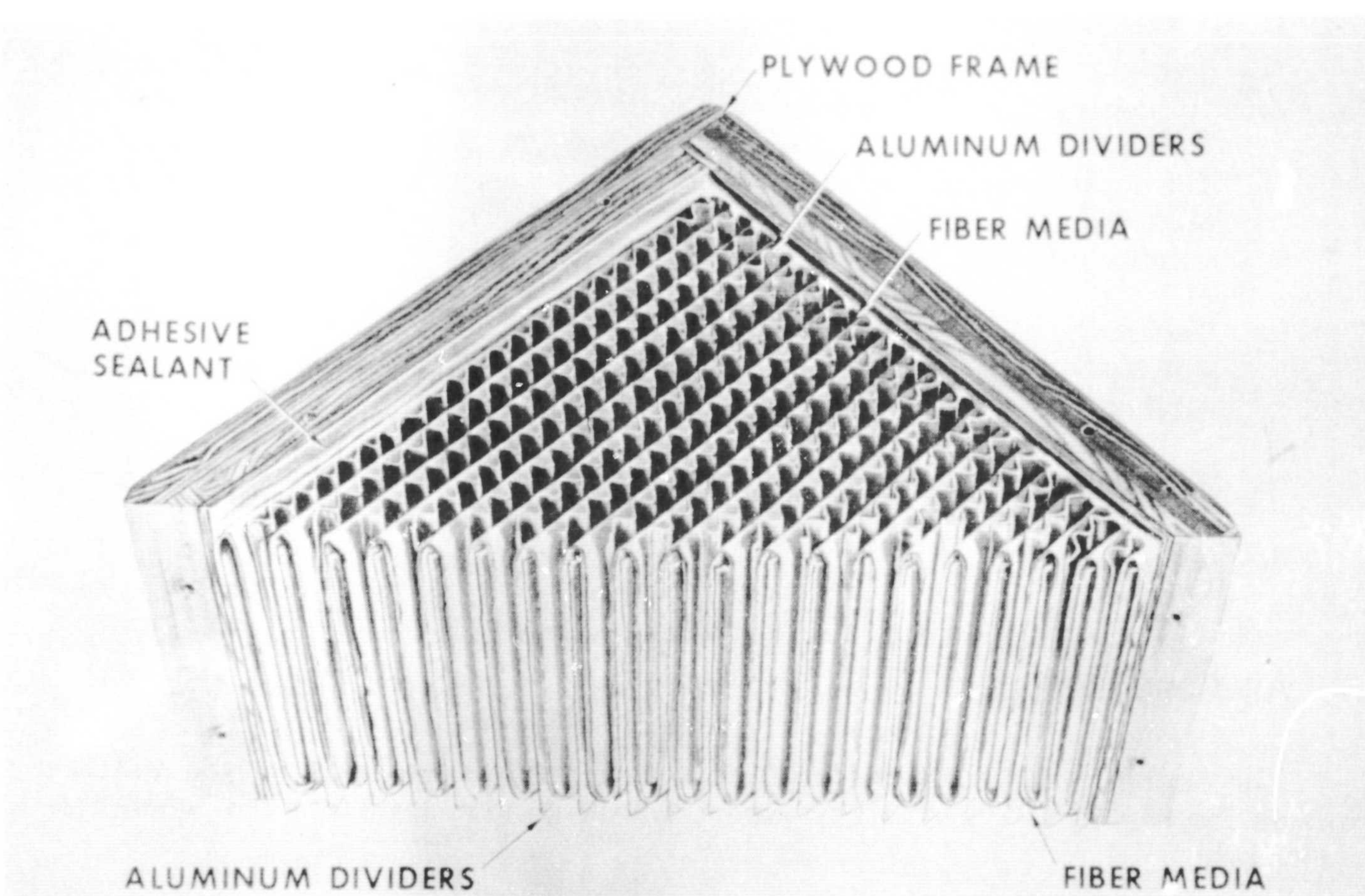

Figure 8. HEPA filter section

b. Filters should be individually 100-percent tested and certified to be leak-free, and the filter installed in the supporting framework should be tested in the same manner to assure a leak-free filtered air supply. A cross section of a typical filter installation shown in Figure 9 illustrates the significant sources of air leaks that should be checked in the testing operation.

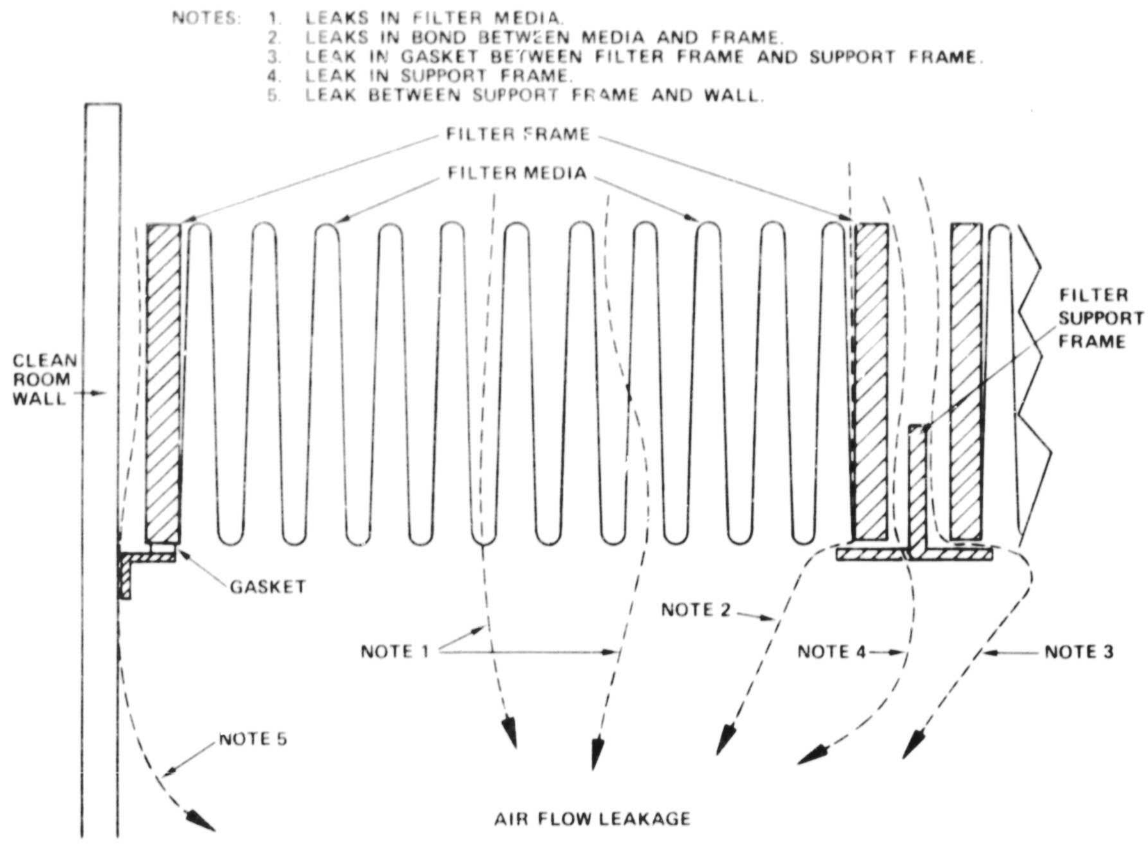

Figure 9. Sources of air leaks in a filter bank installation

3.9 Prefilters

Prefilters should be provided to extend the life of the more expensive HEPA filters.

a. Location of the prefilter will depend on the particular type of facility. However, the location should assure that all of the air supply to the HEPA filter passes through the prefilter. The prefilters should be easily accessible for maintenance because they require periodic cleaning or replacement.

b. Selection of the efficiency level for prefiltration is dependent on the contaminant level of the air, the amount of air recirculated, and the amount of contamination generated in the facility.

Efficiency ratings are directly related to cost and pressure drop, which will increase as the efficiency increases. Prefilter media are available with efficiency ratings from 45 to 95 percent by the weight (synthetic dust) test method.

c. Prefilter media may be in sheet or pleated form. Some media may be cleaned in place by vacuum cleaning or may be removed for washing. Other media are not cleanable and should be replaced as needed.

d. Prefilters should be replaced or cleaned according to a routine schedule to prevent overloading which may result in an increased pressure drop or dirt blow-through to the HEPA filter.

3.10 Lighting

Fluorescent lights are normally used and should provide adequate light intensity (usually 100 footcandles minimum) at the work surface or plane for the type of work being performed. Types and locations of lamp fixtures that minimally disturb the laminar airflow are discussed in the section concerned with the various types of facilities.

3.11 Noise Level

The volume of airflow required for effective operation of laminar flow facilities requires an air distribution system that can create excessive noise levels to the discomfort of operating personnel. Efficiency may consequently be reduced. Two of the characteristics that have a major effect on the noise levels generated and that should be considered for control measures are described below:

a. Blower equipment should be of adequate size and properly balanced and may require vibration-isolation type mountings and coupling to the air ducts. In some instances, an acoustical insulation barrier may be used around the equipment.

b. Air ducts and plenums should be of adequate size and may require lining with acoustical nonparticle shedding insulation to minimize noise radiation.

3.12 Vibration

Equipment vibration is a major source of noise but may not present a problem when the noise is at acceptable levels. However, the work surfaces should be within an acceptable range of vibration velocity for the particular operations performed and at the critical frequency range. Methods of control consist mainly of isolation, damping the vibrating elements, and detuning the resonant condition, whichever may be applicable.

3.13 Electric Power

The specific power requirement is a significant factor for the laminar air-flow facility. The large air-handling equipment and the lighting must be considered for requirements in terms of voltage, phase, and current.

