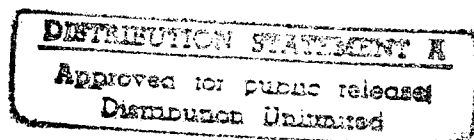


12/8/67

NASA SP-5045

CONTAMINATION CONTROL PRINCIPLES



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

DTIC QUALITY INSPECTED 1

DEPARTMENT OF DEFENSE
PLASTICS TECHNICAL EVALUATION CENTER
PICATINNY ARSENAL, DOVER, N. J.

19960506 033

DTIC

10934

CONTAMINATION CONTROL PRINCIPLES

Prepared by the Sandia Corporation, a prime
contractor to the U.S. Atomic Energy Com-
mission, under NASA Contract No. W-12324



Technology Utilization Division
OFFICE OF TECHNOLOGY UTILIZATION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
1967
Washington, D.C.

NOTICE • This document was prepared under the sponsorship of the National Aeronautics and Space Administration. Neither the United States Government nor any person acting on behalf of the United States Government assumes any liability resulting from the use of the information contained in this document, or warrants that such use will be free from privately owned rights.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 • Price 40 cents
Library of Congress Catalog Number 67-61860

Foreword

The work of the National Aeronautics and Space Administration has both demonstrated the difficulties and accelerated progress in controlling contamination. The experience gained, and the concepts and data generated, can be helpful in pharmaceutical, electronic, and other modern industries as well as in aerospace ventures. This publication was sponsored by the Office of Technology Utilization to help all such potential beneficiaries from the space age technology that it describes. It presents a basic model and the fundamental principles of controlling contamination in an industrial plant.

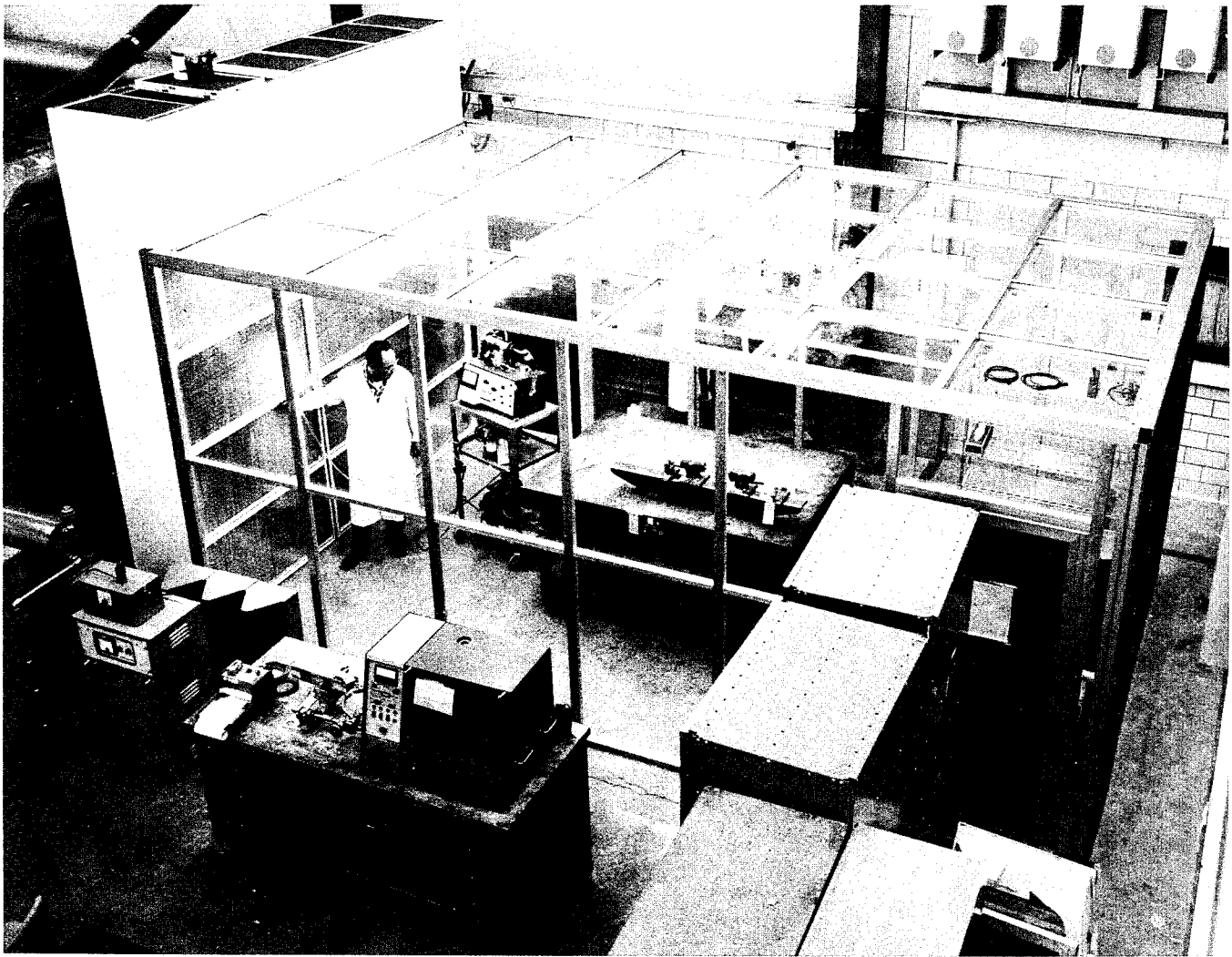
H. D. Sivinski, W. J. Whitfield, J. A. Paulhamus and their colleagues at the Sandia Corporation, a prime contractor to the U.S. Atomic Energy Commission, prepared this monograph to meet a widespread need for guideline information. Attention was called to this need by a NASA Contamination Control Panel, on which Dr. John Gayle represented the John F. Kennedy Space Center, Fred Beyerle represented the George C. Marshall Space Flight Center, and Quintin T. Ussery represented the Manned Spacecraft Center.

GEORGE J. HOWICK

*Director, Technology Utilization Division,
National Aeronautics and Space Administration.*

Contents

	Page
Chapter 1. Scope and Objective.....	1
Chapter 2. A Model for Contamination Control.....	3
Chapter 3. Considerations for Contamination Control.....	7
Chapter 4. Contamination Control Principles in Product Design.....	11
Chapter 5. Clean Rooms, Clean Work Stations, and Other Work Enclosures.....	15
Chapter 6. Cleaning of Product Surfaces.....	23
Chapter 7. Liquids, Gases, and Solids.....	31
Chapter 8. Radiation.....	35
Chapter 9. Microbial Contamination.....	37
Chapter 10. Monitoring for Contaminants.....	41
Chapter 11. Packaging, Transport, and Storage.....	47
Chapter 12. Personnel Control and Management.....	51
Glossary.....	53



A laminar air flow clean room (cross flow).

CHAPTER 1

Scope and Objective

Developed from a basic contamination control model, this document is designed to provide the reader with a broad overview of the subject. Its format and contents relate significant facets of control to the governing factors in the range of technological activities. It contains guidelines, design and planning considerations, and basic definitions.

It was written to help persons having responsibilities for:

1. Approval of funding for contamination control facilities;
2. Determination of the type of facility best suited for specific needs;
3. Selection of techniques to attain the best results;
4. Operation of contamination control installations; and
5. Selection and training of personnel.

This is not a handbook or process guide, although it will raise questions which may well help the reader obtain such information. The control of contamination involves all phases of product development, beginning with design determination and continuing through the proposed end use of the product.

Although the control of temperatures and humidity is not an actual contamination control function, it may exert influences which would affect the type of control needed. For

example, at an abnormally high humidity level, resulting condensation, oxidation, or even rust could occur and endanger the required contamination level. Therefore, the facilities and techniques employed in the control of contamination must be compatible with the temperature and humidity limits.

The authors have attempted to treat those elements sequentially which require attention and determination to the end that the control of contamination will be adequate for the needs of a product, with due considerations for the ever-present economic factors.

Fundamentals are discussed in Chapters 2, 3, and 4.

Bibliography

NEED FOR A UNIFORM SPECIFICATION: Casberg, Thomas R.; Proceedings of Conference on Clean Room Specifications, SCR-652, page 11, Sandia Corporation; April 1963.

GENERAL ASPECTS OF CONTAMINATION CONTROL: King, J. G.; Proceedings of Conference on Clean Room Specifications, SCR-652, page 15, Sandia Corporation; April 1963.

CLEANLINESS VERSUS NEED: Lieberman, A., Proceedings of Conference on Clean Room Specifications, SCR-652, page 17, Sandia Corporation; April 1963.

CHAPTER 2

A Model for Contamination Control

Contamination control cannot be applied effectively without an understanding of (1) what constitutes contaminants and (2) their detrimental effects in environments in which they may be found. Contaminants may be "any unwanted particulate, gaseous, liquid, solid, dissolved matter, or radiation within any environment."

A basic contamination control model is outlined in Figure 1 to provide an overall description of the entire field. This model defines the field both in terms of contaminants and of environments which the contaminants affect.

