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THE DESIGN AND OPERATION OF AN R&D CLEAN ROOM COMPLEX FOR GUIDANCE AND CONTROL SYSTEMS

by
Wilber H. Gibson

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by
Wilber H. Gibson

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Inertial Systems Branch
Army Inertial Guidance and Control Laboratory
Research and Development Directorate
U. S. Army Missile Command
Redstone Arsenal, Alabama 35809

ABSTRACT

Contamination control and air cleaning problems have become an area of increasing concern to research and development (R&D) activities. Over the past 15 to 20 years, R&D engineering laboratories were "clean" after a fashion while the production areas were (comparatively) truly clean rooms with rigid controls imposed. Engineering hardware is characteristically breadboard and/or prototype units built by engineers in the engineering R&D area. Oddly enough, although engineers quite often do not bother with the same stringent requirements imposed on production due to preoccupation or a highly expedited program, management is primarily to blame for poor R&D facilities. This is logically and glibly explained by managerial personnel as the result of lack of funds to provide the required building and equipment facilities. Fortunately, management is beginning to realize that the old saw "penny wise and dollar foolish" has a direct bearing on their product, and they are changing the time worn phrase to "R&D wise is millions of dollars saved."

There are many reasons for the requirements for a clean room. The particular clean room complex utilized as the subject of this report is the Army Inertial Guidance and Control Laboratory at the U. S. Army Missile Command, Redstone Arsenal, Alabama. This laboratory is actively engaged in the design and development of gyroscopes, accelerometers, platforms, and computers for aircraft and missile application. Although some R&D tasks are performed by contractors, a large majority of this work is performed inhouse. The laboratory activities can be broken down into four areas as follows:

1) Prototype manufacturing, fabrication, and evaluation of inhouse designed components.
2) Disassembly, reassembly, and evaluation of inhouse and contractor supplied components.
3) Calibration and design evaluation of "open" components and systems.
4) Evaluation of "sealed" components.

Thus, it is obvious that areas must be provided in which precision parts can be manufactured, assembly and disassembly can be performed, and calibration and evaluation activities can be facilitated.

At this point, one may wonder exactly why a clean room complex is needed in the guidance and control field. The types of components utilized for sensing accelerations and angular movements of the vehicle are precision instruments that are inherently dependent upon fluid flotation, evacuation, inert gas atmosphere, or clean air or gas flow. One micron particle in these instruments could mean failure, ergo, disaster-defeat!

FOREWORD

This report was first prepared as a paper for the American Association of Contamination Control Convention. Mr. Wilber H. Gibson presented the paper to the convention at Miami, Florida, in May 1965.

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Section I. INTRODUCTION

Since the Army Inertial Guidance and Control Laboratory is charged with the responsibility of maintaining a position of leadership with strong technological capabilities in the inertial guidance and control field, exploratory research and feasibility experimentation become necessary. Therefore, the clean room complex was designed to provide the necessary contamination control during the inspection, assembly, and evaluation of mechanical and electro-mechanical components, subsystems, and systems required for the support of future Army rocket and missile systems and aircraft systems in the areas of guidance, control, and navigation, respectively.

Operational requirements of inertial guidance and control systems establish the need for cleanliness. A variety of electronic, mechanical, hydraulic, and pneumatic devices must operate correctly within narrow ranges of performance and with extreme reliability. To operate according to such rigid specifications, the component, the subassembly, or the assembly is required to be free and clear of contaminants. Contamination interferes with the motion of components or devices, whether they are rolling or sliding, uniform or intermittent, or any combination. Contaminants also interfere with energy transmission when mechanical or fluid energy transmission is considered. This can affect the flow rate of fluids and the pressure capability of fluid systems.

There are many ways in which contamination can interfere with the required operation of devices. Minute changes can result from dimensional changes causing friction effects such as galling, seizing, or heating. Such devices as gyros and accelerometers cannot tolerate such phenomena caused by contamination. The device must be free of contaminants that produce these harmful effects. However, the amount and type of contamination that causes the problem can vary from device to device and from requirement to requirement. The type of contamination that is harmful also varies.

There are four major areas where contamination affects the operation of a precise device. These areas include manufacturing, assembly, storage, and operation. Thus, the clean room complex was designed and constructed (and is operated and maintained) in a manner that will permit positive environmental control of contamination, temperature, and humidity in the rooms within certain predetermined limits.

Section II. DESIGN FACTORS

Realizing the importance of the mission of the Army Inertial Guidance and Control Facility, the final design of the facility was formulated only after consideration of many factors. The design, control levels, layout, special features, equipment, operation, cost, etc., of typical facilities throughout the United States were considered and studied.

From these considerations and studies, it was determined that a particular clean room is not fully defined unless the environmental control within the room is related to a standard of some kind. There are currently two published standards that establish limits for the environmental control within rooms. These are Federal Standard 209 (dated 12 August 1963) and Air Force Technical Order T. O. 00-25-203 (dated 1 July 1963). However, with special emphasis on the layout, special features, equipment, operation, cost, etc., the clean rooms in the new facility were designed, as near as possible, according to an earlier revision (7 February 1962) of Air Force Technical Order T. O. 00-25-203 which was current at the time the facility was planned. The general classifications of clean rooms according to Federal Standard 209 are given as follows:

CLEAN ROOM CLASSIFICATIONS

FEDERAL STANDARD 209

Current Classification (1 July 1963 Revision)	Superseded Classification (7 February 1962 Revision)
Controlled Area	I
Standard Clean Room	II & III
Clean Work Station	IV

These standard classifications have certain requirements for the amount of particulate contamination in the air, the air temperature, the relative humidity, and the air pressure within the room. The intent was to provide a basis with which a particular user could work in arriving at a set of operating conditions.

Realizing that this would not be a production facility, the required degree of environmental control for this facility was established by the U. S. Army Missile Command by reviewing the engineering and

research operations that must be performed, and determining as closely as possible the minimum conditions under which these operations could be successfully accomplished. Thus, the U. S. Army Missile Command has, after careful consideration of all factors, equipped itself with one of the world's most advanced R&D facilities in the inertial guidance and control field.

Section III. CONTROL LEVELS

The requirements for keeping the rooms "clean" would seem extreme until it is realized that a particle of dust 1 micron in size (the average for a Class III clean room particle size) is 100 times less than the diameter of a human hair. The particle count, or number of particles 1 micron in size, in this Class III room must average 20,000 particles per square foot or less, whereas the average count in 1 square foot of city air is approximately 1,500,000 particles.

The major sources of contamination to a clean room are the air supply, the component being worked on, the tools used, and the personnel working in the room.

The air supply system, when properly maintained, has been designed to hold the contamination level within safe levels. The proper tools and equipment, combined with the architectural design of the room for ease of cleaning, also helps control the particle count to a safe level.

The control levels for the clean room complex make it one of the world's most precisely controlled clean room facilities from the standpoint of temperature, humidity, and contamination.

Section IV. DESCRIPTION OF THE CLEAN ROOM COMPLEX

1. Plant Layout

All of the clean rooms of the clean room complex are located on the first floor of the building. The floor plan is shown in Figure 1. The rooms are arranged so that access to the more critical areas is through controlled areas. None of the critical areas are located immediately adjacent to an uncontrolled area. This allows for progressive clean-up and makes it easier to maintain the more closely controlled environments.