SECTION 4

BASIC TYPES OF LAMINAR AIRFLOW FACILITIES

The basic type or configuration of those facilities and devices that employ the laminar airflow concept are described in the following paragraphs. These clean room and bench-type facilities are capable of operating well within a cleanliness class for which they are designed. This capability, however, is governed by the basic design requirements for a laminar flow of clean air in the work area and the particular features and characteristics that significantly affect these requirements. Each type of facility has certain features that require special considerations in design and construction which are complementary to the basic design requirements for laminar airflow. These features are described for each of the basic types.

The possible combinations and variations of these basic types are limited only by the design requirements that assure conformity with the laminar airflow concept. All variations of the basic types must be given careful consideration in design and construction so that the basic concepts are retained and the facility operates as intended.

4.1 Vertical Laminar Airflow (VLF) Room

In a VLF room, the air flows vertically from the ceiling (which is completely made up of HEPA filters), through the room, is exhausted through a grated floor and recirculated through plenums and ductwork back through the ceiling filters. A section of this type room is shown in Figure 10, with the major elements located and identified.

The VLF room normally provides the best control of airborne particulate matter throughout the entire clean room area. A properly designed VLF clean room provides the following advantages over other types of rooms:

Operates well within the Class 100 level.

Operates effectively within a wide range of air velocities.

Ensures rapid removal of generated or introduced contaminants from the room.

Reduces cross-contamination between adjacent operations.

Reduces janitorial and maintenance costs.

Minimizes the effects of personnel emissions of contaminants on critical operations.

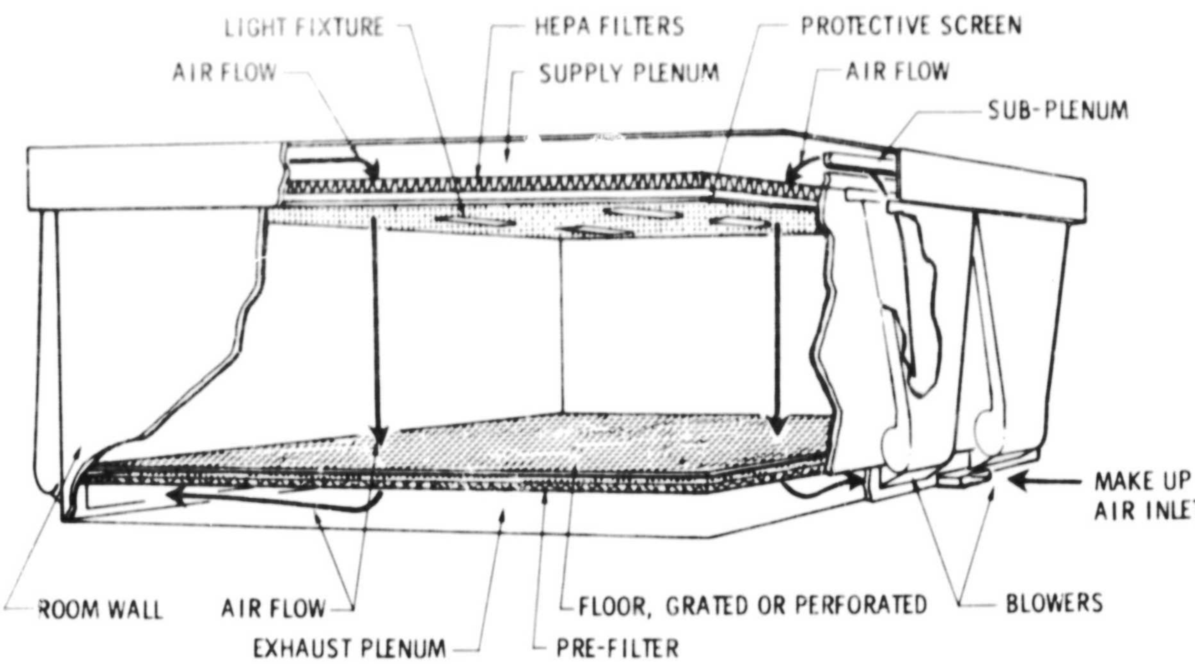

Figure 10. Vertical flow clean room

Some of the basic design requirements that have a significant effect on the operation of a VLF room are listed below:

a. Ceiling -- Supporting framework must be structurally adequate to support the HEPA filters, light fixtures, sprinkler systems, and other required utilities. An airtight seal must be maintained between the support frame and HEPA filter frame. There must be no air leaks in the framework itself or around fixtures such as lights, sprinkler heads, etc. Figure 9 shows some of the possible sources of air leaks in a filter bank installation. A protective grille should always be provided on the room side of the HEPA filter bank to prevent damage to the filter media.

The filter support frame should be designed to allow only a minimum area between filter units. The support frame reduces the effective filter area and creates air turbulences downstream from the filter. Figure 11 illustrates the air turbulence created by the support frame between filters. The major turbulent area in which the air circulates back to the top extends downstream a distance about three times the width of the area, where there is a unidirectional flow of air on both sides. Downstream from this area, minor air disturbances may extend all the way to the floor, gradually diminishing in degree. These disturbances are moving at the same velocity and in the same direction as the normal airflow pattern. Therefore, it is not believed they present any major problem except possibly for the most critical type of operation. The major turbulent areas are limited in the distance they extend and do not present any serious problem except when the work areas are close to the ceiling or the width and subsequent depth of the area are extensive.

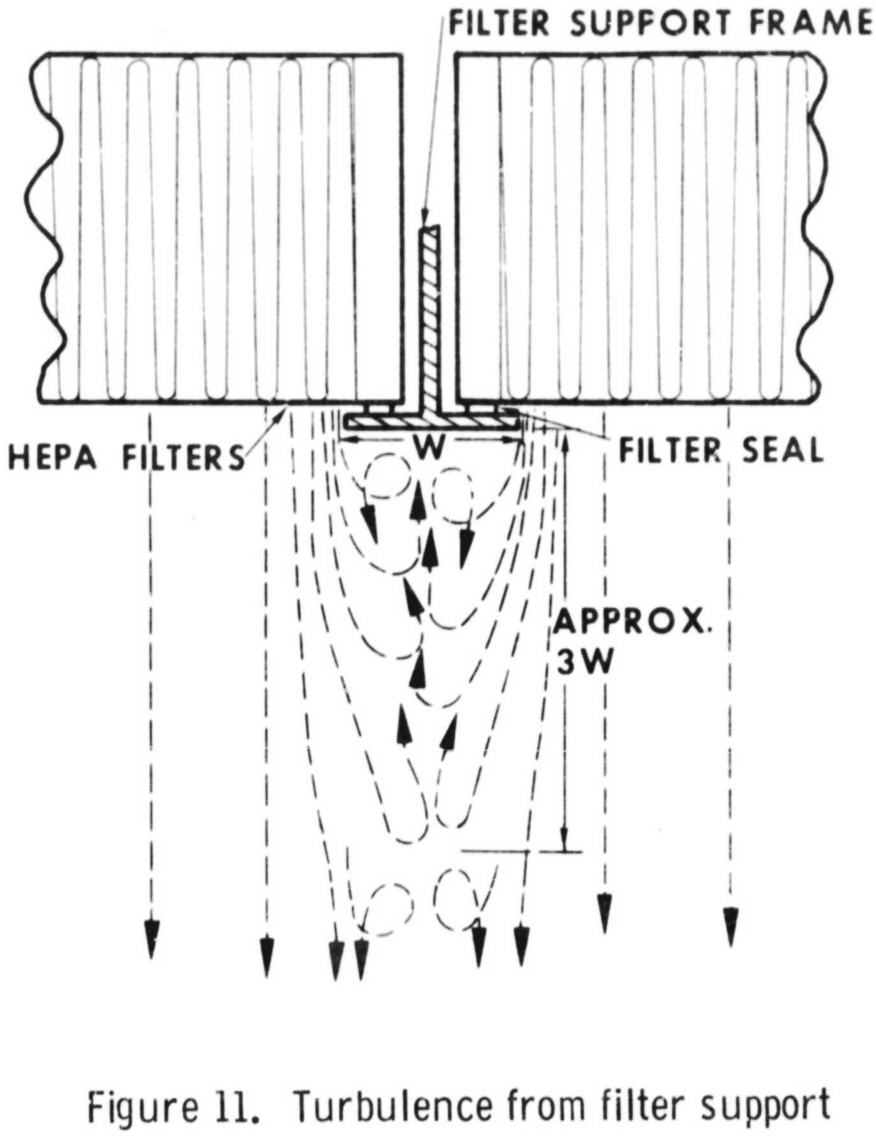

Figure 11. Turbulence from filter support

b. Ceiling Mounted Lights -- Light fixtures mounted on or in the ceiling present the same problems of air turbulences as the ceiling support frame. The total width of the fixture should be kept minimal to shorten the downstream turbulence area. Fixtures should be mounted between filters as shown in Figure 12 or mounted on the support frame as shown in Figure 13. The suspended type fixture illustrated in Figure 13 extends the turbulent area further into the room; this can be an undesirable feature. Single tube fixtures with a width about equal to the width of the support frame and mounted directly to the frame would create the minimum of air turbulence. If the turbulent