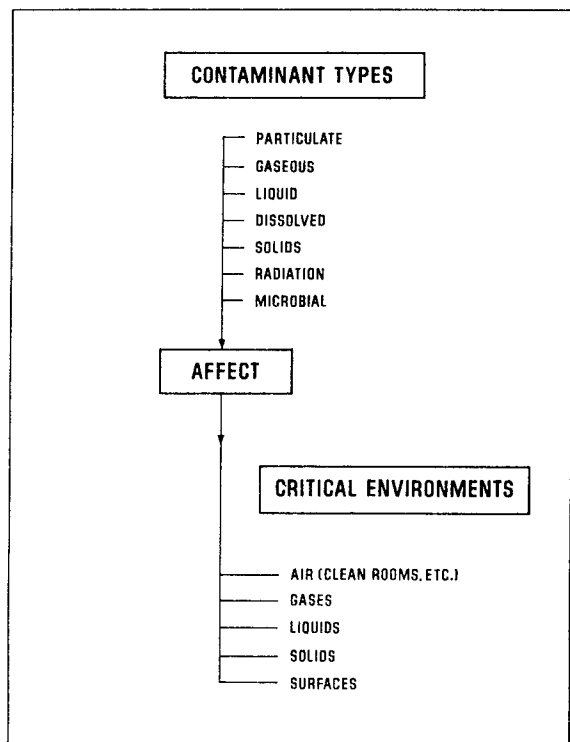


FIGURE 1.—Contaminant types and critical environments
272-806 O-67-2

In Table 1, the model is expanded to include sources and specific contaminant types and to show examples of the affected environments. The principles of control and monitoring discussed in this monograph are directly related to further expansion of the model from the basic contaminant types and their environments.

Contamination may be gross enough to be plainly visible in quantities, or sub-microscopic in size, defying identification by the most advanced analytical procedures. It may be a particulate; it may be a film. Often, the presence of a contaminant is only discovered indirectly through impaired product function. One of the most frequent of these impairments is increased electrical contact resistance of components that have been contaminated by an invisible film.

Many times the unwanted matter may be classified as a contaminant only because of its location. Paint, which is normally used for protection and appearance, becomes a contaminant if it flakes, chalks, or scales, and falls onto the surface of a precision assembly.

Contamination comes in many forms. It may be the metal chip in a pneumatic valve, the lint which clogs a filter, or the loose nut, bolt, or washer in a gas cylinder, fuel tank, or space vehicle. It may also be a germ on a surgical instrument or bacteria in the water supply.

Although microbial (viable) contaminants are particulate and are listed as examples of particulate contamination in Table 1, they are also shown as a contaminant type. Microbial contaminants are listed separately because decontamination of spacecraft and operating rooms is often done by heat or chemical sterilization as opposed to direct removal of the contaminant.

TABLE 1.—*Sources and examples of contaminants and the environments affected*

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 Fluid systems Inert gases Fill gases
		Gases	Fuels Solvents Hydraulic fluids Coolants Lubricants
		Liquids	Metals Plastics Glass Explosives Fuels Electrical contacts Filters Fabrics Mechanical parts Tubing
		Solids	
		Surfaces	
People: Body vapors Production processes: Chemical vapors from cleaning, encapsu- lation, etc. Combustion gases (sub- limated flux, etc.) Product: Sublimated materials from flux, plastics	GASEOUS	Air	Laboratories Fabrication areas Assembly areas Fluid systems Inert gases Fill gases
		Gases	Fuels Solvents Hydraulic fluids Coolants Lubricants Explosives Fuels Plastics
		Absorbed in liquids	Fuels Plastics Fuels Explosives Metals Plastics
		Solids	
		Adsorbed on surfaces	

TABLE 1.—*Sources and examples of contaminants and the environments affected*—Continued

Typical Sources and Contaminants	Contaminant Type	Categories of Affected Environments	
		General	Specific examples
People: Skin oils Production processes: Cleaning solvents Plating baths Machining oils Coolants Lubricants Atmosphere: Condensates Production processes: Condensed flux vapors Chemical films (oxides, etc.) Cleaning residues Product: Condensed flux vapors Condensed outgassing products from plastics Chemical films, oxides	LIQUID	Air (droplets)-----	{ Laboratories { Fabrication areas { Assembly areas { Fluid systems { Inert gases { Fill gases { Fuels { Solvents { Hydraulic fluids { Coolants { Lubricants { Explosives { Propellants { Plastics { Metals
		Gases (droplets)-----	
		Liquids-----	
		Solids-----	
		Surfaces-----	{ Inside tubes { Functional parts and assemblies { Electrical contacts { Bearings { Protective covers { Inside tubes, etc.
		Adsorbed on surfaces-----	
People: Skin oils Production processes: Fluxes Plastic chips, etc. Atmosphere: Dust particles	DISSOLVED	Liquids-----	{ Fuels { Hydraulic fluids { Coolants { Cleaning solvents { Metals { Plastics
		Solids-----	

TABLE 1.—*Sources and examples of contaminants and the environments affected—Continued*

Typical Sources and Contaminants	Contaminant Type	Categories of Affected Environments	
		General	Specific examples
Sun: X-ray Ultraviolet Visible light Electro-magnetic Radioactive materials: Alpha particles Beta particles Gamma rays Electrons Neutrons Production processes: Welding (light and heat) Soldering (heat) Machining (vibration, sound, heat) Product: Heat (electrical, mechani- cal, chemical functions) Vibration	RADIATION	Air	Laboratories Fabrication areas Assembly areas
		Gases	Inert gases Fill gases Fluid systems
		Liquids	Fuels Hydraulic fluids Plastics Magnetic memory core
		Solids	Explosives Solid state devices Transistors, etc.
		Surfaces	Photographic film Magnetic tape Electrical contacts
People and animals: Bacteria (spores and veg- etative cells) Rickettsiae Viruses Soil: Bacteria Fungi Protozoa Plants: Pollen Fungi	MICROBIAL (VIABLE)	Air	Laboratories Fabrication areas Assembly areas Operating rooms
		Gases	Fluid systems Inert gases Fill gases
		Liquids	Fuels Solvents Hydraulic fluids Coolants Lubricants
		Solids	Plastics Fuels Explosives
		Surfaces	Parts Tubes Assemblies
		Living combinations of above	People and animals Plants
		Inert combination of above	Food Animal waste products Soil

CHAPTER 3

Considerations for Contamination Control

Cleanliness is not absolute; it is a relative condition denoting the degree to which a part may be cleansed of unwanted matter. If a mechanism or system must be free of contaminants to function reliably, a well-planned and developed contamination control program must be implemented—and, above all, constantly monitored.

Numerous considerations and analyses are necessary in the evolution of a comprehensive contamination control program. They are needed to justify the investment and to assure that the program is both effective and economical.

Before implementing such a program one should know (1) the type of contaminants which will be encountered, (2) the size, volume, mass, and shape of each of these contaminants, and (3) the effect of these characteristics on the relative ability of the product to tolerate contamination. In addition, careful consideration must be accorded the inherent and generated contaminants associated with the tools, processes, production and test equipment to be employed; the cleaning and cleanliness verification equipment and techniques, and the very important factor of personnel. For the latter there should be not only an original training program but an equally thorough retraining schedule.

Basic Considerations

In addition to the factors already singled out, consideration of other items is necessary. Although a component or system may be capable of tolerating some maximum-size particulate matter, an important consideration is not only the size but the potential accumulation of any contaminant which would render the product ineffective. Concentrations of otherwise tolerable sizes of contaminants will,

in some instances, clog a fluid line filter, an air filter, and a valve or joint not specifically designed for use in a contamination control system.

The four mythical components in Figure 2 could be processed in the manner shown if they had been the subject of proper analysis and preplanning prior to the start of production. Product cleaning between operations during the progress of the product through assembly is also a matter for consideration, plus adequate protection following cleaning and provisions for containers and both temporary and long-term storage facilities. *When contamination control is necessary, it is effective if properly planned, but it may prove costly, so consider it carefully!*

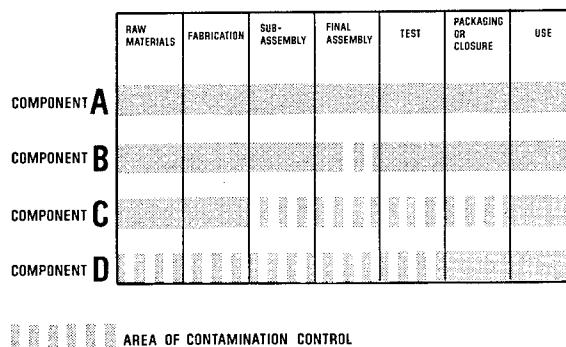


FIGURE 2.—Some examples of product requirements for contamination control

Some of the sources of contaminants and methods by which contaminants are deposited on a product are illustrated in Figure 3. This figure pinpoints areas worthy of close attention, and any process which might be so affected should be considered for inclusion within a controlled work area.

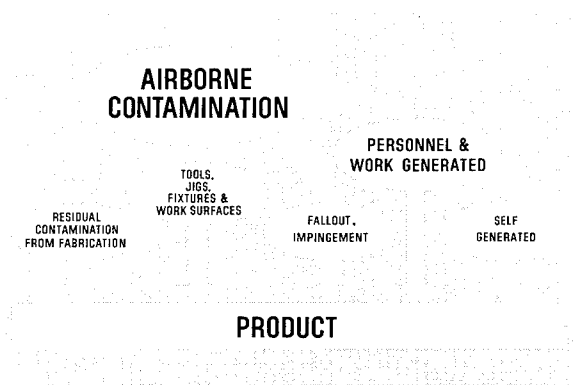


FIGURE 3.—Sources of accumulated contamination

Contamination of functional surfaces is a prime source of product malfunction, the principal reason being that it is a continuing process under even the most favorable conditions. Functional surfaces must be continually monitored until each one is sealed against further formation of surface contamination. The state-of-the-art for surface cleanliness verification is not highly developed. Many methods are laboratory oriented and completely unsuited for the production floor. Therefore, the designated cleanliness level should be consistent with the state-of-the-art.