Again referring to Figure 1, it can be seen that equipment access to the clean rooms is through the equipment preclean room. The personnel change room and the toilet room are located within a controlled area. Access from these rooms to any critical area is through two air locks and an air wash. Items removed from tool and fixture storage, which are to be used in the critical areas, are moved through the equipment preclean room, an air lock, and the air wash to point of use.

The two major sources of contamination (aside from the air supply itself) are materials and equipment, and personnel. The plant layout, as discussed above, has been designed to provide the best possible control of these contamination sources.

2. Architectural Features

A number of techniques and special features have been employed in the design and construction of the clean rooms to keep them from becoming dust producers, to isolate them from outside contamination, and to make them relatively easy to operate and maintain.

a. Materials

In general, materials have been selected which provide hard, smooth, durable surfaces. These offer scuff resistance, minimum dusting, and good cleaning characteristics. Wall and ceiling surfaces are of prefinished hardboard (unpainted). Factory-finished moldings and caulking compound are used in all joints. Floors are covered with sheet vinyl. Air-tight, hollow metal doors are used at the entrances to clean rooms and air locks. Door frames are gasketed to restrict air leakage. The rooms comprising the critical area are windowless to the outside or to contaminated areas (except for door

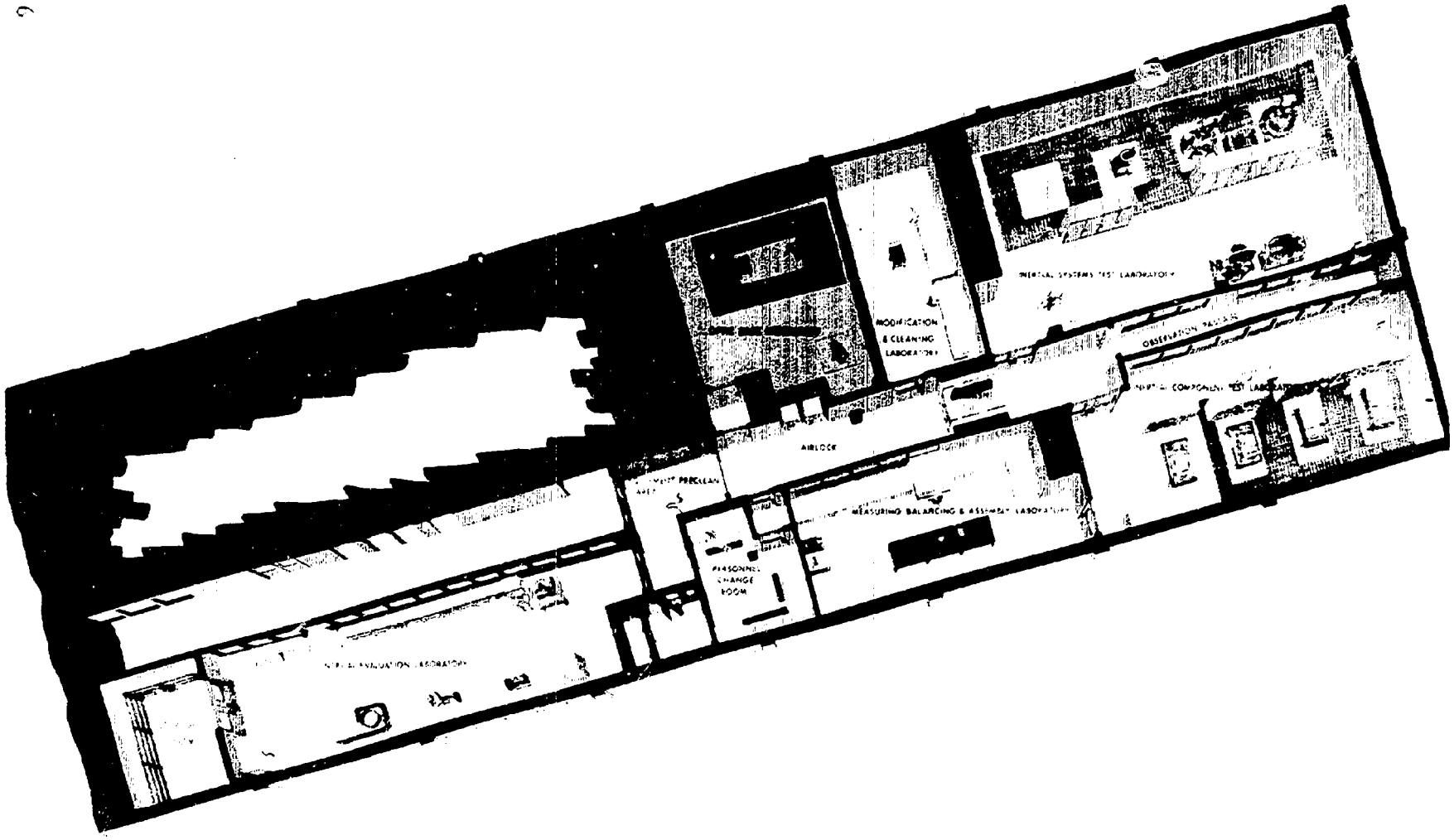

Figure 1. Clean Room Complex

windows and special sight window) for the same reason. The controlled area rooms have specially constructed windows to the outside.

b. Design Details

Volumes of rooms have been kept as small as reasonably possible by keeping the ceiling heights down (8 feet 2 inches). This reduces the volume of air which must be conditioned and results in reduced surface area. Almost all surfaces, and particularly irregular shapes, rough surfaces and horizontal surfaces, are dust catchers and, therefore, sources of dust. For this reason, pipes and utilities of various kinds are inclosed in separate utility chassis. Horizontal surfaces, ledges, and shelves are completely avoided where possible. Walls are kept as smooth and straight as possible and meet floors and adjoining walls with cove corners. The inertia pads, recessed in the floor, have been specially sealed with compressible material between pad and floor or removable plate sections.

3. Air Conditioning

The air conditioning system has been designed and constructed to filter the incoming air of particles smaller than those outlined in the room requirements, and provide temperature and humidity control and monitoring. The air conditioning system will also maintain the clean rooms at a higher pressure than the surrounding areas.

4. Special Utilities

To meet the designed requirements, special utilities and systems for the operation and maintenance of the clean rooms were included in the facility construction. They are mechanical and electrical utilities and communications and particle-sensing systems.

a. Central Control and Recording Console

A central control and recording console has been set up in the controlled area to continuously record room temperature (±1°F), humidity (±2%), and particle count. A Royco Instruments Incorporated monitoring system is utilized, and has a particle size capability of 0.3 to 0.4, 0.4 to 0.5, 0.5 to 0.6, 0.6 to 0.8, 0.8 to 1.0, 1.0 to 1.2, 1.2 to 1.5, 1.5 to 2.0, 2.0 to 3.0, 3.0 to 4.0, 4.0 to 5.0, 5.0 to 6.0, 6.0 to 8.0, 8.0 to 10.0, and 10.0 microns and larger. Twenty remote electronic sensors are programmed for sequential scanning with a monitoring period adjustable to 0.3, 1.0, 3.0, or 10 minutes at a rate

of 30,000 per minute. A digital printed record of particle size, count, size range, time of day, and sensor location is provided. An audible and visible warning is given whenever any preset level of particle count, temperature, or humidity is exceeded. Operational status of sensors is displayed.

b. Air Supported Isolation Platforms

The air supported isolation platforms (Figure 2) are required to isolate the components and systems being tested from the building and all outside disturbances. The air supplied to the support mechanisms is "clean" air. This is air which is produced by a carbon ring compressor and is filtered and dried. Even so, the exhaust air does not enter the rooms but moves through special ducts to the outside of the building.

c. Clean Air

Clean air is used for the operation of test equipment and for the operation of some inertial components. This air is also supplied by a carbon ring compressor but is filtered to the point of being considerably cleaner than the room air supply. This air is available at several points in the rooms through wall or floor units as shown in Figure 3.