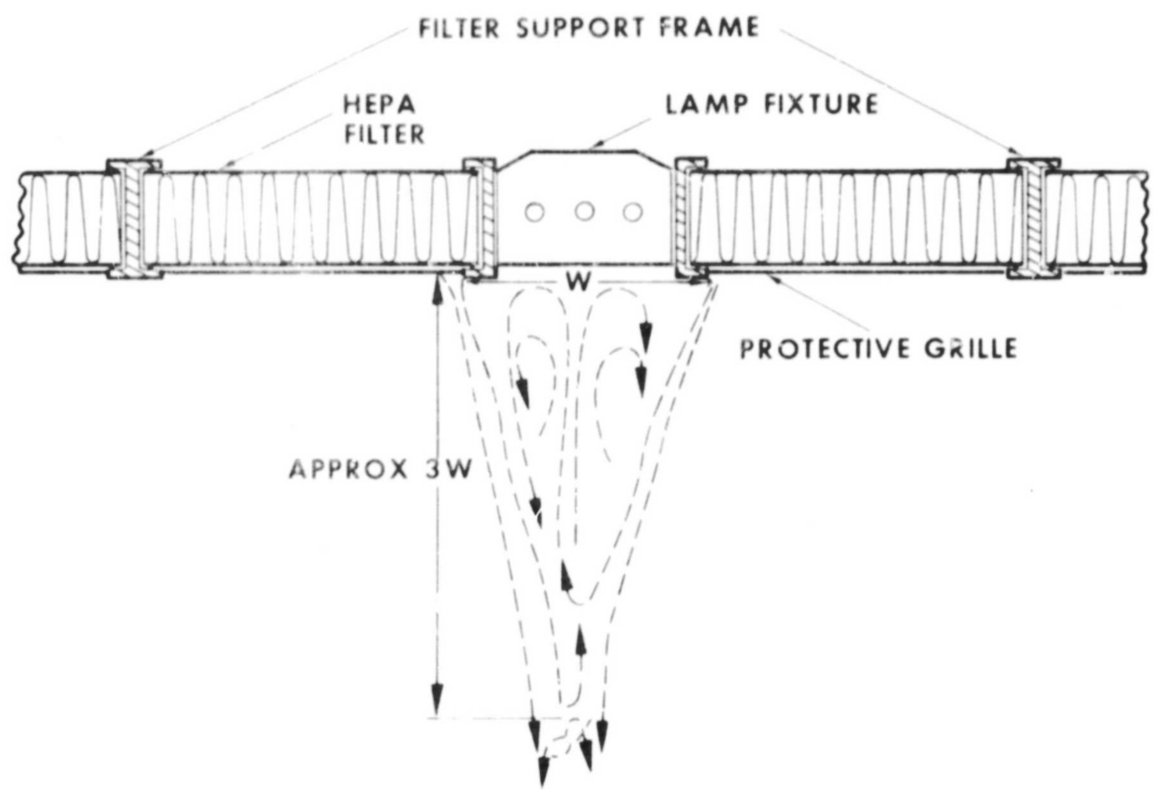

Figure 12. Turbulence from flush-mounted lamp fixtures

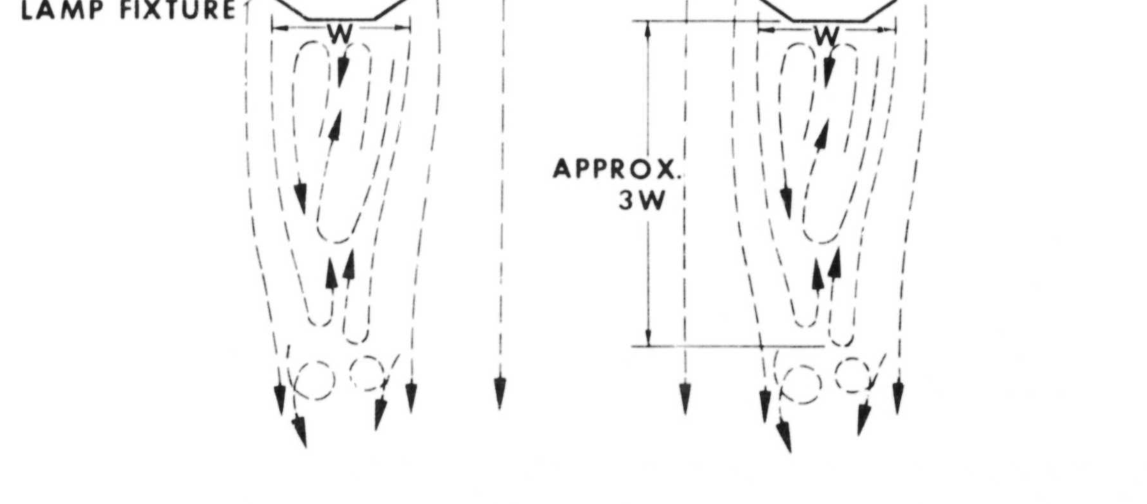

Figure 13. Turbulence from suspended lamp fixtures

areas do not extend into a dirty or work area in the room, they should not present any major problem for normal room operation. Determining the best type of light fixture and the best method of mounting is dependent on the:

1. Type of support frame and filter mounting assembly used

2. Available access for servicing lights

3. Light distribution and intensity required

4. Ceiling height.

c. Walls -- The interior surface of the walls should have a smooth, hard gloss finish. Strips, ledges, and offsets should be kept to a minimum. Doors and windows must be flush with the interior surface. Any wall surface will create a small amount of air drag; therefore, the inner wall surface and the effective edge of the HEPA filter should be as close together as possible at the wall and ceiling juncture. A wall offset at this point will create a major air turbulence extending downstream along the wall a distance equal to approximately six times the width of the offset. Figure 14 illustrates the turbulence created by this type of offset. The same type and area of turbulence would be created by a projection at any point downstream along the wall surface such as a ledge, shelf, lamp fixture, etc. The turbulent area would extend downstream from the bottom side of the projection for the same distance-to-width ratio shown in Figure 14.

d. Floor -- The entire floor area serves as an air exhaust. The floor should be constructed of grating or perforated metal which should have, at the minimum, a 60-percent opening for air passage. Provisions should be included in the floor for adjusting the percentage of opening for air passage to facilitate balancing the airflow within the room. Methods that are used in adjusting the floor openings include variations in the hole sizes in the grating or perforated sheet, varying the thickness of prefilter media (direct under the floor), and utilizing adjustable dampers or baffles in the floor.

The floor should be laid out in sections with adequate structural support to meet floor loading requirements. Sections should be removable and of a size and weight so that two men can safely handle them. The type of material should meet use requirements of the clean room. Some operations may require stainless steel. However, in most instances either plated steel or aluminum is satisfactory.

e. Prefilters -- In the VLF room the prefilter is usually located just under the floor. A sheet or pad-type media is normally used and is held in place by a coarse mesh screen. The filter media catches small items which fall through the floor openings. It also creates some air resistance to aid in uniform air distribution in the room. Located just under the floor, the media can be cleaned and replaced by removing floor sections. Locating the prefilter at other points in the system may be satisfactory when access to the area is practical for cleaning or replacement and the type of media used in the space provided is adequate for the airflow rate encountered.

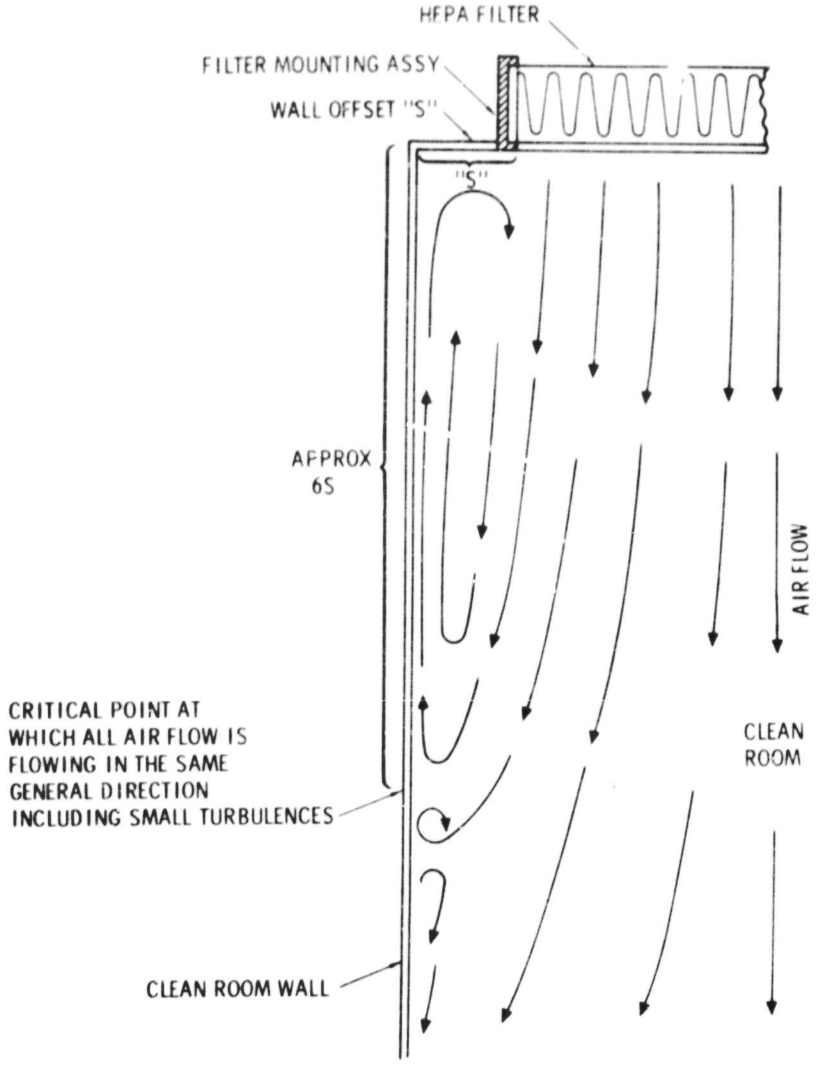

Figure 14. Airflow turbulences caused by wall offset

f. Plenums and Ducts -- The VLF room employs an air recirculating system that is composed of an exhaust plenum under the floor and return air ducts that connect to the supply plenum. This system must be of sufficient size to handle the airflow at the rates required without noise or vibration. The air-handling system must include facilities for introducing makeup air and for tempering the air to the desired temperature and humidity within the room.

h. Pressure Differential -- A positive pressure differential between the room and adjacent areas should be 0.05-inch water gage minimum with all entryways closed. With entryways open, the airflow capacity should be adequate to maintain an outward flow of air. Inability to maintain minimum overpressure in the room is an indication of inadequate air-moving equipment or excessive leaks in the room or air-handling system.