Cleaning solutions become contaminated during their functional use and must be subjected to filtration, distillation, or some purifying process at stipulated intervals. These intervals will vary with the material being cleansed and the cleanliness level required. The alternative to utilizing these contaminant-removing techniques is new fluid!

If the need for contamination control is confirmed and the level of control is established, the next considerations have to do with the facilities to be employed.

Facilities Considerations

The determination of the extent of which facilities will be provided should be tempered by some thought for tomorrow. Today our tolerances may be troublesome, but our progress has been so rapid that our best efforts have become obsolete in a short span of time. How much can be saved by providing facilities that

will withstand the test of time and progress? If you build a quality product, the best may be none too good. Some of the considerations which will have the greatest influence on the selection of the facilities are:

1. Size and weight of product: Is a single unit adaptable to being processed on a bench or on the floor?
2. Number and complexity of processes: Does a progressive multioperation assembly require several workers, or will the space and personnel needs be minimal? Does the product process introduce breaks in the assembly sequence for cleaning, encapsulation, in-process inspection, etc.?
3. Production quantities: Will the scheduled production rate require a sizable volume of material in process?

The actual selection of facilities should not be made until all of the preceding considerations have been resolved. Although much of the necessary information will be derived from factual conditions, some part of the basis for the determinations will be divided between opinion and expectation. The factual portion should be a heavily weighted factor in any final determination.

Cleaning solvents may be a subject for close scrutiny for several reasons. First, if the volume of disposed solvents is great and the municipal code will not permit dumping into the sewerage system, provisions must be made for some other disposal method, such as neutralization or dilution to a degree which will permit sewer disposal. Second, the safety factors will require very close attention to potential flammability, high vapor accumulations which might explode, and mixing of otherwise non-toxic chemicals to form a hazardous and highly toxic fluid or gas.

Personnel selection and training under a knowledgeable and competent instructor is a highly important consideration. This training should be mandatory for all personnel associated with critical work requiring contamination control. Maintenance and janitorial personnel should undergo instruction to enable them to pursue their duties without contributing to downgrading the facility. Retraining should be scheduled for all personnel at appropriate intervals, and the schedule followed!

Considerations in contamination control may be summarized as:

1. Need for contamination control.
2. Tolerance levels in contamination-controlled product.
3. Relationship of processes, product, contaminant sources, and facilities.
4. Product cleaning.
5. Personnel factors.

CHAPTER 4

Contamination Control Principles in Product Design

Ideally, a product would be designed to tolerate the contamination to which it is likely to be exposed during:

1. The fabrication cycles;
2. The assembly stages;
3. The testing and verification processes;
4. The packaging, storage, and both internal and external transport;
5. The end use of the product.

The designer should evaluate the materials and the product size and function which might influence compromises between materials, the product, and contamination controls.

To assure reliability at a reasonable cost, the designer must anticipate the potential effects of various kinds of contaminants on the life and function of the product. This requires careful consideration of the sources of contamination; the sizes, types, and quantities of contamination which will originate from these sources, and their effect on the product.

The relationship between production stages and the sources of contamination versus the methods of contamination control is depicted in Figure 4. A more detailed enumeration of contamination control considerations and characteristics is set forth in Table 2. This listing

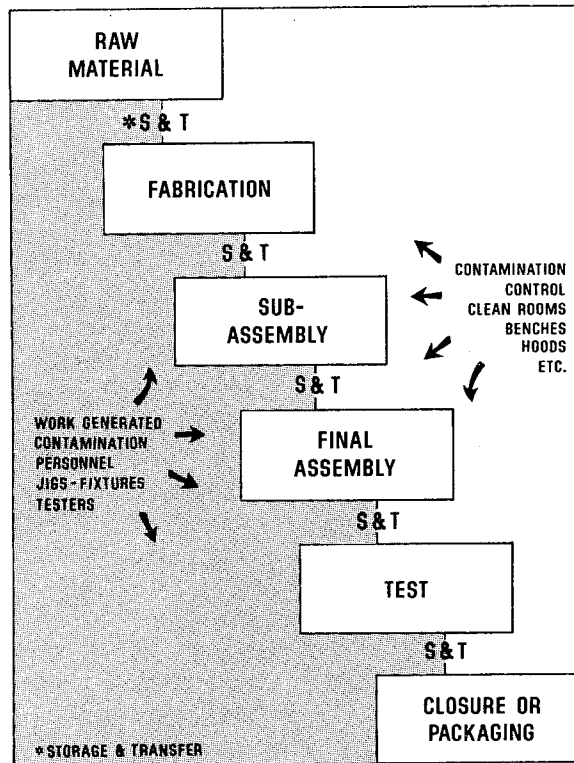


FIGURE 4.—Contamination control considerations for design and manufacture of product

TABLE 2

Contamination control considerations		Characteristics and elements affecting contamination
General	Specific	
Materials	Purity	Electrical Mechanical
	Material as a source of contamination	Corrosion Outgassing Shedding, flaking, etc., due to age and use Wear

TABLE 2—Continued

Contamination control considerations		Characteristics and elements affecting contamination
General	Specific	
Materials (continued)	Compatibility with other mating materials	Cleaning reaction Corrosion Galling Galvanic action Reaction to lubricants, etc. Wear
Fabrication	Casting	Sand and cores Residues Blind holes Capillary traps Entrapped gases
	Molding	Flash Mold release residue Mold wear particles
	Forming, drawing, extrusion	Burrs Lubricants Release compounds Particles and scale
	Forging	Scale
	Machining	Blind holes Burrs and sharp edges Capillary traps Coolants Cutting oils
	Chemical milling	Etch residue
	Plating	Flaking and scaling Residue
	Heat treat	Scale
	Cleaning	Residue Effect on materials
Assembly	Product flow	Particulate transfer from surfaces of jigs, fixtures, work surfaces
	Rivets	Galvanic action Fragments from swaging
	Nuts, bolts, screws	Plating shedding Burrs and chips Abrasives

TABLE 2—Continued

Contamination control considerations		Characteristics and elements affecting contamination
General	Specific	
Assembly (continued)	Welding, brazing, and soldering	Metal fragments Solder fragments Flux residue Airborne fumes Surface oxides
	Gaskets	Flaking, shedding Excess lubricant
	Jigs, fixtures	Non-shedding materials Abrasive action
	Sealing, encapsulation	Outgassing Shedding, flaking Reaction due to heat
	Lubricants	Excess Migration from heat, etc.
	Cleaning	Residue Compatibility with all materials Entrapment due to assembly Gas generation
	Marking	Etch residue Particle generation Shedding
	Personnel	Scale, hair, lint, fibers Cosmetics Finger prints
Inspection and test	Connection and disconnection of electrical and mechanical connectors	Burrs, chips Plating scale Wear Leaking seals
	Test equipment and gages	Shedding Abrasive residue
	Chemical tests	Dyes, etc.
	By-products	Released fluids and gases
	Personnel	Scale, hair, lint, fibers Cosmetics Finger prints

TABLE 2—Continued

Contamination control considerations		Characteristics and elements affecting contamination
General	Specific	
Storage and transport	Maintain cleanliness during product flow	Containers Wrapping materials Cushioning materials Desiccants Lubricants
Closure and packaging	Containers	Shedding Contaminant Exclusion
	Environment	Temperature Humidity Pressure Shock Vibration
End use	Environmental requirements	Temperature Humidity Pressure Shock Vibration
	Operation a.—Continuous b.—Intermittent c.—Self-destructive	Wear Lubrication Particle generation Radiation
	Servicing	Introduction of or exposure to contamination

is in a format which a designer or process engineer can use as a checklist.

The need for highly reliable products has caused industry to turn to the precise control of manufacturing environments. This need has been amplified by the wider use of new and more sensitive materials and alloys, the relentless march toward microminiaturization, and greater complexity of hardware leading to increased costs and time involved.

Close control of temperature and humidity is relatively easy to achieve. Control of contamination, although frequently stubborn and frustrating, may be equally effective if "planned and organized action to contain the degree or level of contamination, in, on or around any object or product" is thorough and complete.

The information in the chapters which follow

is intended to provide the designer, engineer, and process engineer with guidelines for the implementation of a well balanced contamination control program.

Bibliography

CONTAMINATION CONTROL CONSIDERATIONS FOR DESIGNERS AND MANUFACTURING ENGINEERS: Ballard, D. W.; SCR-65-888, Sandia Corporation; April 1965.

STERILIZATION AND QUARANTINE PARAMETERS FOR CONSIDERATION DURING THE DESIGN OF PLANETARY VEHICLES: Craven, Charles W.; McDade, Joseph J.; and Light, Jay O.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 43; November 16, 1965.

CHAPTER 5

Clean Rooms, Clean Work Stations, and Other Work Enclosures

Clean rooms, clean work stations, and similar facilities are used to control airborne contamination in critical area. Airborne contamination is usually particulate matter, although at times a gas may have to be controlled, too. The control of humidity and temperature is common in clean rooms and in some hood devices.

Standard air cleanliness classes for airborne particulate contamination control are specified in three classes by Federal Standard No. 209a, as follows:

Classifications, as shown in Table I, are based on particle count with maximum allowable number of particles per unit volume permissible 0.5 micron and larger or 5.0 microns and larger. Particle counts are to

10,000 but less than 100,000 particles per cubic foot of a size 0.5 micron and larger. This would not apply if special conditions dictated the establishment of a class between those listed in Table I of Federal Standard 209a.

In our discussions of various types of clean rooms, benches, and other contamination control facilities we will assume that all filters are properly installed, sealed, and free of leaks. For information about checking for filter leaks, see Paragraphs 50 and 60 in Appendix A of FED-STD-209a. Table 4 gives general guideline information.