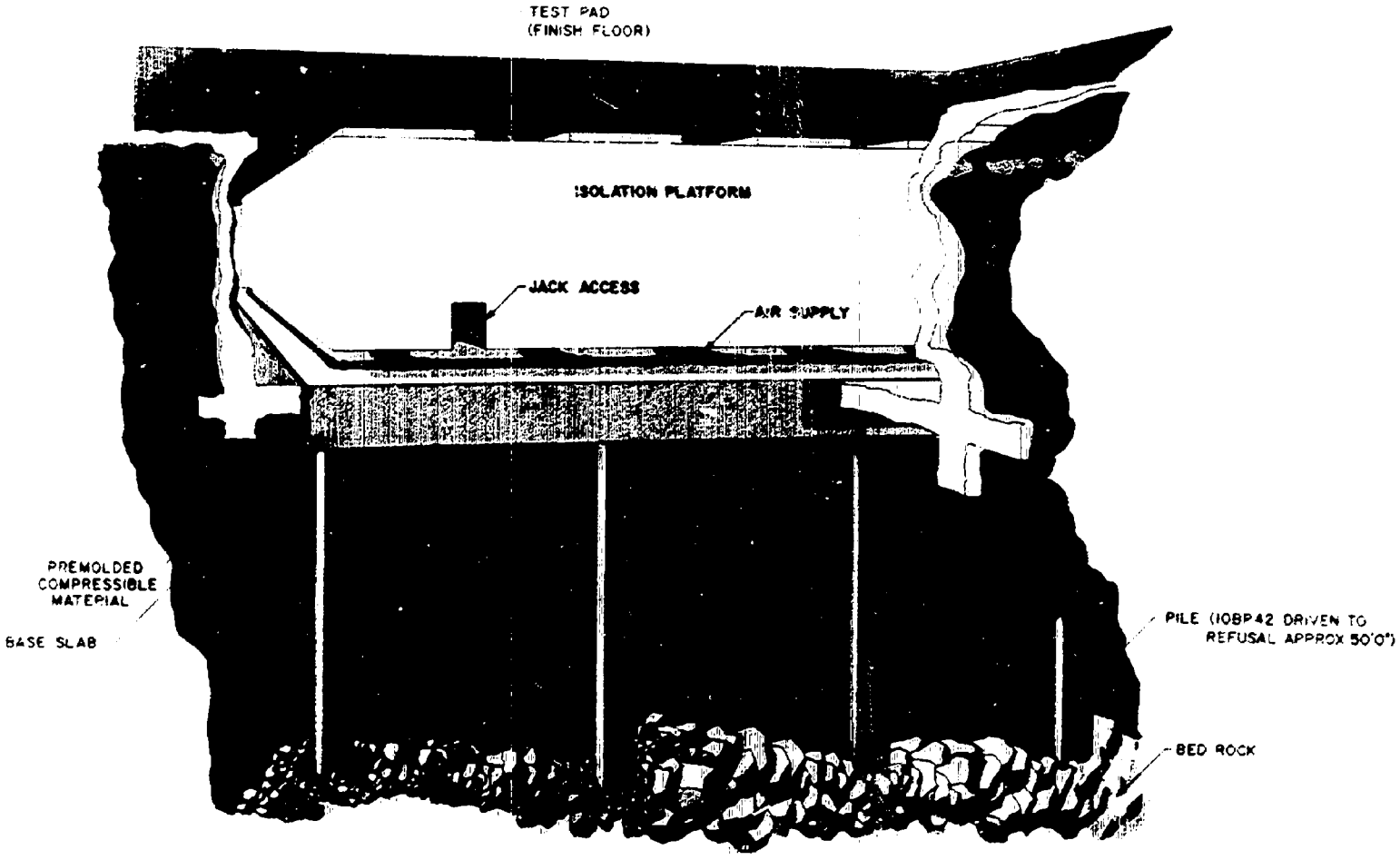

Figure 2. Air Supported Isolation Platform

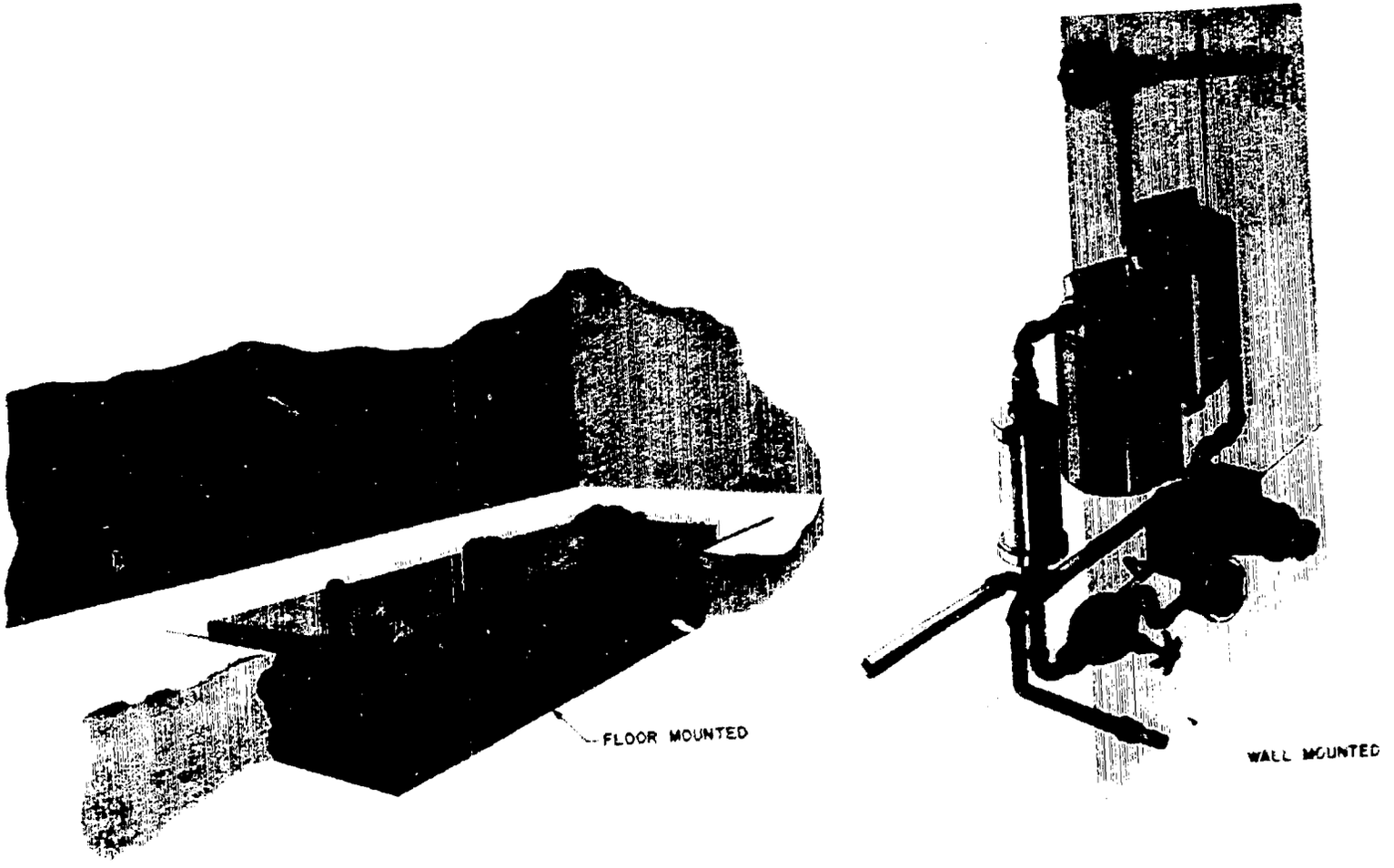

Figure 3. Clean Air Panels

Section V. OPERATION

1. Personnel Requirements

The personnel working in the clean rooms and their activity is the main cause of contamination and is the most difficult to control. Experiments show that when workers leave the room, the number of particles in the air decreases. Figure 4 shows the changes in contamination levels as personnel enter and leave the clean rooms. There is also a definite relationship between the amount of personnel activity in the clean room exhibit and the contamination level. The more active the workers, the greater the number of particles in the air. Ideally then, the number of clean room personnel and their activity should be reduced to the minimum. To accomplish this, the operations the clean room personnel perform have been analyzed with a view toward eliminating unnecessary functions.

To function properly in the clean rooms, personnel must develop an attitude of cleanliness and be prepared to meet the challenges of maintaining the room in a state of cleanliness. Since clean rooms are unlike any other working conditions, common habits, physiological problems, and allergies have been studied and eliminated where it was found to be detrimental to clean room standards.

To deal with the problems of selection; indoctrination, and control, clean room personnel are chosen by management, micro-biologists, and applied psychologists. Their studies involve consideration of both physical and human factors, including such items as manual dexterity, visual acuity, patience, concern for details, attitudes toward repetitious operations, skin conditions, and reaction to the rigid discipline that accompanies confinement in a controlled environment facility.