4.2 Vertical Laminar Airflow (VLF) Curtain Room (Portable)

The portable curtain room is an adaptation of the VLF room except that the air is exhausted under the walls of the unit all around the perimeter; also, the air is not recirculated and the side walls are plastic curtains. The portable room is capable of being transported and can envelop the product, which may be heavy, cumbersome components or structures less capable of being transported to a standard-type clean room. A typical VLF curtain room showing location of major elements is illustrated in Figure 15. This room is capable of operating within the Class 100 level and can be a completely self-contained unit except for electric power. Design requirements that have a significant effect on the operation are the same as for the VLF room except as follows:

a. Walls -- The walls are plastic curtains which should be attached to the ceiling filter bank in a manner to preclude any air leaks in this area. The inside surface of the curtains must be at the effective edge of the filter to eliminate any offset and resulting air turbulence as shown in Figure 14.

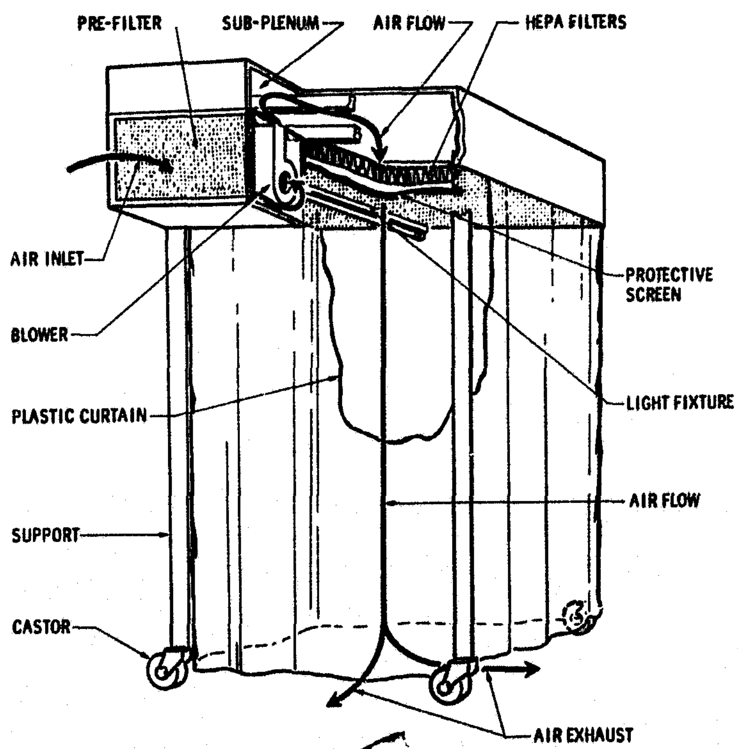

Figure 15. Vertical flow curtain room (portable)

The curtains should preferably be of a nonstatic plastic material and should extend to within 12 inches of the floor. Weighting along the bottom edge may be required to assure an unwrinkled, even surface for uniform airflow. Seams in the material should be vertical and any junctures for access should have zipper closures that are as airtight as possible and present a smooth surface on the interior side of the curtain.

b. Floor -- The portable room has no floor of its own and may be set up on any type surface that will support it, the product, and the activities performed in the room. Care should be exercised to prevent the rise of dirt from a dirt floor. The effective clean work area should be at least 18 inches above the bottom of the curtain walls.

c. Lighting -- Ceiling mounted light fixtures should receive the same considerations as for the VLF room. Overhead lighting may also be augmented by light through the transparent curtain walls as required.

d. Prefilters -- In the portable room, the prefilter is usually located at the air inlet to the blower system. Because the unit may be operated in exceptionally dirty areas, the prefilter requires frequent inspection and cleaning or replacement to prevent overloading.

e. Air Velocity -- The normal velocity of 90 ± 10 ft/min will maintain a Class 100 condition. However, severe conditions may necessitate higher airflow velocities.

f. Pressure Differential -- With the open perimeter exhaust system, no pressure differential is maintained.

g. Supports -- Legs supporting the room should be rigid with no height restriction commensurate with required balance. Casters may be used with the legs to provide lateral movement. Lift rings may be provided on the top of the unit to facilitate lifting and movement (by a crane) or for suspending the unit over the work area.

4.3 Horizontal Laminar Airflow (HLF) Room

The HLF room may be regarded as essentially a VLF room placed on its side. This does create some differences in construction as the filter bank is now in one wall and the airflow is exhausted through the opposite wall. Figure 16 shows a typical HLF clean room and the locations of some major elements.

The HLF room cannot be characterized according to any one air-cleanliness class. The first operating position directly downstream from the filter-bank wall is capable of Class 100 conditions or better. The succeeding stations downstream are at some increasingly higher particle count level as the number of upstream stations increases. These levels can be determined only by actual particle counts at each station while normal operations and activities are being performed at all upstream stations. Any change in operations and activities at a station will probably change the particle count level at all stations directly downstream.

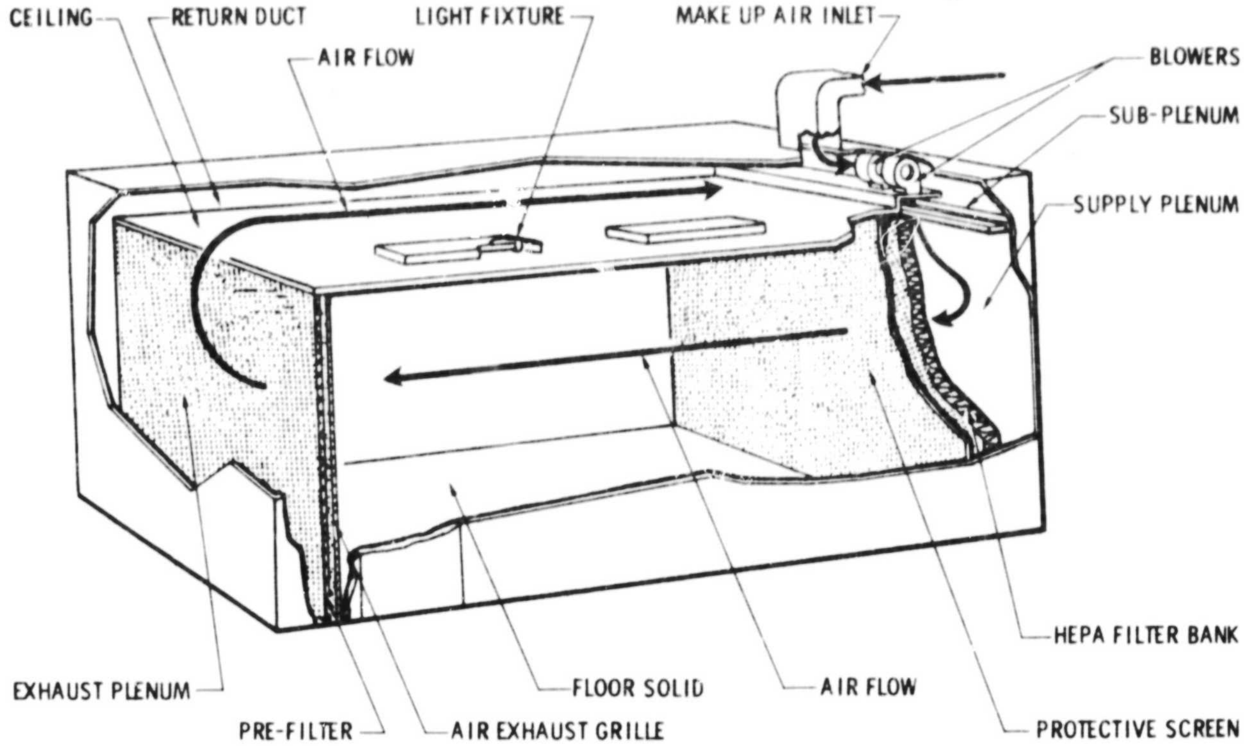

Figure 16. Horizontal flow clean room

The basic design requirements that affect the operation of the HLF room are much the same as those for the VLF room and should be given the same considerations, except as noted below:

a. Ceiling -- The ceiling should be of solid construction except for required openings for light fixtures, sprinkler systems, and other utilities. The interior surface finish should be smooth and hard and should present an even surface to the airflow for minimal drag.

b. Ceiling Mounted Lights -- All light fixtures should be flush-mounted to avoid interference with the airflow.

   Methods of servicing the lights (whether it is to be done from inside the room or above the ceiling) must be considered. The fixture and the manner of mounting must provide airtight sealing.

c. Filter Wall -- One wall of the room is constructed completely of HEPA filters. This requires supporting framework and mounting assembly for the filter units. The framework and assembly are similar to that of the VLF ceiling, and the same considerations must be given to sealing for air leaks (Figure 9) and minimizing downstream air turbulences (Figure 11). A durable screen to protect the HEPA filter media from damage is required due to exposure to movement of personnel and equipment. (This is usually more critical than in VLF rooms.)