TABLE I—Federal Standard No. 209a
Air Cleanliness Classes

Maximum number of particles per cu. ft. 0.5 micron and larger	Class	Maximum number of particles per cu. ft. 5.0 microns and larger
100-----	100	See note below.
10,000-----	10, 000	65.
100,000-----	100, 000	700.

NOTE: Counts below 10 particles per cu. ft. are unreliable except when a large number of samplings is taken.

be taken during work activity periods and at a location which will yield the particle count of the air as it approaches the work location. Special classifications may be used for particle count levels where special conditions dictate their use. Such classes will be defined by the intercept point on the 0.5-micron line in Table II of FED-STD-209a, with a curve parallel to the three established curves.

It should be understood that Class 10,000 includes any facility having more than 100 but less than 10,000 particles of a size 0.5 micron and larger per cubic foot. Class 100,000 similarly includes all facilities with more than

Non-Laminar Air Flow Clean Room

This type of facility usually has ceiling ports, grills, or diffusers, through which air is pumped into the room. The normal volume of air moved approximately equals from 15 to 20 changes of the cubic room air capacity per hour, or a single change in from three to four minutes. This air enters the room through a delivery duct in which a filter is installed. This is usually a high efficiency particulate air (HEPA) filter, rated 99.97% efficient on all particles 0.3 micron and larger. The air is exhausted from the room through ports or grills which may be located (1) in the ceiling, (2) in the floor, or (3) in the wall(s). The location may vary from the lower to upper periphery. To eliminate undesirable exit velocities, the air exhaust area is usually equal to the area of the air entrance grills or diffusers.

These arrangements contribute to random air flow patterns (see Figure 5) which will vary according to the relative placement of air entrance and exit locations. Personnel movement and equipment relocation can alter the air flow patterns in the room, and these changes will not necessarily be an improvement.

Ordinarily the non-laminar flow clean room will achieve Class 100,000 if it is well operated and controlled. The cleanliness level of this

TABLE 3

Type of installation or equipment	Attainable class of air cleanliness	Normal requirements				
		Suits	Smocks	Caps	Boots	Gloves
<i>Vertical laminar air flow room</i> -----	100	-----	X	X	-----	X
<i>Laminar downflow curtained unit</i> (care must be exercised to preclude dirt from the floor migrating to critical work zone)-----	100	-----	X	X	-----	A
<i>Laminar air flow work station</i> —Vertical or horizontal-----	100	-----	X	A	-----	A
<i>Laminar air flow hood</i> —Vented and others-----	100	-----	X	A	-----	A
<i>Horizontal laminar air flow room:</i>						
First work location-----	100	-----	X	X	-----	X
Subsequent work locations (depending on contamination generated by processes and personnel)-----	10, 000	-----	X	X	-----	A
<i>Horizontal laminar air flow tunnel:</i>						
First work location-----	100	-----	X	X	-----	A
Subsequent work locations (depending on contamination generated by processes and personnel)-----	10, 000	-----	X	X	-----	A
<i>Non-laminar flow room</i> (with strict garmenting control and continuous janitorial attention)-----	100, 000	X	-----	X	X	X
<i>Non-laminar flow room</i> —With 25% of the entire floor space consumed by operating laminar air flow clean work stations (no relaxation of strict garmenting control and continuous janitorial attention)-----	10, 000	X	-----	X	X	X
<i>Factory or laboratory room</i> —With filtered air supply, free from wall or ceiling cracks or openings, windows and doors relatively leak free (plus 25% of floor space occupied by laminar air flow work stations, and with good personnel controls and moderate use occupancy)-----	100, 000	A	A	X	A	A

A—Will depend on the work piece size and degree of control sought.

NOTE: If new facilities are to be acquired, horizontal rooms or tunnels should be selected in place of non-laminar flow facilities, because the original cost will normally be equal or less, plus the reduction that can be made in garmenting restrictions, with better clean-down capabilities, and reduced particle count levels.

type of facility depends directly upon the ability of the janitorial staff to remove contamination (a) brought into the area by clean

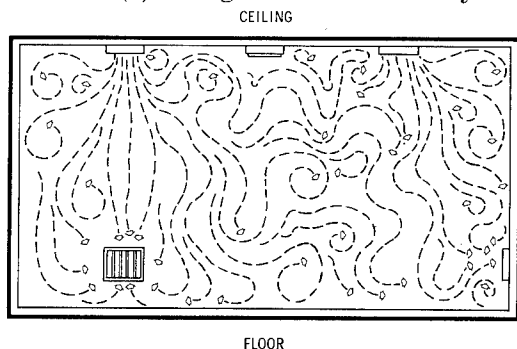


FIGURE 5.—Conventional (non-laminar air flow) clean room

room personnel, and (b) generated within the room by both the personnel and the operations being performed. Non-laminar flow clean rooms have very little self-clean-down capability, and attempts to operate them at levels below 100,000 class will require extremely rigorous personnel controls and continuous janitorial cleaning—which is impractical and not economical in most instances.

Non-laminar flow clean rooms have a mandatory requirement for highly controlled clothing change facilities for both male and female workers. Additional requirements include air showers, air-locked entrances and exits, and shoe cleaners or provision of clean-room shoes for each worker.

Construction costs of the non-laminar flow clean room vary with the size of the room and the type of material used. The interior of such rooms is generally finished with a high gloss enamel on dry wall sheeting. Usually a good grade vinyl tile is used for floor covering.

The non-laminar flow clean room will generally require a rather high static operating pressure to exclude exterior contamination.

Laminar Air Flow Clean Rooms

This type of facility was developed because of basic needs for clean rooms:

1. A self-clean-down capability to combat both contamination brought into and generated within the room;
2. Air-flow patterns which carry airborne contamination away from the work and the work area;

TABLE 4.—General guideline information—controlled environment areas versus critical equipment requirements

Clean room class*	Particle size limit in or on device (microns)	Typical categories of critical devices and equipment
100	< 10	Precision guidance control equipment. Miniature contacts, bearings, optics, hydraulic components. Precision gyros and measurement equipment.
10, 000	< 50	Small instruments, missile components. Medium tolerance bearings, gyros, actuators, regulators, and other hydraulic, pneumatic and LOX system components. Electronic assemblies for missile systems.
100, 000	< 200	Measuring instruments and instrument calibration. Missile overhaul. Electronic equipment. Regular hydraulic, pneumatic, and oxygen systems, LOX systems. Pumps, actuators, motors.

*As designated in FED-STD-209a.

3. Reduced personnel restrictions; and
4. Lower maintenance costs.

The first laminar air flow clean room, a wall air inlet to floor exhaust facility is illustrated in Figure 6. It proved the value of laminar air flow, and was the catalyst for the adaptations of the concept in the types described in the following paragraphs.

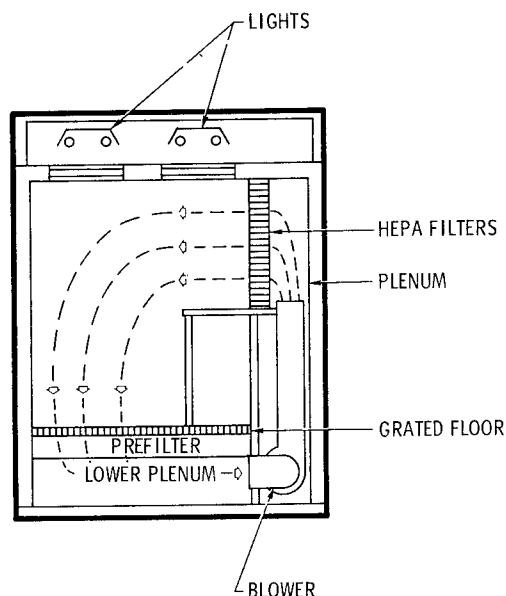


FIGURE 6.—Cross section of wall-to-floor laminar flow room

Vertical laminar air flow clean room

This type of room utilizes the basic laminar air flow principle, the air flow being vertically downward, as in Figure 7, throughout the entire cross section. Figure 8 shows a typical vertical laminar air flow room, with a full ceiling HEPA filter tank, and the air exhausting through the grating floor.

Normally, the vertical laminar air flow room will:

1. Operate within the Class 100 level;
2. Operate with air velocities up to 100 feet per minute;
3. Provide for very rapid removal of generated or introduced contaminants from the room;

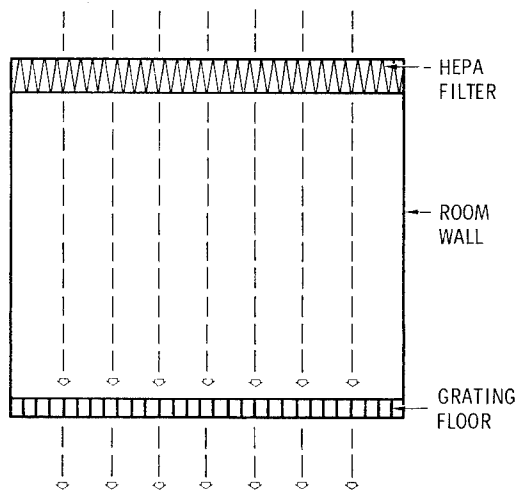


FIGURE 7.—Basic air flow pattern in vertical laminar air flow room

4. Eliminate cross-contamination between adjacent operations;
5. Eliminate the need for continuous janitorial attention; and
6. Minimize the effects of personnel on critical operations.

Construction costs will depend upon the materials chosen. The walls may be the dry-wall type with a gloss enamel coating. The grating costs will depend upon the load the floor must sustain, and the grating suspension system will depend upon the size of the span.