Therefore, clean room personnel attitudes are of paramount importance. Personnel must be prepared to meet the challenges of clean room work before they are allowed in the rooms. They must be instructed to consider everything but their immediate work areas as being contaminated and to recognize the common types of contamination.

2. Security

Access to the clean rooms is held to a minimum, because of contamination possibilities, as indicated above. Only those persons who have been authorized, properly trained in clean room procedure,

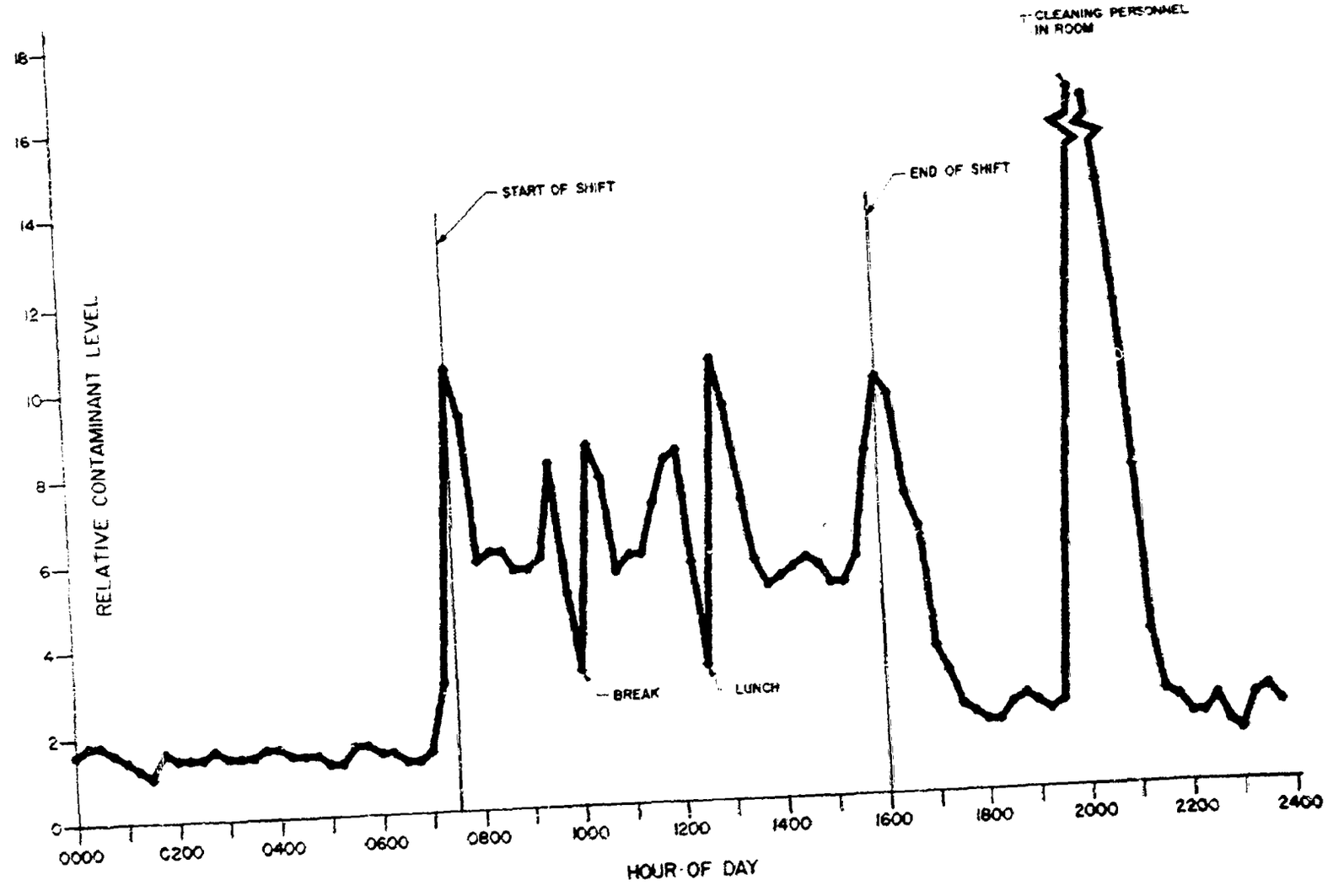

Figure 4. Typical Clean Room Contaminant Levels (T. O. 00-25-203)

and properly dressed to enter a clean room are permitted access. This includes top management, supervisors, and visitors as well as all clean room personnel.

Supervisor discipline determines the quality of a clean room product; therefore, supervisors should enforce good housekeeping practices.

3. Entry and Exit Procedures

Before entering a clean room, personnel are properly trained in clean room regulations governing cleanliness and proper clothing requirements.

Protective clothing is used at all times by individuals entering the Class II and III clean rooms. This clothing is worn only in the room and is never worn outside of the clean room complex.

Control begins before the employee even enters the clean room area. Items such as raincoats, overcoats, rubbers, and galoshes are stored in a room completely isolated from the clean rooms. Only after disposing of these does the employee enter the corridor that leads to the clean room entrance. At this point, the operator treads on a sticky mat, enters the equipment preclean room, again treading on a sticky mat as he enters the personnel change room and reaches his personal locker.