The juncture of the filter wall with the interior surfaces of the side walls, floor, and ceiling should be at the effective edge of the filter. An offset at this point creates air turbulences similar to those so created in the VLF room (see Figure 14).

d. Exhaust Wall -- The wall opposite the filter wall is constructed entirely of material which has sufficient openings such as louvers, perforations, etc., that permit free movement of the air. Adjustable dampers or baffles or other means of adjusting the airflow should be provided to facilitate balancing the airflow within the room. The exhaust opening may be in the ceiling at this end of the room provided some sacrifice in the cleanliness level can be tolerated at the exhaust end of the room.

e. Side Walls -- The two side walls of the HLF room should be standard solid construction with smooth interior surfaces for a minimum of drag or turbulence in the airflow. Doors and other access openings in the room should be as near as possible to the exhaust end of the room.

f. Floor -- The floor should be of solid construction and structurally adequate to support the anticipated loading within the room. The interior floor surface material should meet the use requirements of the room and should be easy to maintain. Vinyl or similar floor covering is satisfactory for most clean room operations.

g. Prefilters -- In the HLF room the prefilter is usually located behind the exhaust wall in the exhaust plenum which normally provides access for cleaning or replacement. Sheet form media is normally used and should be supported in a manner to minimize the amount of air bypassing the filter. Other locations may be utilized, but the airflow capacity and type of media must be considered the same as in the VLF room.

h. Plenums and Ducts -- An air recirculating system is employed and requires the same considerations as the VLF room with respect to size, makeup air, and air-tempering facilities. Location of the return air ductwork is optional and is usually determined by the space that is available (over the ceiling as shown in Figure 16, under the floor, or along the side walls).

i. Air Velocity -- The linear air velocity within an HLF room is normally a little higher for efficient operation than in the VLF room. The length of the room or the distance the air travels from HEPA filter wall to exhaust wall is a determining factor for the most effective velocity. A relatively short room will operate well at around 100 ft/min with velocities increasing up to 140 ft/min or more for unusually long rooms. Other factors to be considered in determining the air velocities include the type of operations being performed and the density of people in the room.

j. Pressure Differential -- Same as for a VLF room.

4.4 Horizontal Laminar Airflow (HLF) Tunnel Room

The HLF tunnel room is essentially the HLF room with the exhaust wall open. Figure 17 shows a tunnel room and the locations of major elements.

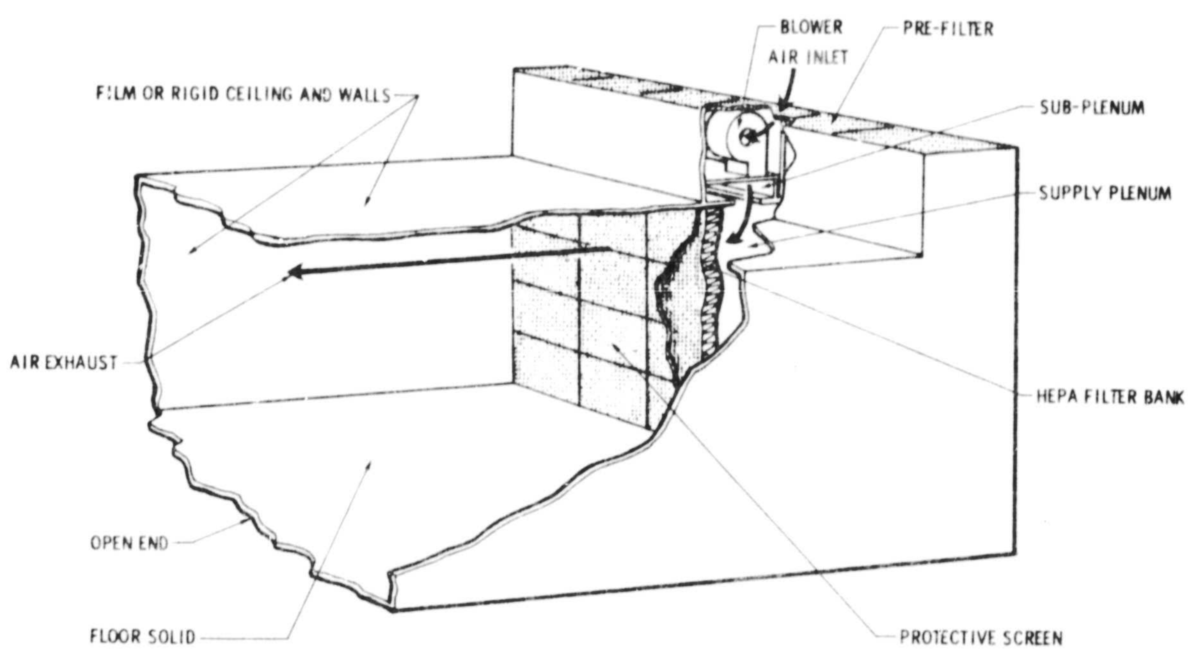

Figure 17. Tunnel clean room

The airflow is exhausted from the open end into the surrounding area, and the air supply is obtained from the surrounding atmosphere. This eliminates the closed air recirculating system. However, other design requirements are the same as for the HLF room, except as noted below:

a. Ceiling and Side Walls -- The type of construction may vary to suit particular needs. Both walls and ceiling may be constructed of standard solid construction, rigid transparent, materials, or a rigid framework to support transparent plastic film. Regardless of the type of construction, the interior surfaces should be smooth and even to reduce airflow drag and turbulence. Transparent or translucent materials are utilized to take advantage of lighting already in the area which may be augmented as needed with auxiliary equipment.

b. Filter Wall -- This wall usually consists of a series of laminar airflow modules which includes the HEPA filter bank, air-supply plenums, blowers, and filtered air inlet. A number of these modules may be joined together to achieve the desired width of the room. Standard ceiling height of the filter bank in the module is usually 8 feet.

c. Exhaust Wall -- The exhaust end of the room is usually left open. However, it may be constructed of louvered or other open-type material.

d. Floor -- The floor of the area in which the tunnel room is located is usually also the floor of the room. However, a separate floor may be provided or a suitable covering on the existing flooring may be used as required.

e. Prefilters -- The prefilters are provided at the air inlet to the blower system. The prefilter on this facility is exposed to the dirty air of the surrounding area and must be readily accessible for replacement or cleaning.

f. Plenums and Ducts -- The air-supply plenums and any ductwork associated with the air inlet and blower system are normally part of the laminar airflow module. This includes access to the HEPA filters for servicing and replacement. The entire air supply for the tunnel room is normally obtained from the surrounding atmosphere; therefore, this air must have a temperature and humidity acceptable to the clean room operations.

g. Air Velocity -- The air velocity may be slightly higher than the velocity range for the HLF room to compensate for the open exhaust end and overcome any infiltration upstream at this end.

h. Pressure Differential -- No pressure differential is maintained with the open-type exhaust.

4.5 Wall to Floor Airflow Clean Room

This type room employs some features from both the VLF and HLF rooms. With a complete air recirculating system, the air supply is furnished through the upper portion of a wall composed of HEPA filters. Figure 18 shows a section of this type room and the locations of major elements.

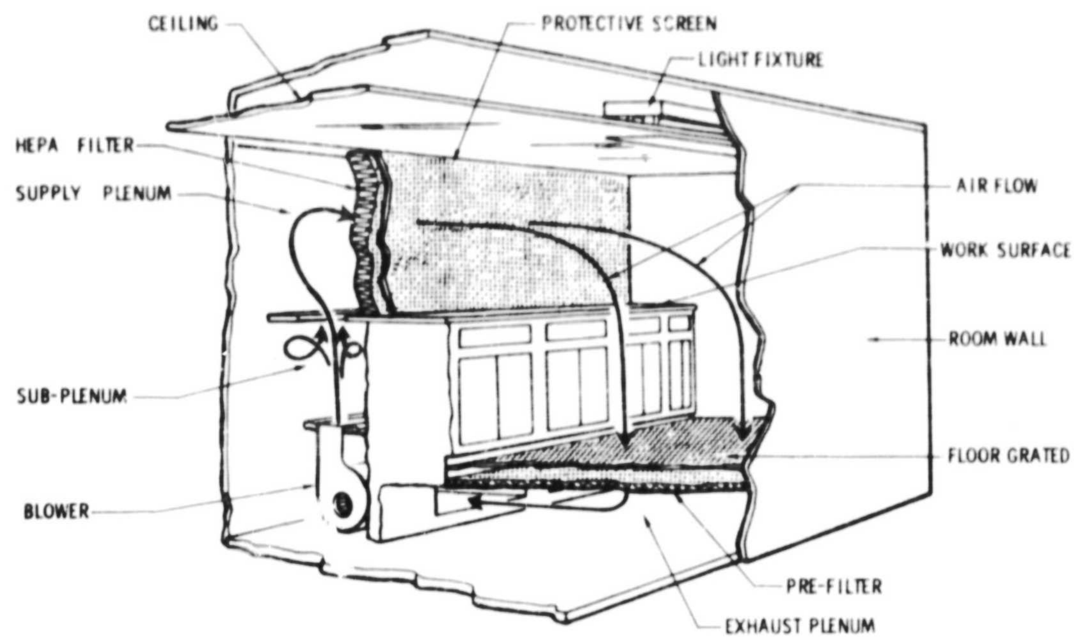

Figure 18. Wall to floor airflow clean room

The basic design requirements are essentially the same as for a VLF room except as noted below:

a. Ceiling -- The ceiling requirements are the same as for the HLF room with flush-mounted light fixtures.

b. Filter Wall and Bench Area -- As shown in Figure 18, the HEPA filters extend from the ceiling down to the bench top and along the length of the bench area. Consideration must be given to minimizing air turbulences extending from the face of the filter into the work area over the bench, the same as for the HLF room.

c. Other Walls -- The same requirements as for both VLF and HLF solid walls apply here.

d. Floor -- The floor area excluding that covered by the bench serves as the air exhaust. The same consideration should be given as for the VLF room to include prefilters, exhaust plenum, air ducts to blowers, supply plenums, etc.

e. Air Velocity -- The air velocity range is the same for the VLF room and provides a minimum of a Class 100 condition in the work area over the bench.