The use of air showers, air-locked doors, and

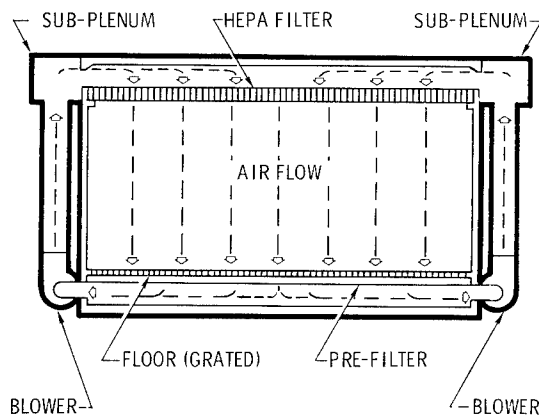


FIGURE 8.—Basic laminar down-flow clean room

shoe cleaners is not normally required in this type of installation. A small amount of overpressure may suffice to repel any contaminant liable to enter when a door is open. Further precautions, of course, may be needed in extremely critical installations and those concerned with microbial pollution.

Laminar horizontal or cross flow clean room

This type of installation differs from the vertical flow room fundamentally in the direction of the air travel. The air enters from a HEPA filter bank in one wall and is exhausted through the opposite gridded or louvered wall, as illustrated in Figure 9. The plenums are located behind the HEPA filter bank and the exhaust grill, which is normally backed up with the prefilters. The return air may travel over the ceiling, as a means of eliminating ducting, or through a side wall which has no openings, or under the floor via ducting.

A horizontal flow room from 40 to 60 feet long will normally provide a Class 10,000 room, although the first work locations are capable of providing a Class 100 condition. The air velocity for a horizontal laminar air flow room should be no less than 100 fpm and, depending upon the type of work to be performed, may go as high as 140 fpm.

Care must be exercised in the placement of

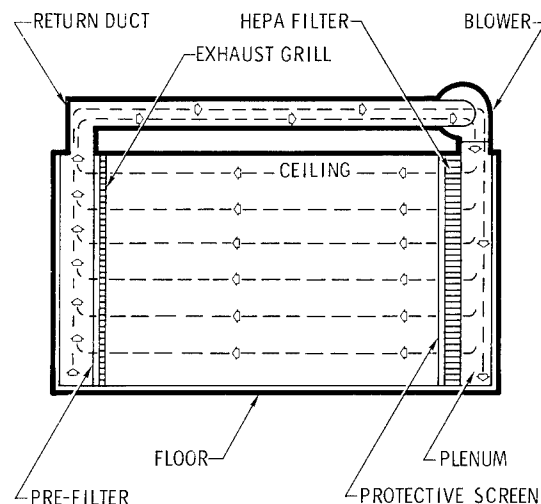


FIGURE 9.—Wall-to-wall laminar flow room

high contaminant generating operations, to be certain that they do not adversely affect an adjacent or downstream operation. If the flow of work is such that it permits the placement of these operations near the exhaust end of the room, this is desirable.

Facilities of this type clean down very rapidly, and when medium or large size rooms are required, this type of installation is low in cost.

Since a horizontal facility is not intended to attain a Class 100 rating, the maintenance costs will be low, and the need for highly restrictive personnel garmenting is avoided, as is the need for air shower, air locks, and similar facilities.

Laminar air flow tunnel

The laminar air flow tunnel differs from the laminar horizontal air flow room in the following aspects:

1. The tunnel is open at the end opposite the HEPA filter bank.
2. The air exhausted from the tunnel is dumped into the surrounding area, whereas in the horizontal room, at least a part of the exhausted air is recirculated.
3. The tunnel has no positive pressure to exclude contamination, but depends upon the air velocity to retard the infiltration of airborne contamination.
4. The temperature and humidity must not be required to be other than that of the area in which the tunnel is located.

This type of facility is frequently composed of a series of HEPA filter modules, fastened together and sealed to preclude leaks between the modules. Figure 10 shows a cross section of this type of room. The walls and ceiling may be merely a sheet of transparent plastic film or sheet stock to permit utilization of the existing lights. Naturally, the film or sheet must be fastened to the HEPA filter bank and at the floor to eliminate leaking of any air. It is normal for an installation of this character to have an air velocity of from 100 to 130 fpm, and the air cleanliness level that may be expected will reach 10,000 if the above cautions are observed.

A tunnel facility is likely to be the least expensive clean room attainable. It need not be a permanent installation, and can be moved from

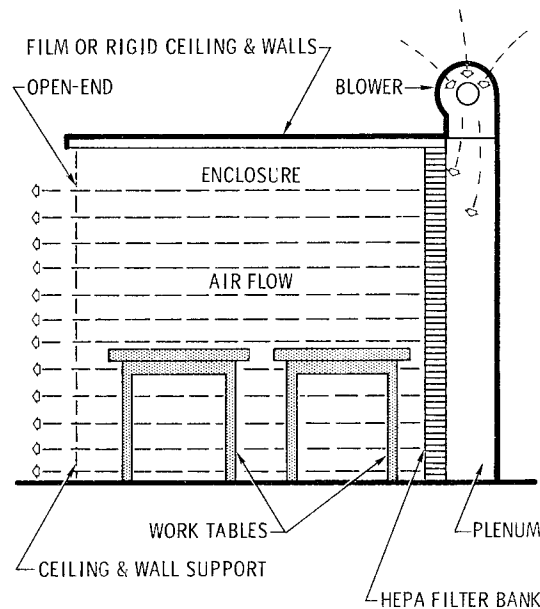


FIGURE 10.—Laminar air flow tunnel

one location to another with a minimum of lost time and labor cost.

Vertical laminar air flow curtained unit

This configuration was developed to provide a "portable clean room," with the capability of the best air cleanliness class facilities, that can be moved readily to a large cumbersome structure. As illustrated in Figure 11, such a facility may preclude moving large structures via traveling crane or forklift to a clean room. This is often very costly because of the size of a unit and the cost of sealing large openings in a stationary clean room. These units are not restricted to any particular size or height, although the larger they are, the greater the problem of moving and storing.

Basically the curtained unit is a vertical flow room having (1) plastic curtains for side walls, (2) blowers, (3) a HEPA filter bank, and (4) support legs with casters for unrestricted movement to or from a structure. It is self-contained except for electric power. It is equipped with its own illumination, and utilizes conditioned (cooled or heated) air from the building in which it is located. It is a satisfactory piece of equipment to use in

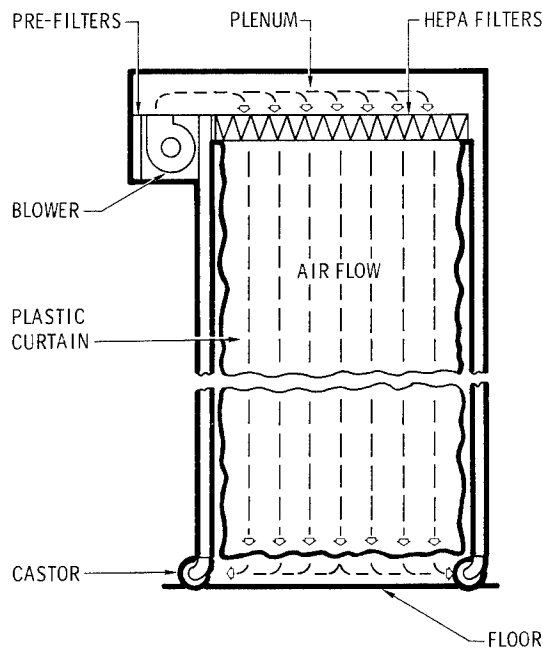


FIGURE 11.—Curtained down-flow laminar flow unit

the open, even when a moderate breeze is blowing. The curtained unit will perform to the same standards as vertical laminar air flow units if care is exercised to avoid the rise of excess floor dirt to the critical work area. The air velocity should be determined by the use to which the unit will be subjected.

Laminar flow clean work stations

The clean work station is a device that provides a localized "clean zone" for bench-type operations. The units may be located in shop areas with high concentrations of particulate matter and, with a few restrictions, will function with full efficiency. A typical clean bench cross section is shown in Figure 12. Various configurations are available. Some have the air intake located above the plenum and work surface, instead of below it. Either place may be satisfactory. The operational characteristics are similar to those of other laminar air flow devices. The laminar air flow clean bench provides a uniform filtered air flow to remove airborne dirt from the work area of the bench. It will normally provide a Class 100 condition in the work area, under operational conditions.

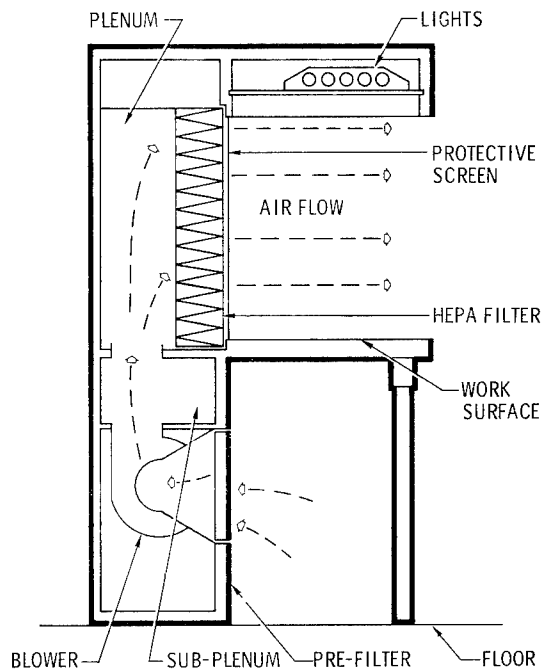


FIGURE 12.—Cross section of laminar flow clean bench

Features of this type of facility include:

1. Rapid self-clean-down capability;
2. Ready access to the work area through the open front;
3. Reduction of personnel restrictions; and
4. Portability—it is easily moved from one location to another, requiring electric power only at the location.