The employee may now approach his work station in any Class I area.

In making a routine entry from the general clean area (Class I) to the Class II or III clean areas, each person is required to put on the necessary clothes for the area about to be entered, and enter room. Here, the second shoe cleaner must be used in the manner prescribed above. Each person then passes over a sticky mat and enters the air wash. The air wash (Figure 5) has its own intake and outlet duct system with micronic filters and a blower capable of delivering 101 mph clean air at the ceiling inlet and a complete air change every 2.1 seconds. Figure 6 shows the air shower velocity versus personnel time in the shower. An interlock is provided on the double door system, on each end of the air wash, to start the fan cycle and unlock the doors to the Class II clean room side at the end of the cycle.

A timing device is provided to control the cleaning cycle and door interlock. The fan will start when the active leaf of the door on the west side of the air wash is closed. The fan will stop and the doors

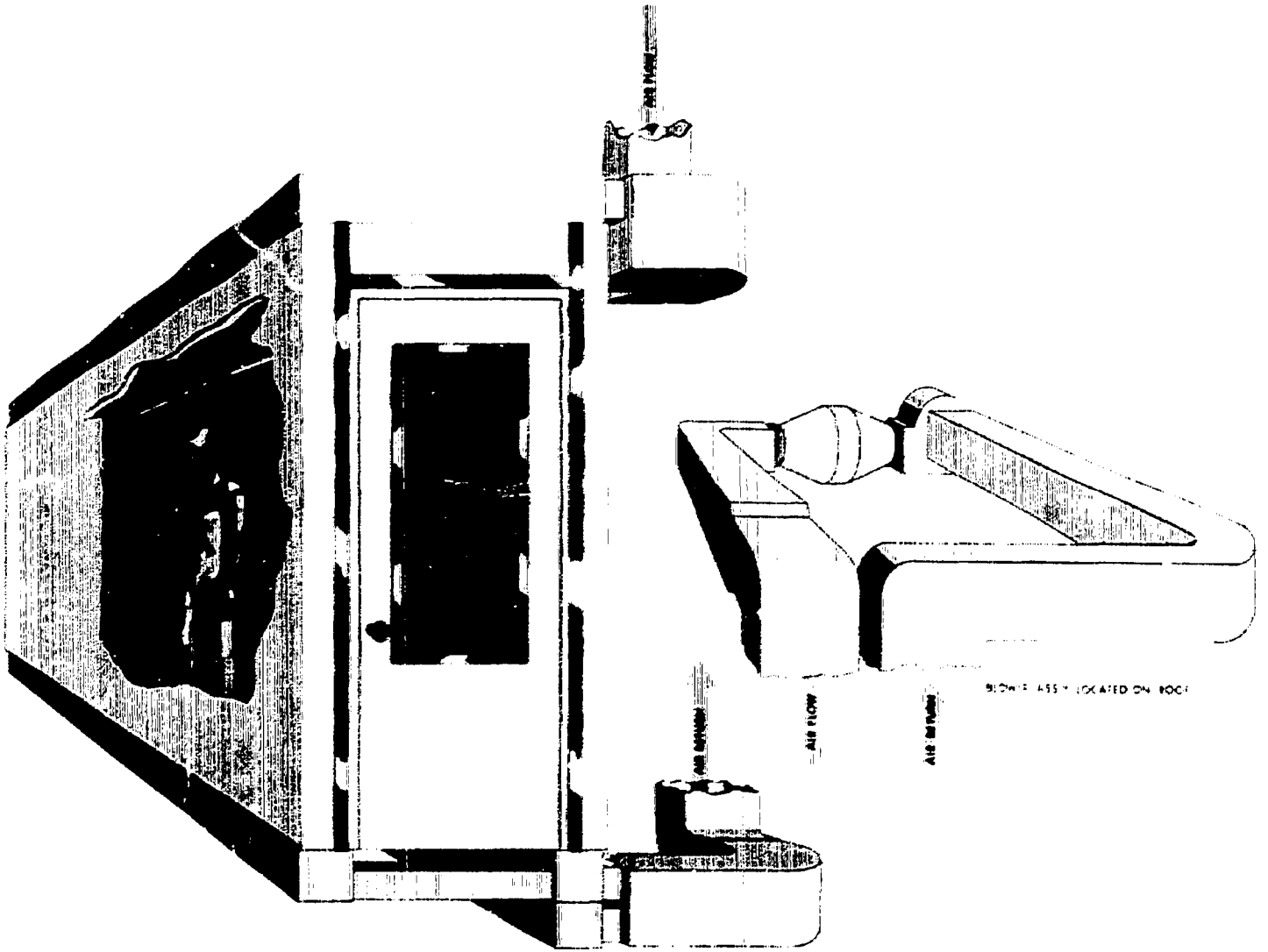

Figure 5. Air Wash

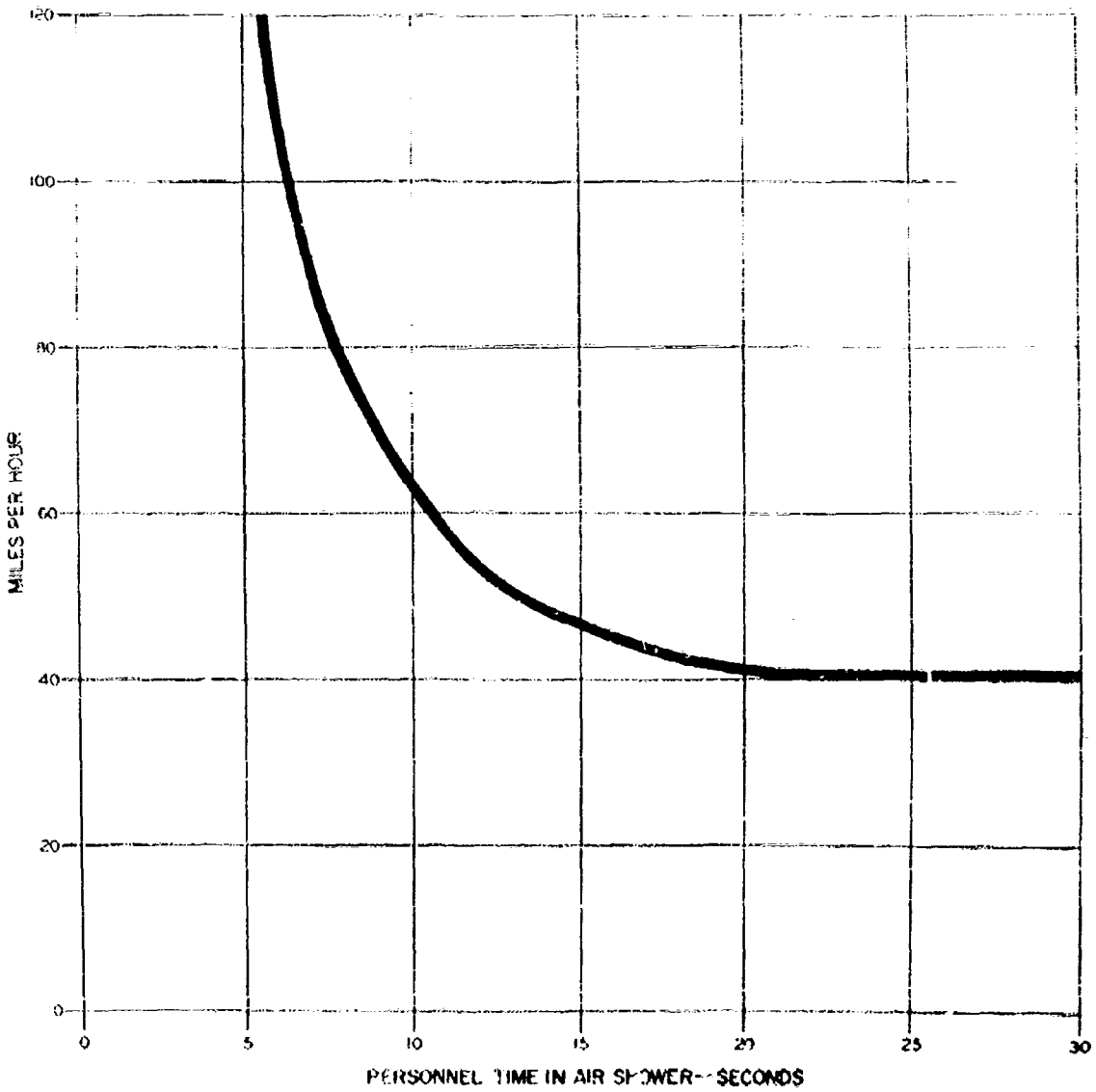

Figure 6. Free Stream Air Impact Velocity on Personnel (T. O. 00-25-203)

unlock at the end of the cleaning cycle. Override switches have been provided outside both doors of the air wash to de-energize the entire interlock system. The control system design also provides for automatic unlocking of the doors on power failure.

All air to the air wash is filtered by passing through a prefilter section and an after-filter section of the micronic type.

While in the air wash, each person must hold arms aloft and rotate the body 360 degrees for 20 to 30 seconds. They may now pass from the air wash to the vestibule and on to the Class II or III clean rooms, stepping again on sticky mats provided at the entrances of each room, and to their work sections.

While at their work station, the personnel follow specific rules and practices of housekeeping.

Upon leaving the Class II or III clean room, the employee removes his boots in the change room. He then removes his clean room clothes, replacing them on the racks provided. He may now pass into a contaminated area.

If reentry is necessary, even though immediately following exit, the entire procedure of individual cleaning must be repeated.

4. Equipment Entry and Exit Procedures

Prior to entry into the clean room, all parts, tools, equipment, and material are cleaned. The selection of cleaning methods is dependent on the type of contaminant, the materials of construction of the items to be cleaned, and the class of room the material must enter.