4.6 Horizontal Laminar Airflow (HLF) Bench

The laminar airflow bench provides a means for establishing localized clean "zones" in any area where the bench-type work station operation is employed. A typical HLF bench is shown in Figure 19. Many variations to this bench are available (including size variations). This facility utilizes the air in the area for the air supply and exhausts the air into the area at the open front of the bench.

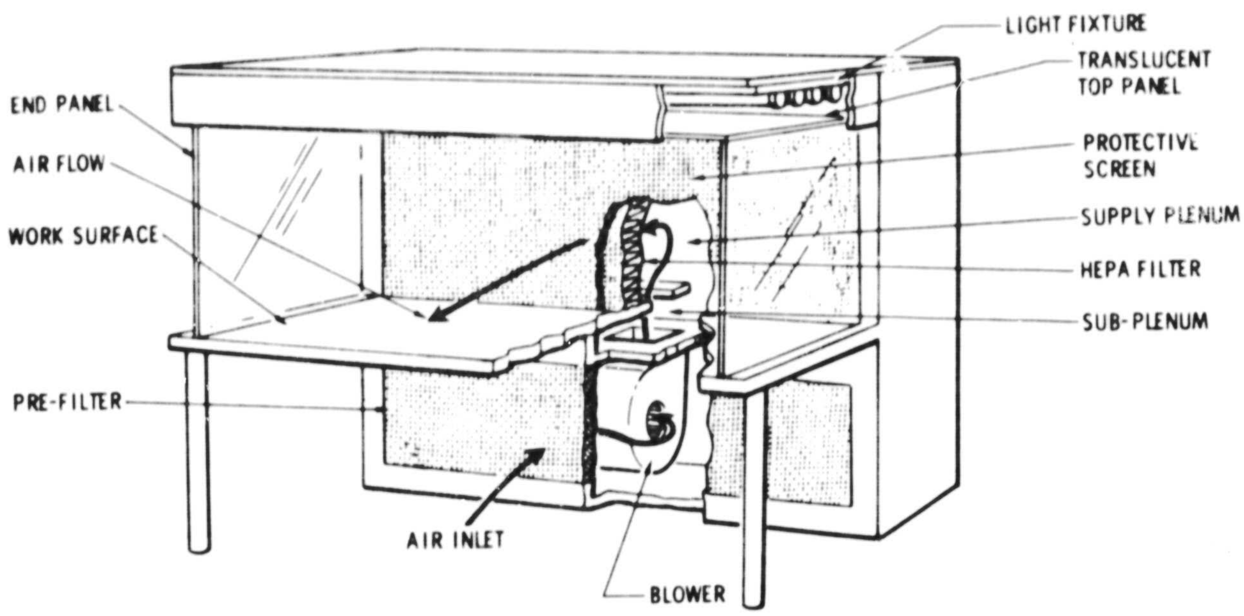

Figure 19. Horizontal flow clean bench

The HLF bench is capable of providing at least Class 100 conditions with a laminar airflow velocity of 90 ± 10 ft/min through the work area. All of the basic design requirements for laminar flow clean air apply to this facility. Some design features and construction details that have a major effect on the efficiency of operation are given below:

a. The air-supply plenums and blower must provide an equal distribution of air to the HEPA filter.

b. The HEPA filter must be leak-free both in the media and around the filter and support frames (see Figure 9 for some types of air leaks).

c. The inside surfaces of the top, end panels, and work surface must be flush with the effective edge of the filter. An offset of this type with the resulting air turbulences is shown in Figure 14. The juncture of these edges with the filter frame must be airtight.

d. The downstream airflow across the entire face of the HEPA filter must be uniform. Air turbulences created by support frames (as seen in Figure 11) or other similar blockage of the filter area must not be great enough to extend into critical areas of the work surface on the bench.

e. The size of equipment and material on the work bench must be proportionate with the size of the bench. The introduction of large objects into the face of the bench and over the work surface will create objectionable air turbulences and permit the infiltration of outside air upstream into the work area.

4.7 Vertical Laminar Airflow (VLF) Bench

The VLF bench provides the same type of work station operation as the HLF bench and is also available in a variety of models and sizes. A typical VLF bench is shown in Figure 20 with the major elements identified.

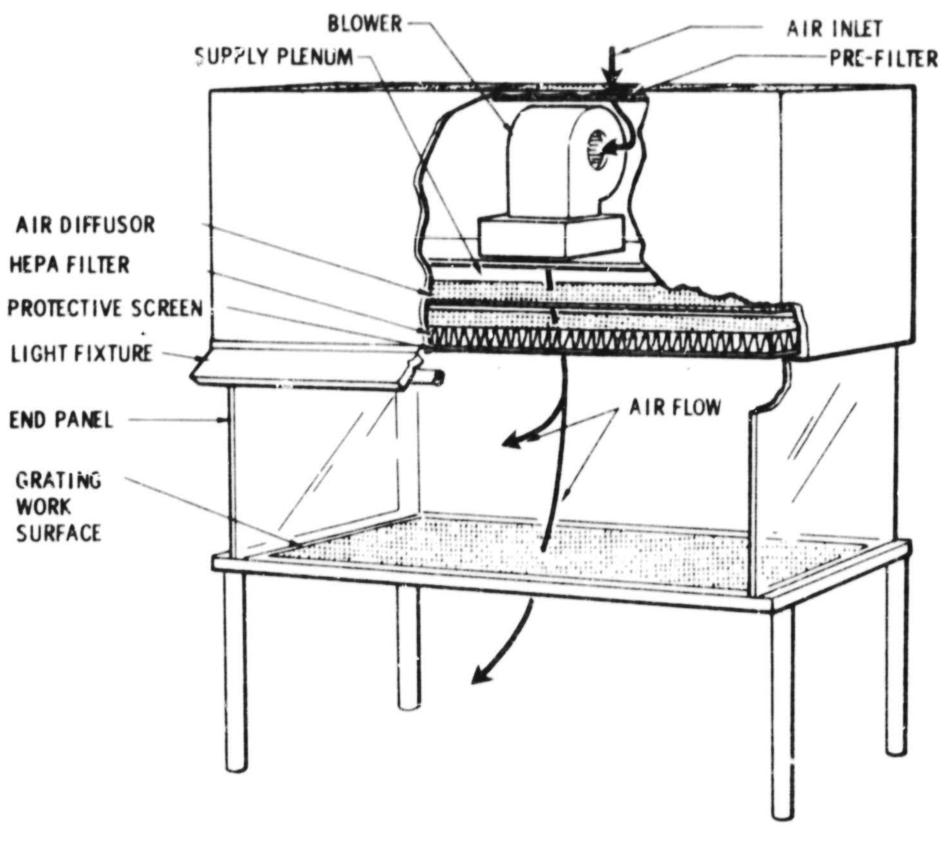

Figure 20. Vertical flow clean bench

The VLF bench is capable of providing Class 100 conditions or better with laminar airflow velocities ranging from 65 to 145 ft/min. Perforated metal work surfaces with openings for air passage ranging from 30 to 60 percent provide a more uniform flow of air through the work area. The operations performed on the bench determine the particular operational requirements f ' capabilities.

All o' the design features and construction details that applied to the HLF bench must also be considered for the VLF bench except as follows:

a. The surfaces joined to the effective edge of the HEPA filter are the back panel, the end panels, and a face panel that may extend part way down the otherwise open face.

b. Th majority of airflow should be vertical from the filter through the openings in the work surface with a minimum of air spilling out through the open face or front.

4.8 Balanced Vertical Flow Bench

This device provides an open access fume-controlled area and the particle cleanliness capabilities of the VLF bench. The balanced flow bench provides a space for safely working with toxic fumes and also functions to control unwanted odors.

The principle of operation of this device is the removal of air from the bench work area at the same rate as it enters the area. This is accomplished by adding to a standard VLF bench an exhaust plenum and blower system under the work surface and a sliding sash to permit adjustment of the opening in the face of the unit. A typical design is shown in Figure 21 with the major elements identified. The clean air flows into the work space through the HEPA filter, the sliding sash is adjusted to the minimum opening necessary for the operations, and the air-exhaust blower draws the air out through the work surface. The exhaust damper can be adjusted to where a balance exists in the work space with no air spilling out of the space through the opening in the face and no outside air entering the space through this opening.

The exact configuration of this type of device is governed by the specific operations and processes employed. Some possible variations include such items as a filter system for the exhausted air, recirculating the air to include air tempering and conditioning, provisions for tanks, sinks, and other equipment in the work surface, and many more.

The design requirements and construction features that applied to the VLF bench should also be considered for this type of device. In addition, the exhaust system must be reasonably compatible with the air-supply system to assure balance. Additional facilities for specific application must be considered accordingly to assure conformity to the laminar flow clean air concept.