A Class 100 progressive assembly line can be set up by placing a series of laminar air flow clean benches end to end, with the end panels removed and the joints between benches sealed to preclude leakage at these points. The line of benches may consist of as many benches as are required. Such a line of benches does not need to be within a clean room of any type. It may be installed in an existing room with an air cleanliness class that does not meet the requirements. A side benefit from installing a bench or benches in any room is that, proportionate to the room volume involved, the bench(es) will decrease the contamination level of that specific room.

If 25% of the floor space in a room reasonably free of leaks is occupied by clean benches, it is entirely possible to have this room cleaned

down to a Class 100,000 level—and to a Class 10,000 if cleaning and personnel controls are rigidly followed and the benches are operated around the clock. Thus, the laminar air flow clean work station provides a method for upgrading an existing conventional or non-laminar air flow room. The economic value is self-evident.

Laminar air flow vented hood

Units of this type may be capable of controlling four environmental factors:

1. Airborne particulate
2. Noxious fumes
3. Temperature
4. Humidity

This device differs from other devices having the same environmental characteristics, in that the controls are obtained without sacrificing open access to the work area. As illustrated in Figure 13, the vented hood provides a source of highly filtered air which is moved into a work area from the HEPA filters to a grated work surface of the unit and exhausted to the exterior of a given structure or building. This movement is achieved by a blower with a variable flow rate, adjusted to remove air from the hood work area at a rate equal to that at which it is brought into the hood work area by the filtered air supply.

Basic design considerations for the development of a laminar air flow vented hood should include:

1. A clean air supply, which normally consists of a blower-HEPA filter assembly to supply filtered air to the work area;
2. A semi-confined work area with a vertical interior liner that is flush with the inside of the filter frame;
3. A perforated (or grated) floor for the work area; and
4. An exhaust blower with adjustable air flow capability.

Special Applications for Laminar Air Flow Facilities

Many specialized adaptations of laminar air flow are currently solving problems that plague industry. An example of a specialized application employed to solve an annoying problem is

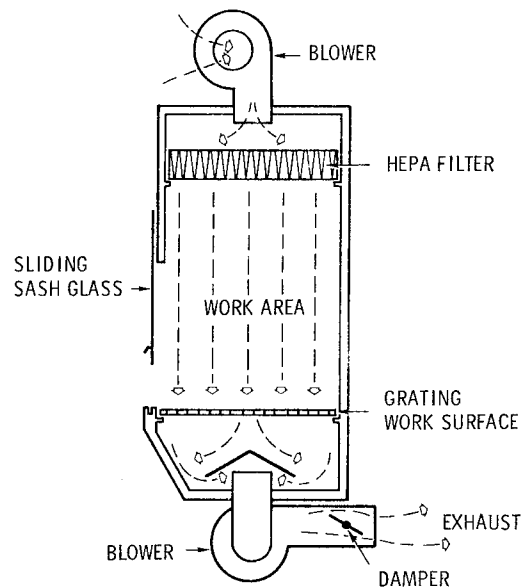


FIGURE 13.—Clean air exhaust hood

a vertical laminar air flow room for the control of plastic dusts and fumes. This particular operation demanded absolute control of toxic fumes generated during encapsulation procedures. Normal currents of air ducted to the outside were inadequate, but the laminar flow installation solved the problem.

A study of troublesome problems will most likely result in still other adaptations of this technique.

Gas and Vapor Control in Clean Room

A common method of gas and vapor control in clean rooms is charcoal filtration. Filters filled with activated charcoal provide the necessary control.

Activated charcoals have strong selective power for the adsorption of organic vapors from gases, even in the presence of water vapor and are, therefore, widely used for gas purification and solvent recovery.

Charcoal filters are available in a large variety of sizes and configurations and may be used alone if only needed for gaseous contamination. They also may be procured in the same size as HEPA filters and mounted in tandem when the requirement involves both gaseous and particulate contamination.

Bibliography

A NEW APPROACH TO CLEAN ROOM DESIGN: Whitfield, W. J.; SC-4673(RR), Sandia Corporation; March 1962.

A PORTABLE CLEAN WORK STATION: Mashburn, J. C.; Neitzel, W. E.; and Whitfield, W. J.; SC-4690(RR), Sandia Corporation; June 1962.

OPERATING MANUAL FOR THE SANDIA CLEAN BENCH: Marsh, R. C.; and Whitfield, W. J.; SC-4733(M), Sandia Corporation; November 1962.

THE DESIGN OF A DUST-CONTROLLED VENTED HOOD UTILIZING LAMINAR AIR FLOW: Whitfield, W. J.; SC-4905(RR), Sandia Corporation; June 1963.

THE ADAPTABILITY OF LAMINAR AIR FLOW FOR CONTAMINATION CONTROL: Marsh, R. C.; SCR-691, Sandia Corporation; July 1963.

EVALUATION OF A CURTAINED LAMINAR DOWNFLOW CLEAN ROOM (U): Whitfield, W. J.; Neitzel, W. E.; Mashburn, J. C.; and Marsh, R. C.; SCDR-221-63, Sandia Corporation; August 1963.

A CONTROLLED ENVIRONMENT FILM DEPOSITION SYSTEM: Bergsten, W. E.; Knudsen, N. L.; and McDowell, J. F.; SC-TM-64-536, Sandia Corporation; April 1964.

BASIC DESIGN REQUIREMENTS FOR LAMINAR AIR FLOW DUST CONTROL DEVICES: Whitfield, W. J.; Mashburn, J. C.; Neitzel, W. E.; and Trujillo, L. C.; SC-R-64-145A, Sandia Corporation; May 1964.

A COMBINATION FINAL RINSING STATION USING FREON TF SOLVENT: Marsh, R. C.; SC-TM-64-604, Sandia Corporation; May 1964.

AN ABSOLUTE FRAME FOR ABSOLUTE FILTERS, Little, J. C.; Y-EA-38, Union Carbide Corp., Oak Ridge, Tenn.; AEC Contract Number W-7405-eng-26; May 21, 1965.

SINGLE VERSUS DOUBLE ABSOLUTE FILTRATION: Little, J. C.; Y-EA-39, Union Carbide Corp., Oak Ridge, Tenn.; AEC Contract Number W-7405-eng-26; May 21, 1965.

CLEAN-UP CHARACTERISTICS OF A LAMINAR FLOW LABORATORY: Little, J. C.; Y-EA-40, Union Carbide Corp., Oak Ridge, Tenn.; AEC Contract Number W-7405-eng-26; May 21, 1965.

SIGNIFICANT PARAMETERS OF CLEAN ROOM DESIGN: Choat, E. E.; and Little, J. C.; Y-EA-37, Union Carbide Corp., Oak Ridge, Tenn.; AEC Contract Number W-7405-eng-26; June 8, 1965.

FILTER APPLICATIONS FOR SPACECRAFT STERILIZATION PROGRAM: Decker, Herbert M.; and Buchanan, Lee M.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 259; November 16, 1965.

HIGH PURITY DE-IONIZED WATER CLEANING STATIONS: Marsh, R. C.; SC-TM-66-49, Sandia Corporation; February 1966.

Y-12 CLEAN ROOM FACILITIES: Little, J. C.; Y-EA-49, Union Carbide Corp., Oak Ridge, Tenn.; AEC Contract Number W-7405-eng-26; March 14, 1966.

APPLYING "DOWNFLOW" TO DUST-FUME CONTROL IN A PLASTICS FACILITY: Kenagy, J. A.; SC-R-66-922, Sandia Corporation; June 1966.

CLEAN ROOM AND WORK STATION REQUIREMENTS, CONTROLLED ENVIRONMENT: Federal Standard No. 209a; August 10, 1966.

CHAPTER 6

Cleaning of Product Surfaces

Contamination of functional surfaces is a major cause of malfunction of electrical contacts and close-fitting mechanical parts. Contamination on surfaces adjacent to these areas also can contribute to product failure through sloughing or scaling of particulate matter not removed by the stipulated cleaning process.

There are numerous accepted techniques for detecting surface contamination, but none is applicable to all materials or to all contaminants. The few methods suitable for production use have limited application. Before methods and processes are chosen, the principles of surface cleaning should be explored in depth, because the method required to clean a surface may be a clue to the appropriate method of detection or verification.

Many variables are involved in surface cleaning, such as type of material to be cleaned, type of contaminant, types of cleaning methods and processes, with varying equipment as well as the consideration of further treatment to the material. There are many forms of contaminants to be removed and broad groupings of materials.

One of the potential problems is that the first or second cleaning process or solvent may cause some adverse reaction to subsequent cleaning processes or solutions. Thus the entire manufacturing process must be surveyed and each intermediate cleaning operation analyzed for its impact on the whole process.

There is no general answer to the question, "When may a part be considered clean?" For example, a metal part may be wiped free of oil with a rag. It then may be visually clean, provided it is not subject to further finishing. But, if it is to be chrome plated, any residual organic soil must be removed by electrolytic cleaning in an alkaline solution before it may be considered chemically clean. Even then it may not respond satisfactorily to electroplating due to a passive oxide film on the metal that renders the

surface inert. In this instance, the part must be acid dipped, with or without current, and with the possible use of activators calculated to remove that film. The part then may be considered metallurgically clean.