Large items of equipment being moved into the clean room are thoroughly vacuumed prior to entry. Rough cleaning is accomplished in an uncontrolled area; however, the final cleaning operation is accomplished in the equipment preclean room when operations in the room are "shutdown."

Small hand tools used in the Class II and III clean rooms are cleaned ultrasonically prior to entry and at scheduled intervals.

Since the work station is the area in which most of the clean rooms contamination will arise, area housekeeping is rigidly enforced. It is the one section which cannot tolerate contamination. The parts and assemblies for which the rooms were designed consist of permanent test equipment and portable hand tools.

Section VI. MAINTENANCE AND CONTROL PROCEDURES

1. General

Once a room has reached a sufficient degree of decontamination to be called a "clean room," constant monitoring and cleaning will be require to maintain this state. Aside from the automatic particle count, particle counts are taken with the filter dust collector twice a day in different parts of the room as contamination levels will vary throughout the room, depending on "hot spots" of contamination generation and air flow.

Constant cleaning of work stations by operational personnel is performed aside from the periodic maintenance by cleaning personnel. Testing of filters is performed at initial start-up and at every filter change thereafter. Also, air flow velocity at the grill is confirmed to be in accordance with the design requirements at two-week intervals. Frequency of wet mopping and wall, ceiling, and lighting fixture cleaning is outlined in this section. This function is performed by the cleaning and maintenance personnel.

2. Class III Clean Work Stations

The Class III clean work stations are benches having an air filtering and blower unit independent of the room filtering system. These benches, incorporating a laminar air flow design, are the most critical of the work stations and, therefore, require the most stringent cleaning and monitoring. Figure 7 is a cutaway view of one of these work stations.

a. Checking Filters

Two tests are necessary to ascertain that the work station is operating correctly and providing a clean atmosphere. These tests are made on all new work stations or when any of the final filters are changed. These tests are the leak test and the air flow test.

(1) Leak Test. The leak test is made to determine that the final filters are properly sealed and not leaking contaminated air.

The leak test is performed by introducing smoke from a smoke generator into the inlet ducts of the station and then checking for the presence of any smoke inside the station. (Since the test must be accomplished in a clean room, it is done when the room is not operational and with adequate time allowed prior to room use for purging of the smoke.)