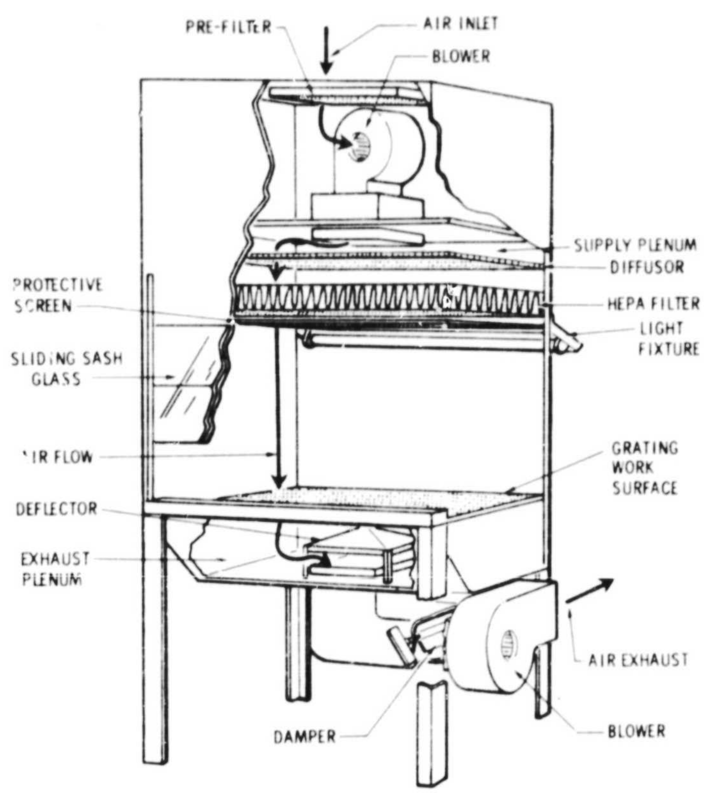

Figure 21. Balanced vertical flow bench (exhaust hood)

APPENDIX

GUIDELINES FOR THE PREPARATION OF CLEAN ROOM SPECIFICATIONS

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GUIDELINES FOR THE PREPARATION OF CLEAN ROOM SPECIFICATIONS

1. Introduction

A comprehensive and definitive specification is essential for the construction and acceptance of an effective and operable clean room. The many elements of design and construction that affect the performance and the air-cleanliness capabilities of a specific clean room installation must be considered and defined. The following paragraphs provide a listing and in some cases some explanation of items which are considered essential in a clean room specification.

The list is designed to provide some guidance and direction in the preparation of specifications for laminar airflow clean rooms for any type of installation. The list is not all-inclusive and must be supplemented as required for each specific situation. All the items are not necessarily essential to each specific situation and should be considered only as applicable. The items are grouped according to the major elements of clean room requirements.

2. General Specification Guidelines

a. Dimensions and Location -- A layout of the room and adjacent area should define the following features:

(1) inside dimensions of the room

(2) room connection points for service lines--water, gases, electricity, drains, vacuum, etc.

(3) maximum length, width, and height available within an existing structure

(4) location within an existing structure

(5) type of existing structure--supported or free-standing. or located outside any other building.

NOTE: The use of standard sized filters, filter modules, floor modules, and wall panels may result in lower costs, reduced lead time, and better quality construction.

b. Type of Room -- The type of room will reflect the air-cleanliness class needed and the operations to be performed. One of the following types will usually be specified:

(1) vertical airflow with full perforated floor exhaust

(2) vertical airflow with partial or perimeter floor exhaust

(3) vertical air downflow curtain units with perimenter exhaust

(4) limited vertical airflow with less than a full filter ceiling located above a perforated ceiling

(5) horizontal airflow with return duct location optional--above ceiling, below floor, or along side wall

(6) horizontal airflow tunnels with modular motor/blower/filter units and open-end exhaust.

c. Room Occupancy -- Specification planning should include an estimate of:

(1) the number of people normally occupying the room

(2) any abnormal amount of personnel movement in the room

(3) the amount of traffic in and out of the room.

d. Operations and Equipment -- Heat and contamination generating equipment as well as any unusual features should be noted. These may include:

(1) motors and other machinery

(2) ovens, vacuum chambers, sterilizers, etc.

(3) fume hoods, including the cfm of air exhausted.

e. Portability -- The specification should indicate whether the room is a permanent installation or whether it should be of modular construction and have the capability to be dismantled and relocated.

f. Electrical Power Load -- Specify the following:

(1) maximum power required for operations within the room

(2) voltage, phase, and current requirements - 110, 220, and 440 volts, single or three phase, and AC or DC.

3. Performance Requirements

The performance requirements of a room should be specified in sufficient detail to assure the level of performance desired. It is recommended that the following items be included in any laminar airflow clean room specification:

a. Air-Cleanliness Class -- The class number listed indicates the maximum number of particles 0.5 micron and larger per cubic foot of air (Fed. Std. 209a):

(1) Class 100

(2) Class 10,000

(3) Class 100,000

(4) other intermediate classes as needed.

b. Airflow -- While the airflow characteristics will be dictated generally by the type of room considered, the following parameters and their acceptable tolerances should be specified as applicable:

(1) velocity in feet per minute issuing from the filter bank

(2) air direction at specified points in the room

(3) air dispersion patterns in the unoccupied room.

c. Temperature -- Temperature requirements should include:

(1) temperature

(2) allowable tolerance

(3) specific location or zone in which readings will be taken

(4) expected heat dissipation from processing equipment.

d. Humidity -- Humidity requirements should specify:

(1) percent of relative humidity desired

(2) acceptable tolerance

(3) any conditions which would have an unusual effect on humidity control.

e. Lighting -- Lighting requirements may be specified as follows:

(1) fluorescent, incandescent, special

(2) minimum footcandles

(3) height and location(s) at which footcandle measurements will be made.

f. Noise and Vibration -- Stipulate maximum noise and vibration levels resulting from operation of the room itself (motors, blowers, air movement through ducts, etc.). These levels should not include noise or vibration produced by other equipment located in or outside the room.

4. Design and Construction Requirements

In order to achieve and maintain the performance requirements enumerated in the preceding paragraph, certain requirements concerning design, materials, and construction must be included in the specification. This paragraph lists some of these items which may be included in a clean room specification.

a. General Requirements --

(1) The room must be airtight without the use of caulking or extensive use of mastic compounds. Mastic gaskets are acceptable.

(2) The room structure must be rigid to preclude the generation of contaminants due to structural vibration or movement.

(3) All interior surfaces in the room, return air ducts, and plenums should be fabricated from nonshedding materials and should have smooth surfaces with a minimum of interruptions.

(4) Metal surfaces should be either finish grade stainless steel, anodized aluminum, or painted with one coat of chromate primer and two coats of hard-gloss enamel or epoxy.

(5) All wood or composition surfaces should be painted with one coat of primer and two coats of hard-gloss enamel or epoxy.

(6) All glass surfaces should be polished, laminated glass stock.

b. Walls --

(1) Permanent walls should be rigidly constructed with all exposed surfaces in the room properly treated.

(2) Modular metal walls should be so constructed that they may be disassembled for reuse without permanent damage.

(3) All walls should contain a vapor barrier.

(4) To the extent possible, all walls should be free of ledges, ridges, or other irregularities.

c. Ceiling - Vertical Laminar Airflow --

(1) The ceiling framework should be of rigid metal construction, and designed to have HEPA filters installed and removed from inside the clean room.

(2) The ceiling framework should be equipped with pressure-locking devices to adequately seal the filter frame to the support frame.

(3) The ceiling framework should be free from air leakage and should be sealed around its own perimeter to prevent leakage of air between it and the walls.

(4) The ceiling framework should provide for the passage of electrical lines for the light fixtures.

(5) The ceiling framework should be designed to provide for mounting sprinkler heads on the room side of the module and connecting water lines to the heads. Each sprinkler head connection should be sealed to prevent air leakage.

d. Ceiling - Horizontal Laminar Airflow -- The ceiling may be any approved material, rigidly installed and sealed. Installation of lighting fixtures and sprinkler heads must not create any air leaks.

e. Ceiling - Perforated -- A perforated ceiling can be used to effect uniform air distribution when less than a full HEPA filter ceiling is required. This ceiling should be located below the structure in which the filters are mounted and should preferably be nonvibrating metal or plastic grille construction. A structural framework will be required to provide rigidity for the installation of lights and sprinkler heads.

f. Floor - Perforated or Grating -- The floor should be sectional type construction designed to support the anticipated loading. It should provide:

(1) modular sections of a size and weight easily removed for cleaning, interchangeability, and access to the exhaust plenum

(2) adequate space below the flooring for prefilters and restrictive elements for balancing airflow

(3) for the use of modular sections with self-contained prefilters and air-balancing elements, when desired.

g. Floor - Solid -- Masonry or wood floors should be covered with an easily cleaned low-shedding material, installed to eliminate cracks or openings in which dirt might lodge. Wood or wooden-supported flooring should be deflection free.

h. Plenum - Air Supply -- The materials employed in the construction of the air-supply plenum should be nonshedding, free of obstructions and rough surfaces, and adequate in size to permit proper dispersion of the air. In a horizontal installation, it should permit entry for cleaning or changing prefilters, if they are located in the plenum. It must be airtight.

i. Plenum - Exhaust --

(1) If leakage or spillage of liquids in the clean room is anticipated, the plenum material should be stainless steel or a material compatible with the liquids used.

(2) Joints must be airtight, and access to the interior should be provided for cleaning.

(3) The exhaust plenum should be of sufficient depth to permit an essentially noiseless and uniform flow of air to the return air ducts.

j. Air Ducts --

(1) Whether fabricated ducts or wall sections are used as return air ducts, they must be airtight with smooth surfaces and joints. Ducts should be large enough to facilitate cleaning.

(2) Duct capacity should be adequate to carry the volume of air being handled at velocities less than that at which noise is generated.

(3) Bends in ducts should be gradual. All duct bends or turns should have a radius sufficiently large to prevent the generation of noise and heat.

k. Doors --

(1) All door edges, frames, and sills should be equipped with a continuous seal to prevent air leakage from the room due to the planned overpressure.

(2) Standard pressure door-closers, with an enclosed mechanism, should be mounted outside the room to assure that the doors will be closed.