Thus, when speaking of metal cleaning, it is necessary to distinguish between "visually clean," "chemically clean," and "metallurgically clean." All these terms suggest that "cleaning of metals" or the "cleanliness of metals" are relative terms; the interpretation depends on the type of soil to be removed, the activity of the metal, the finish to be applied, etc. It may be necessary to remove an undesirable film, or replace it with a more desirable type of film, or one that can be controlled in subsequent operations. Some typical examples are:

1. The removal of natural oxide films on aluminum alloys and their replacement with artificial but controlled oxides, as in anodizing prior to painting, etc.
2. The removal of normal chromate films on stainless steel to replace them with chrome plate, for better appearance.
3. The removal of oxides from aluminum alloys and replacement with a zincate film prior to plating with copper, nickel, and chrome.

There are seven broad classifications of processes for removal of surface contamination, any one of which may be employed in single or multi-stage operations. They are:

1. Acid cleaning;
2. Alkali cleaning;
3. Solvent cleaning;
4. Emulsion cleaning;
5. Electrolytic cleaning;
6. Pickling and descaling; and
7. Mechanical cleaning (blast or grit, abrasive tumbling, wire brushing, and flame cleaning).

All of these methods except mechanical cleaning require electricity and liquids or fluids which may differ widely. Liquid cleaning media involve the complex phenomena of wetting activity, emulsification, deflocculation, colloidal activity and suspension, solvent power, pH values, buffer activity, alkalinity and acidity, water conditioning, sequestration and chelating, and rinsing. Each of these factors will be discussed briefly.

Wetting

For a surface to be cleaned, it must first be wetted by a cleaning solution. Wetting action brings the detergent or cleaner in close contact with the soil, ultimately penetrating the soil so that detergency can be brought to bear where it accomplishes the most. A metal surface that is wetted completely by a detergent is separated from the contaminant by a cleansing film, and is therefore well on its way to being cleaned. While wetting activity is popularly believed to be a natural property of all liquids, in reality, liquids vary greatly in their ability to wet out a surface. Water, reputedly one of the wettest of all substances, actually has less wetting power than ammonia, acetone, benzene, and most oils. But water's wetting power can be greatly increased by chemical treatments.

The wetting ability of any fluid can be increased by reducing its surface and interfacial tension. Pure water has a much higher surface tension than most oils. When pure water is carefully poured on an oil surface, the surface tensions of the oil and water will resist one another with the result that the water is unable to spread over or wet the oil film. Instead, the water forms individual round droplets or pools with convex domes, a precise reflection of the forces of surface and interfacial tensions involved in the situation. But if the surface tension of the water is reduced so that it is actually less than that of the oil film, the water will penetrate and displace the oil. The oil then forms droplets on the surface of the water film. These droplets may not yet be completely detached from the soiled surface, but the oily mass will have been penetrated and its adhesion weakened by complete wetting.

Emulsification

The forces of cohesion which hold an oily film to a surface are remarkably strong. It is almost impossible to remove an oily film completely by the shearing action of wiping or scrubbing alone. One can demonstrate this by repeatedly wiping a lard-coated frying pan with a cloth until no lard is visible, then applying the water-break test. Invariably, water will resist wetting such a surface, proving that an oil film, perhaps no more than one molecule in thickness, still persists. The surface may be considered physically clean, but it will not be chemically clean until water refuses to break on the surface.

As previously stated, thorough wetting results in the formation of globules of oil on the surface of the detergent film. Here the process of emulsification comes into play. If there is an emulsifying agent in the detergent, the oily globules will be detached from the surface and will be dispersed through the cleaning solution. The adhesion of the oil to the surface will be permanently disrupted. Once so scattered, the portion of the oil removed cannot be redeposited as a film.

When part of an oily film has been removed in this manner, another layer of the film is exposed to the wetting action of the detergent. Emulsifying action then comes into play again and disperses an additional portion of the oily mass. Thus we see that emulsification is contingent upon wetting, and that further wetting is contingent upon emulsification, and the combined effect of the two actions is the loosening, breaking up, and dispersion of the oily film.

Saponification

Saponification is the process whereby the fatty acids in animal and vegetable oils unite chemically with certain alkaline substances to form soap. The soap so formed is quite similar to household soap in its chemical properties and behavior, if not in external appearance. The removal of fatty acid soil is one of the major problems of detergency. Many greases consist of a mixture of animal fats (such as

tallow) and petroleum oils. Petroleum or mineral oils cannot be saponified and therefore must be removed through the process of wetting and emulsification. But the fatty acid components of lubricants do react with certain alkaline detergents to form water-soluble soaps.

Deflocculation

Many types of soils or contaminants encountered in metal cleaning are of a solid or semi-solid nature. Chemical materials which have the ability to break up a solid mass into small particles and to disperse them through a liquid medium are known as deflocculating agents. The earliest detergent known, far predating soaps and chemical detergents, is fuller's earth, a highly colloidal clay that possesses notable deflocculating powers. Colloidal activity plays a vital part in the removal of solids composed of insoluble solid particles. Carbon, clay, road film, food deposits, and paint fumes are among the soils removed by colloidal forces.

The mechanism of deflocculation is believed to involve the neutralization of those forces of surface tension responsible for the attraction between solid particles. Experimental data reveal that in every instance deflocculation is attendant upon a reduction of the forces of surface and interfacial tensions involved. Complete wetting of the solid is absolutely necessary to initiate deflocculation.

Colloidal forces are important not only in the direct dispersion of solid particles but in softening and swelling resinous binders, which are a factor in the adhesion of paints, enamels, and similar coatings, and in cleaning impacted buffing compounds.

Solvent Activity

Solvents may be divided into two broad classifications: aqueous, or water base, and non-aqueous, or organic base. The solvent properties of water are utilized in cleaning to remove many salts, acids, sugar, and syrup deposits. In aqueous cleaning solutions, water also acts as the solvent medium for the detergent compounds, thereby liberating the energies

which result in wetting, emulsification, saponification, and deflocculation of soil. Besides its solvent activity, water also acts as a dispersal medium for oils and particles which it will not dissolve, but which it can be made to carry in suspension. Further, it serves as a means for the application of heat energy and for applying the mechanical energy of agitation, all of which play a part in detergency.

The chief limitation of aqueous solvents as detergent agents is that they have little or no solvent effect on oils or greases. Such ionizing solvents are described as *lipophobes* (fat haters). Their counterpart, the non-aqueous organic solvents, are similarly described as *lipophiles* (fat lovers).

Since most solvent applications have some hazards due to combustion, toxicity, or other characteristics, the use of any particular operation is dependent on establishing and maintaining an adequate safety program.

Another approach to the employment of solvent activity in cleaning is the use of the second broad classification of solvents, the non-aqueous solvents. Derived basically from petroleum, coal, and wood, these solvents are unable to dissolve many substances which are readily soluble in water, but they do possess the ability to dissolve not only oils and greases but many resins, rubber, bitumens, paraffin, waxes, and plastics. One of the fundamental advantages of the organic solvents is that they are capable of formulations that are chemically neutral, so that they offer a method for the safe cleaning of reactive metals, such as aluminum, magnesium, copper, and zinc. Some of the most difficult problems in detergency, such as the removal of carbon from engines and stripping of paints and organic enamels, are assigned to organic solvents. The tenacious, intensely hard carbon deposits which form on engine surfaces are held together by resins formed during combustion of petroleum fuels. No available detergent has been found to exert a direct solvent action on carbon, but certain organic solvents are capable of softening and dissolving the resins which bind the carbon particles together into masses and hold them to the surface. A similar situation exists in the removal of paint where the pig-

ment is insoluble, but where the resinous bonding agent may be softened, swelled, or dissolved by the use of suitable solvent reagents.

pH and Its Control

pH is a yardstick for measuring the degree of alkalinity or acidity of water solutions. It is the measure of the energy but not of the amount of alkali or acid in solution. When table salt dissolves in water, a certain portion of it splits up into groups of electrically charged particles called ions, which are molecules of the component sodium and chlorine. Similarly, when hydrochloric acid dissolves in water it splits up, or dissociates, into groups of chlorine and hydrogen ions. When the familiar alkali caustic soda, or sodium hydroxide, dissolves in water, it yields sodium and hydroxyl ions. All acids share in common this ability to yield hydrogen (H^+) ions in water solution. All alkalis yield hydroxyl (OH^-) ions in water solution. Alkalis and acids differ greatly, however, in the number of hydroxyl or hydrogen ions they release per given weight in a given volume of water. A fluid ounce of 50 percent hydrochloric acid solution would yield a far greater number of hydrogen ions than a fluid ounce of a 50 percent solution of acetic acid. An acid which yields a great number of hydrogen ions is energetic in entering chemical unions with other substances, and is therefore described as a strong acid. The same distinction holds between strong and weak alkalis, except that the release of hydroxyl ions rather than hydrogen ions is responsible for the difference in activity in alkalis. It may be concluded, therefore, that the concentration of hydrogen and hydroxyl ions determines the relative degree of acidity or alkalinity of a water solution. To simplify expression of the values, a scale has been devised that is based on the logarithm of the reciprocal of hydrogen (or hydroxyl) ion concentration.

Values so arrived at are known as the pH values and may be arranged on a scale from 0 to 14, with 7 as the neutral point. Values above 7 indicate degrees of alkalinity; values below 7 indicate degrees of acidity. Both alkalinity and acidity become more intense as values move

away from the neutral point. Thus pH 8 represents a weak alkaline solution, and a pH of 6 a weak acidic reaction. At the other extreme, a pH of 1.5 indicates a strongly acid reaction while a pH of 13.5 represents a strongly alkaline solution. Each increment in pH, expressed as a whole number since it is based on a logarithmic scale, represents a tenfold increase or decrease in acidity or alkalinity: pH 5 is 10 times stronger in acid than pH 6; pH 4 is 10 times more strongly acid than pH 5 and 100 times more strongly acid than pH 6, and so forth.