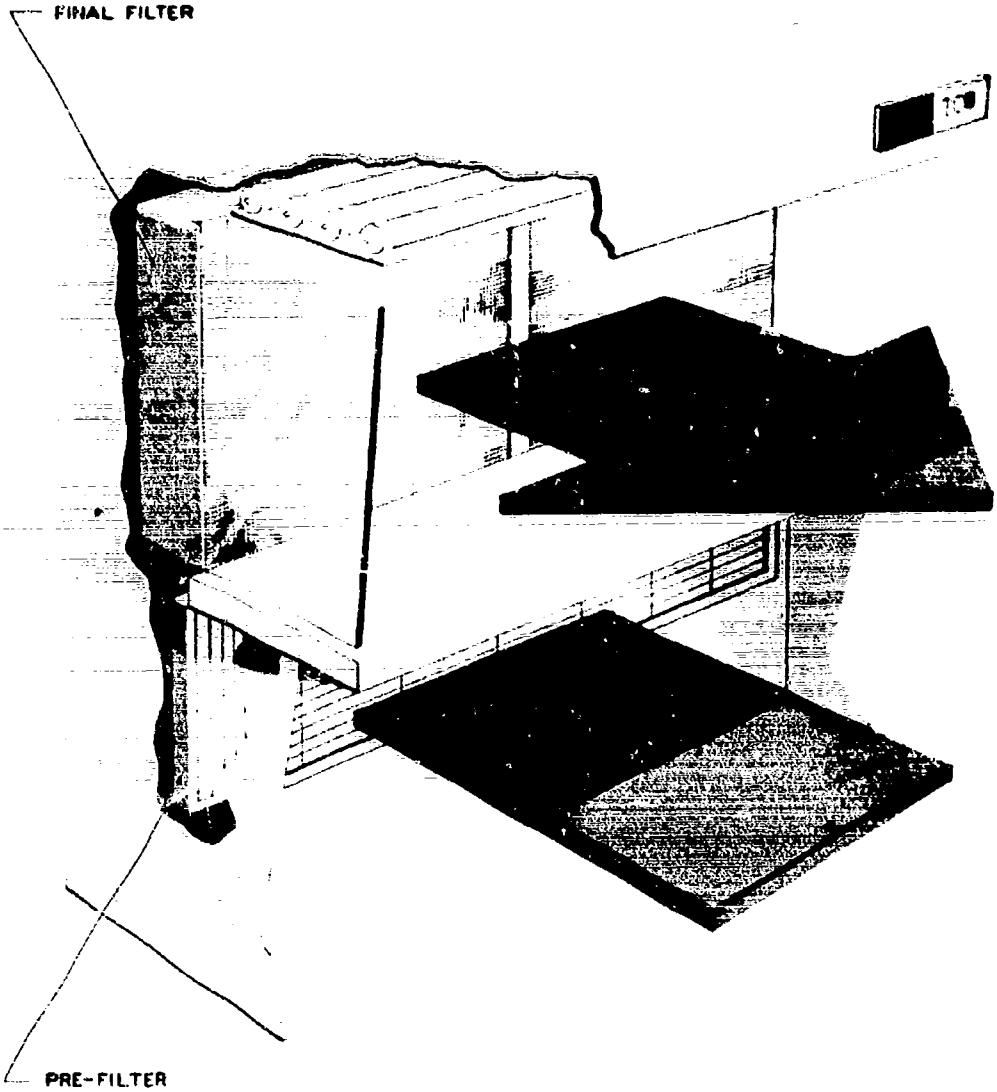

Figure 7. Laminar Air Flow Work Station

A smoke generator is needed to produce a continuous supply of smoke. A cigarette smoke generator consisting of a rubber squeeze bulb and cigarette will suffice. In addition, an aerosol smoke photometer is needed which is capable of detecting small concentrations of smoke.

With air supply to station operating, smoke is introduced into inlet duct nearest the filter to be tested. The filter is carefully checked for the presence of smoke around the edges and across the entire filter surface. If no leaks are detected, the test is repeated for each filter. If a leak is detected, a closer inspection is necessary to determine if

leak is coming around the filter (indicating a poor seal) or if leak is in the filter itself (indicating a ruptured filter). The filter is replaced or the pressure is tightened on seal as necessary.

(2) Air Flow Test. The air flow test is made to determine that the proper air flow velocity is being maintained across the front opening of the bench section. Air flow velocity across the front opening of the bench section is measured for uniformity from side to side and from top to bottom. An air flow velocity meter is needed which is capable of measuring the expected air flow (100 ± 25 fpm). With the air supply to the work station operating, the air flow velocity across the face of the filter is measured at a distance from the filter equal to the distance of the work piece from the filter. The air flow is measured continuously, starting at one corner and moving the velometer slowly across the filter and then back across at another level, etc., until the entire filter has been covered in one smooth continuous path. The velocity is noted as the meter moves across the filter. If air flow is too low (below 75 fpm) or extremely uneven (25 fpm variation), blowers and/or filters are checked to determine the cause of the trouble. Extremely high localized readings indicate leaks.

b. Handling of Work Inside and Outside the Work Station

Although the atmosphere inside the work station meets Class III specifications, the air around the work station will not meet these requirements. Care is taken to prevent this contamination from reaching critical work parts. Even more important is the prevention of contamination of the part by direct transfer of contamination from the worker's hands or tools used to handle the part.

Proper personnel operating techniques are followed to control transfer contamination which is carried into the bench on hands, tools, fixtures, etc., and is deposited on working surfaces. Of prime importance is the education of the worker on the possible sources of contamination and the techniques for its control.

The air supply to the work station is turned on at least 10 minutes before any work is performed within the work station. The protective screen provided in front of the filters is cleaned to remove any captured particles before work begins. A vacuum device with a plastic intake nozzle is used for this cleaning. All sensitive material is removed from the station or properly covered during this operation. After the screen has been cleaned and the air supply has been operated for at least 10 minutes, the work surface is wiped thoroughly with a clean work station cloth or synthetic sponge dampened with filtered

(0.5 micron) isopropyl alcohol. A clean work station cloth possesses limited linting properties. The work surface is wiped as stated at least once per shift. More frequent wiping is required if much material is carried in and out of the station.

All material (work pieces, tools, containers, jigs, etc) are free of particulate matter before being placed inside the station. The bench section is kept as free as possible of any material not being used immediately. Any material that must be kept inside the station is stored along the sides of the work station. Nothing is placed along the back edge of the work station nor between the work piece and the filters. Positioning of objects between the filter and work piece will disturb the air flow pattern and may contribute particulate matter to the air flow.

Papers, paper products, and lead pencils are not allowed inside a clean work station. Nothing is placed or stored on the top or canopy of a clean work station. When such objects are removed, particles large enough to penetrate the air stream can be brushed off the top of the cabinet or the bottom of these objects.

3. Class II Clean Room

Wet washing of floors, walls, and ceilings by cleaning personnel is performed at least once a day, after the work shift, and more often, if necessary, as determined by the particle count tests. Only damp mopping is used in inertia pads.

All cleaning personnel will follow the required entry procedure. All cleaning equipment is precleaned prior to entry and is stored in the closet when not in use. Cleaning equipment is never removed from the clean room area, except for disposal or repair. Such equipment is replaced at the first signs of deterioration.

Daily cleaning consists of the following:

1) Benches - damp cleaned with sponge.
2) Utility fixtures - damp cleaned with sponge. Crevices and cracks are vacuum cleaned where damp sponge is ineffective.
3) Sticky mats - when the top lamination of the sticky mats becomes soiled, it is peeled off, leaving a new surface exposed. This soiled lamination is rolled as it is removed with soiled surface turned inward. A piece of plastic from the cleaning area is used to dispose of the lamination.

4) Floors - mopped with neutral detergent and water.
5) Walls, doors, and covers - spot cleaned with damp sponge.
6) Interior glass (this does not include optical glass) - spray cleaned and dried with lint-free wiping cloths. (Note: These cloths are not shaken out in the clean room but are placed in a plastic bag for disposal after use.)
7) Vacuum outlets - damp cleaned with sponge. Weekly cleaning consists of the following:

   a) Walls, ceilings, and outsides of lighting fixture glasses are thoroughly washed with liquid detergent and water, and vacuum dried. This task is performed when operating personnel are not in the room.
   b) Inside lighting fixtures, above glass, will be cleaned with a damp sponge when lamps are replaced.

4. Class I Clean Room

Wet washing of floors, walls, and ceilings by cleaning personnel is performed at least once a day, after the work shift, and more often if necessary, as determined by the particle count tests. Only damp mopping is used in inertia pads.

All cleaning personnel follow the required entry procedure. All cleaning equipment is precleaned prior to entry and is stored in the closet when not in use. Cleaning equipment is never removed from the clean room area, except for disposal or repair. Such equipment is replaced at the first signs of deterioration.

Daily cleaning consists of the following:

1) Benches - damp cleaned with sponge.
2) Utility fixtures - damp cleaned with sponge. Crevices and cracks are vacuum cleaned where damp sponge is ineffective.
3) Sticky mats - when the top lamination of the sticky mats becomes soiled, it is peeled off, leaving a new surface exposed. This soiled lamination is rolled as it is removed with soiled surface turned inward. A piece of plastic from the cleaning area is used to dispose of the lamination.
4) Dressing room lockers and benches - damp cleaned outside with detergent and water; inside lockers are vacuum cleaned.
5) Shoe cleaner - exterior is damp cleaned and unit is removed and blown out with compressed air or gas as required. (Procedure for reentry same as equipment.)