5. Air-Handling Equipment Requirements

This includes that equipment which is built into the clean room as an integral part of the clean room operation, and includes but is not limited to air-blowers, electric motors, blower-motor coupling facilities, air conditioning and tempering equipment, and humidity control equipment.

a. All equipment should be of standard make and model with maintenance and replacement parts readily available from the manufacturer.

b. All equipment should be of adequate size and capacity to handle the volume of air for all specified operating conditions.

c. All rotating parts and equipment should be factory precision-balanced and equipped with vibration isolators or dampers as required.

d. Any portion of the equipment that is exposed to the air stream in ducts, plenums, or in the room should be of a material and finish that are nonshedding or minimum contributors of contaminants.

e. Rotating or moving parts which generate contaminants due to wear, abrasion, etc., should be isolated from the airstream by covers or other forms of enclosures where required to preclude releasing generated contaminants into the air-supply system.

6. Electrical Requirements

Electrical installations should comply, as a minimum requirement, with the applicable rules of the National Electrical Code and any local codes, and all wiring should be in accordance with best industrial practice. All electrical material and equipment must be manufactured in accordance with NEMA Standards and must be Underwriters Laboratory labeled, if applicable.

a. Distribution Points -- The buyer shall provide power for lighting and other needs, at a point to be stipulated in the final installation contract.

b. Wiring -- All controls, control panels, and air-conditioning units should be factory-wired. Connections from controls, control panels, air-conditioning units, blowers, motors, and any other electrical equipment are generally wired by the room manufacturer. Conductors shall be continuous from outlet to outlet, and no splices shall be made except within outlet or junction boxes. Slack should be left in all pull boxes and at equipment to allow for neat, workmanlike terminations. A wire-pulling lubricant should be used when pulling conductors.

c. Wire Types and Sizes --

(1) All wire sizes should be specified American wire gage.

(2) All wire should be pure copper of the stated gage, with 98-percent conductivity.

(3) All wire insulation and size should be determined for each application and shall comply with applicable electrical codes.

(4) When heat is a factor, insulation should be heat-resistant Type THW.

(5) All wires for final connections to high-temperature devices (i.e., heating coils) should be Type AVA.

d. Conduit Systems --

(1) Conduit should be installed for connecting lighting fixtures, receptacles, and switches and extended to junction boxes located outside the clean room and to the main supply system. Conduits should be concealed within walls and ceilings where feasible. Approved conduit locations should be shown on the installation drawings.

(2) Conduit should be galvanized and of appropriate size. Any conduit running inside the clean room should be painted with one coat of chromate primer and two coats of hard-gloss enamel or epoxy. Conduit which must be bent or formed should be painted after the forming is completed. All bends or offsets which cannot be avoided should be made with approved hickey or conduit-bending equipment. All conduit should be free of foreign matter and moisture when installed.

e. Lighting - Fluorescent --

(1) Light fixtures in vertical rooms should not be more than 6 inches wide.

(2) All fixtures should be equipped with thermally protected, automatic reset, Class A sound rated, high-power factor ballasts, UL and CBM approved, with an in-line fuse for each ballast.

(3) All fluorescent lampholders should be white phenolic compound, positive spring-action type. Interior wiring of all fixtures should be Type AF fixture wire of appropriate gage.

(4) Fixtures must be manufactured so that all parts will be continuously grounded. All fixtures and lamps shall be supplied and installed by the room manufacturer.

(5) Separate night-light switching and special lighting requirements should be specified where required.

f. Motor Controls --

(1) Magnetic motor starters should be installed in all cases where remote control is desired and "no voltage" or "undervoltage" protection is required. Two overload relays for installation of interchangeable overload relay heaters should be furnished with each starter.

(2) Combination starters with fused disconnect switches should be installed with fuse clips and fuses sized properly for the load. *

g. Electric Motors -- Electric motors should be of the continuous operation type, adequately sized, and precision-balanced at the factory (statically and dynamically).

*Protection Handbook of the Bussman Manufacturing Division, McGraw-Edison Company.

h. Switches -- Control switches for the blower motor should be mounted on the control panel located outside the clean room. An emergency turn-off switch shall be located in the clean room, near the entrance door. If acids or other fume-producing liquids are used in the clean room, an emergency turn-off switch shall be located adjacent to the position(s) where these liquids are used.

7. Air Filtration and Control System

The air filtration and control system concerns itself with cleaning and conditioning the clean room air and maintaining the conditions specified. It is related to but should not be confused with the air-handling system which includes the blowers, plenums, ducts, and baffles.

a. Rough or Ventilation Filters -- Primarily intended to remove contaminants of gross sizes, the material selected for rough filtration should be nonshedding, inexpensive, and easily changed or removed for cleaning or replacement. It is not advisable to select a loosely packed fibrous-type (home furnace-type) filter. A controlled open-pore structure urethane is recommended. This material is inexpensive, may be washed in a detergent, retains its resilience, and in the 20-cell type is reasonably efficient for gross contaminants.

b. Prefilters -- The purpose of prefilters is to sustain the life of the more expensive HEPA filters. The selection of the efficiency level for prefiltration, therefore, is directly related to the contaminant level of the air. The efficiency of prefilters used for a clean room is dependent on the amount of air recirculated and the contamination generated within the room. Filter efficiencies are directly related to cost and pressure drop, which will increase as the efficiency increases. Prefilters are available with efficiency ratings from 45 to 95 percent by the weight (synthetic dust) test method.

c. Final Filter - High Efficiency Particulate Filter (HEPA) -- Generally, the manufacturers of HEPA filters each have individual identification systems, but all make essentially the same type filters. When ordering HEPA filters, the purchase order should stipulate on the face of the order that the filters are for "Laminar Airflow Clean Room Installation." This will alert the manufacturer to the requirements for the production of a filter which is acceptable for the intended end use.

Each manufacturer publishes a specification for his own filters. If a specific manufacturer is selected, reference should be made to that manufacturer's printed specification by number.

The following basic information is provided to define 5-7/8 inch deep HEPA filters in a specification. Filters of other dimensions should be defined accordingly.

(1) Filters should be individually 100-percent tested and certified leak-free (Fed. Std. 209a) and must have an efficiency of not less than (99.97) (99.99) (99.999) when tested with 0.3-micron dioctylphthalate smoke. The clean filter pressure drop should be no greater than 1 inch WG (1.25-inch WG for 99.999) when operating at a nominally rated capacity of 150 cfm/ft^2 of filter area with a 5-7/8 inch deep filter. Average ratings are:

24 x 24 x 5-7/8 in. is rated at 600 cfm
24 x 30 x 5-7/8 in. is rated at 750 cfm
24 x 36 x 5-7/8 in. is rated at 900 cfm
24 x 48 x 5-7/8 in. is rated at 1200 cfm.

(2) Filters must be factory constructed by pleating a continuous sheet of 100-percent glass media into closely spaced pleats, with corrugated separators (Kraft paper) (aluminum) (plastic) inserted between each fold of the pleated media.

(3) The media/separator assembly should be installed in a rigid holding frame with overall frame dimensions held to ±1/16 inch, and squareness to within 1/8 inch. The rubber base sealer, providing a leak-free bond between the media and the frame, should be resilient and self-extinguishing.

(4) The material used for the separator and frame should be selected to meet the humidity and fire-resistant requirements of the specific installation. Kraft separators and a plywood frame will produce a flammable filter and will break down at more than 80% RH. Aluminum separators and exterior fire-resistant plywood frame will produce a reduced fire hazard and will increase the moisture resistance to 100% RH. Aluminum separators with aluminum or steel frames are fire-resistant and will withstand 100% RH.

d. Clean Room Filter Bank Pressure Gages -- There are three commonly used types of gages employed to provide filter bank pressure-drop measurement. A specification for each type of gage should include information as follows:

(1) Flex-Tube Manometer -- A manometer mounted in a convenient location on each filter bank should be complete with pressure fittings for duct and flexible double column plastic tubing. The pressure range scale should be from 0 to 3 inch WG static pressure.

(2) Inclined-Tube Air-Filter Gage -- An inclined-tube air-filter gage mounted on each filter bank should include 3-way vent valves, be of solid acrylic plastic construction with built-in level vial, should have an adjustable scale and should be furnished complete with aluminum tubing, static pressure tips, and mounting assembly. The gage should have a pressure-drop range of 0 to 3 inch WG static pressure.

(3) Magnehelic Pressure Gage -- A magnehelic differential pressure gage mounted on each filter bank should be of the diaphragm actuated, dial type with 3-7/8 inch diameter white dial with black figures, and graduations should have pointer-zero adjustment. It should be furnished complete with aluminum tubing, static pressure tips, and mounting assembly. The gage should have a pressure-drop range of 0 to 3 inch WG static pressure.

e. Air Conditioning -- Specifying requirements for air conditioning involve many variable factors such as mean local temperatures, humidities and elevation, and room size or demand. However, some points which should be considered are as follows:

(1) Air conditioning for the clean room may need to be completely independent of the regular plant system.

(2) If the clean room is to encompass operations which will require some equipment to be operated continuously, some provision should be made for auxiliary cooling in the event of any equipment failure.

(3) The selection of the unit capacity should include a safety factor, which would depend upon the climate zone.

8. Applicable Standards

Standards, specifications, and codes prepared by the following groups may be useful in preparing clean room specifications:

Air Conditioning and Refrigeration Institute - ARI

Air Moving and Conditioning Association - AMCA

American Society of Heating, Refrigeration and Air Conditioning Engineers - ASHRAE

American Society of Mechanical Engineers - ASME

American Society for Testing and Materials - ASTM

General Services Administration - GSA (Fed. Std. 209a)

National Electrical Manufacturers Association - NEMA

National Fire Protection Association - NFPA

Sheet Metal and Air Conditioning Contractors National Association, Inc. - SMACNA

Underwriters Laboratories, Inc. - UL

United States of America Standards Institute - USASI