6) Floors - mopped with neutral detergent and water. This includes all areas, vestibules, air showers, air locks, dressing rooms, wash rooms, etc.
7) Wash room - all porcelain, valves, and fixtures are damp cleaned.
8) Walls, doors, and covers - spot cleaned with damp sponge.
9) Interior glass - spray cleaned and dried with lint-free wiping cloths. (Note: These cloths are not shaken out in the clean room but are placed in a plastic bag for disposal after use.)
10) Vacuum outlets - damp cleaned with sponge. Weekly cleaning consists of the following:

    a) Walls, ceilings, and outsides of lighting fixture glasses are thoroughly washed with liquid detergent and water, and vacuum dried. This task is performed when operating personnel are not in the room.
    b) Inside lighting fixtures, above glass, will be cleaned with a damp sponge when lamps are replaced.

11) Corridor walls leading to the clean rooms will be vacuumed every week.

5. Periodic Maintenance

Aside from the maintenance and cleaning of clean rooms as described above, periodic maintenance of the room air conditioning system and electrical and mechanical utilities is required. Although much of this maintenance is performed by the building department rather than the clean room personnel, the clean room supervisors must coordinate shutdown time of the support equipment with the clean room requirements. They are also familiar with the maintenance operations required in case of emergency.

6. Special Tests for Contamination

Rooms are monitored continuously by the built-in airborne-particle monitoring system and the results recorded at the data center. The data center, located outside the clean rooms, gives an audible and visible alarm, if the particle count exceeds the preset limit. Receptacles are located throughout the clean rooms for different sensor positions. The light-tight sensor is used in the optical dark room. The monitoring system is desirable because it does not require constant observation and, therefore, frees a worker for other duties and at the same time gives a continuous monitoring that insures against an unforeseen incident.

However, it is not the most accurate count system; therefore, other tests are necessary to maintain the particle count at a safe level.

The filter dust collector and microscopic analysis system requires a high degree of skill in microscopy and the techniques of particle sizing and counting.

After thoroughly cleaning all the equipment to be used for this test, a clean filter, which has been examined for background count, is placed in the dust collector unit and the sample is taken. This is done in four to six different parts of the room, each sample being taken with a new filter, and with the filter holder held horizontal. The used filters are placed in a covered petri dish and handled only with clean forceps.

The petri dish, with the cover removed, is placed under the microscope, and the necessary eyepiece and light adjustments for a 100x magnification are made. This allows a counting of particles 5 microns and larger.

Analysis of particles in the 0.5 and 5.0 micron size range is achieved by employing transmitted light techniques, after rendering the white filter transparent. A magnification of at least 500x is required.

These tests are made twice a day, after the work shift has started and later in the shift, when the particle count should be low.

Because of their fragile construction, highly efficient micronic filters are susceptible to damage during manufacturing, shipping, and subsequent handling by the user. The frequency with which filters are received in damaged condition has made it desirable to inspect each filter, prior to use, with a DOP filter tester.

This unit consists of an air-operated Dioctyl Phthalate generator and a Sinclair Phoenix forward light-scattering photometer. The generator produces a poly-dispersed aerosol with an average particle diameter of 0.8 to 1.0 micron. The generator and photometer are mounted together on a cart.

The filter is placed in the test stand and the DOP from the generator is introduced in the upstream air flow.

Filter damage is detected by drawing a sample of the downstream air through the light-scattering photometer. No attempt is made to express results in percentage penetration. The filter is either "good" or "bad."

7. Special Equipment

a. General

The type of equipment and tools used in the clean room is of primary importance in maintaining a dust free atmosphere. The following are the governing factors in the choice of equipment:

1) Ease of cleaning.
2) Simplicity.
3) Minimum wear to moving parts.
4) Nonchipping or splittering parts.

Four types of equipment were required in the clean rooms as follows:

1) Equipment for testing the air for particle count.
2) Equipment for maintaining and cleaning the room itself.
3) The equipment necessary to perform the function for which the room was designed.
4) Personnel clean room clothing and cleaning equipment.

b. Testing

The following equipment is used for particle count:

1) An airborne-particle monitoring system is installed in the Class II and III clean rooms. This consists of a data center, two remote particle sensors, and one light-tight remote particle sensor.
2) Hand particle collector.
3) The following clean room monitoring equipment helps to maintain a dust free atmosphere:

    a) Filter dust collector unit.
    b) Particle analysis equipment.
    c) Binocular microscope with ocular-objective combination to obtain 40/45x and 90/150x magnifications.

d) Microscope equipment, (slides, petri dishes, lamp, etc.).
e) DOP tester (an air operated DOP generator and a light-scattering photometer for filter testing).

8. Maintenance and Cleaning Equipment

The building vacuum system provides outlets in the clean room. Also provided are plastic vacuum hose with plug-in adapters and cleaning fixtures with storage cabinets.

The following is a list of additional cleaning equipment:

1) Nylon mops with aluminum handles.
2) Cellulose sponges, phototype (this sponge will shed large particles as it begins to deteriorate and will be discarded at first signs of wear).
3) High-grade plastic buckets which are not subject to flaking, 10-quart capacity.
4) Six-foot anodized aluminun step ladders with rubber base pads for legs.
5) Low-residue-producing detergent.
6) Deionized or distilled water (less than 100,000 particles per cubic foot, greater than 0.5 micron).
7) Ultrasonic tool and equipment cleaner.

Section VII. COST

The clean room complex includes an area of 4840 square feet. The basic building cost was derived by estimating the concrete shell, the masonry interior walls, exterior partition with gypboard, the gypboard covered ceiling, all windows, and all painting. This cost was then marked up and divided by the total square footage involved. Cost per room was obtained by multiplying the room square footage by the unit cost.

The air conditioning system cost was derived by estimating the cost of air handling unit AH-103 and associated equipment less the diffusers and ducting to the clean room. This system serves the clean room exclusively. The total cost is then appropriated to each room according to the design air flow for the room.

The lighting system cost was derived by estimating the cost of the conduit and wire system serving the entire clean room area and the cost of the panelboard in the area. This cost is divided by the total number of fixtures and the unit cost applied to each outlet.

The cost of each utility outlet includes a unit cost to cover conduit and wire to the local point of origin of the service.

The cost of isolation pads is derived by estimating the actual cost of construction. The cost of the Barry spring system is the actual purchase order price to the general contractor marked up and apportioned to each pad in proportion to the springs involved.

The mechanical and electrical special outlets included in the equipment section are from the actual subcontractor's prices. The cost for each item includes the apportioned labor and material to connect the outlet to the service, based on dividing the total service cost by the total outlets for each service.

The cost of the rooms in this complex has averaged about $40.00 per square foot without test equipment. Since each industry uses different types of equipment, this cost is not added.

Section VIII. HOW DOES IT WORK?

Anyone can design and build the finest clean room complex in the world. Does this mean that once the operation is started that it is still the finest clean room complex in the world? Certainly not! The point that is so obvious to all of us is that the rules of operation and the training of the personnel must be carried out to the fullest extent possible. How does it work? How can it be made to work? The answer to these questions is simple, but it is also the hardest part of any program of this type. Management must be trained! Did you ever try to tell the president of the company that he "must not do that"--- or "you can't come in here unless you dress properly?" The most important training is that given to the workers utilizing the clean room complex. If generals, admirals, (and even the President of the United States), are all willing to follow the simple rules established for visitors, then industry managers should be made to help enforce these rules by understanding them. The key to success is then embodied in one word that applies to all --- TRAINING!