Since pH is a method of stating the concentration of electrically charged groups of molecules, the most accurate method of measuring pH involves the use of a sensitive voltmeter (a pH meter) which measures the electrical potential across the charged ions and registers this in terms of pH values.

Buffer Activity

The degree of acidity and alkalinity of a cleaning compound plays a part in rust and scale removal, in etching and pickling metal, in saponification, and emulsification. Buffering, the means by which a solution resists a change in the degree of acidity or alkalinity, requires very accurate pH determination. pH readings are helpful in proving comparative data on the action of a given detergent, if all other conditions have been carefully controlled.

Some of the most difficult tasks in the field of detergency, the stripping of paint from reactive metals and the removal of carbon deposits, are assigned to solvents in which ionization does not take place.

The detergent effect of a compound is not determined merely by the acid or alkaline strength of the solution. If this were the case, then raw caustics such as sodium hydroxide should be among the most efficient detergents known. Yet research and experience prove that such materials are relatively ineffective as detergents. Their potency is rapidly exhausted and, being deficient in wetting properties, they are slow to initiate cleaning action. They have no effect in conditioning hard water and are difficult to rinse.

Alkalinity and Acidity

In the discussion of the pH, reference was made to the distinction between the degree and the amount of alkalinity or acidity. The active alkalinity or acidity is a factor of the extent to which the detergent ionizes to yield hydrogen or hydroxyl ions. If the detergent disassociates completely during the course of the cleaning, the total amount of acid or alkali in the detergent is gradually made available for useful cleaning. Conversely, if a considerable amount of acid or alkali fails to disassociate or become active, it merely represents so much inert material or filler which plays no part in the cleaning and which is a source of rinsing difficulties.

In the selection of a detergent, the criterion of value is not the amount of acid or alkali by weight or volume which is offered, but the extent to which the acid or alkali can be made available for the removal of dirt or soil. A cleaning compound may consist entirely of alkaline substances, yet only 10% of this amount may actually be effective in removing soil. In the formula of a scientifically balanced detergent, the choice of each component can be justified in terms of the definite function assigned to it in the cleaning operation. Moreover, the components will not merely fulfill their individual functions, but will support and reinforce each other, so that the whole compound will be more active and more stable in cleaning activity than any of its parts.

Hard versus Soft Water

If distilled water could be used in the make-up of aqueous cleaning solutions, many problems could be avoided. It is, unfortunately, impractical to use distilled water in the tremendous gallonage required for industrial cleaning operations. Local natural water sources are employed and these almost invariably contain dissolved bicarbonates and sulphates of calcium and magnesium. The presence of these minerals is responsible for water hardness, and the fact that soaps lose much of their efficiency in the presence of hard water has long been recognized. Soap reacts with the dissolved magnesium salts to form insoluble, adhesive precipitates. The soap which takes part in this reaction is

thus unavailable for cleaning, and the gummy deposits resist rinsing and may form a more stubborn and objectionable soil than the original dirt.

Vapor Degreasing

The process of cleaning metals with non-flammable solvents is commonly known as vapor degreasing. It is one of the most widely used procedures for cleaning metals of all kinds prior to inspection or assembly, or in preparation for subsequent processing or finishing operations such as rust-proofing, painting, electroplating, anodizing, and galvanizing.

Essentially the process comprises suspending the work in the vapors of trichlorethylene, perchlorethylene, freon, etc., so that the pure, condensed liquid solvent rinses the parts free from grease or oil. The vapor stage is often used in combination with immersion in boiling or warm solvent or spraying with warm solvent, as may be required by the size, shape, and type of parts, and the nature of the soil to be removed. The unique feature of the process is that regardless of which combination of treatments may be used the work leaves the machine through the vapor level, and is thus washed with pure liquid solvent which has condensed on the surfaces. The parts being heated to the vapor temperature (and on rising above the vapor level) dry quickly by evaporation before removal from the machine.

Acid Cleaning

A strong hydrofluoric, muriatic, or nitric acid bath is used to remove scale and rust or oxides from metals in a process known as pickling. When the need arises to remove oil, dirt, and soil additions to the scale and rust, the use of acids or acid compounds containing detergents is termed acid cleaning. Acid cleaning may be accomplished by circulating the cleaning compound through the parts, components, or assemblies to be cleaned. This may be in tumbling barrels, spray equipment, or in soak tanks or vats. Either hot or cold solutions may be used, according to the product, the application, and the nature of the soil to be removed.

When considering acid cleaning, one should

be certain that chemical reaction to the detriment of the material will not occur.

Ultrasonic Cleaning

The cleaning action of a sonic system depends to a major extent on the phenomenon technically termed vaporous cavitation. The pressure differentials imposed in a solution by the implosion of minute cavities or bubbles within the solution account for cavitation. This energy imparts an intense and distinctive mechanical action which is extremely effective for cleaning.

Cavitation may be generated in several ways. The most common way is to use a sound wave to produce acoustical cavitation. A sound wave is a longitudinal or a compression wave. As it passes through a medium, its energy is transferred from molecule to molecule from the radiating source. The speed with which this motion takes place will differ with each medium. In a sonic cleaning system, the sound wave is transmitted by a transducer into the cleaning fluid. Under the proper conditions, three important and basic effects occur:

1. The free bubbles in the solution that are visible to the naked eye are caught by the compression wave; they coalesce, become buoyant, and rise out of the solution. The bubbles below visibility (60 microns) are mechanically stabilized in the solution and are not outgassed. The effect of degassing the large bubbles is an important phase of the ultimate cleaning efficiency of the solution. If the larger bubbles remained in the solution, they would act as sound absorbers and impede the subsequent sound waves, making them ineffectual for any practical cleaning purposes.
2. The sound wave also generates what is technically termed gaseous cavitation. During this phase of cavitation, gas-filled bubbles in the liquid are compressed and expanded by the alternating pressure caused by the passing sound waves. This pulsating action is the beginning of sonic cleaning.

3. The most important effect is labeled vaporous cavitation. In this case the compression wave causes the bubbles to collapse and leave a void or hole in the liquid. The liquid under hydrostatic pressure immediately rushes to fill the void, creating tremendous transitory pressures. This alternate vacuum and pressure action constitutes the major aspect of a properly designed sonic energy cleaning system.

Barrel Finishing or Tumble Cleaning

Although once used mainly for burnishing parts to impart a luster or surface for plating, tumbling now includes a multitude of operations which can be accomplished with a combination of water, chemical compounds, steel balls, and stones. In addition to burnishing, this method is very widely used for deburring, self-tumbling, barrel cleaning, descaling, and oxide removal, and is usually the most economical method to process small parts. Barrels are infrequently filled more than two-thirds or even half full, with the liquid media normally covering the load level (parts and media) by half an inch or so. Parts to be burnished should be well cleaned first for the best results.

Immersion Cleaning—Soak Cleaning—Vat Cleaning

These different terms denote the immersion of parts to be cleaned into a tank or vat of some selected solution until clean. This is followed by rinsing. The cleaning of metals usually involves some alkaline soak cleaning. Nonferrous metals, such as zinc and aluminum, require use of inhibited cleaners that do not attack the metal; steel, cast iron, magnesium, and copper normally require stronger alkaline cleaners that also do not attack the metal. Soak or vat cleaning is the popular method for removal of rust, for paint stripping, aluminum etching, and aluminum soak cleaning; salvage cleaning of parts, tools, engines, and equipment; carbon removal from engine parts; and cleaning of parts prior to vitreous enameling. Various agitation techniques, such as pumps, stirrers, and sound (ultrasonic), are employed to augment the action of the media and frequently prove of great value.

Electrocleaning

This is the soak process with the addition of an electric current to improve the quality of the cleaning action. Metals which are to be subjected to plating are usually cleaned this way. Except for nickel and stainless steel, nearly all metals are cleaned (in the U.S. and Canada) by the reverse current flow method, which means that the part itself becomes the anode, with the current flowing between it and the cathode—quite naturally, direct current would involve the part acting as the cathode and the current flowing to an anode. The voltage range is usually from 6 to 12 volts; the current density range is from 25 to 50 amperes per square foot for nonferrous alloys and 50 to 100 amperes per square foot for steel.

Spray Cleaning

This is usually a progressive arrangement through which the parts are conveyed. Spray washers are quicker and function at lower concentrations than soak cleaning tanks, and take advantage of the full hydraulic force of the sprayed solution to penetrate and remove soil. The most common uses include removal of cutting oils and chips between machining operations or prior to heat treat, the cleaning of metals prior to phosphating and painting, and removal of buffing compounds. The spray technique can also serve as a complete cleaning process. Spray washers have one to six stages, with some special equipment having more than six.

Steam or Vapor Cleaning

Either of these processes (and the name is usually a matter of local preference) is a special application of the hydraulic principle of cleaning. A cold alkaline solution is passed through oil-fired coils, or the alkaline solution may be fed into the water after it has passed through the coils. Enough steam must be generated to raise the pressure to 60 or more pounds per square inch, which forces the hot cleaning solution through the nozzle so that it impinges with considerable force against the surface to be cleaned.

Surface Cleaning by an Ionized Gas Jet

Ion bombardment of surfaces to remove the last traces of residual contamination is sometimes more effective than washing, and is usually accomplished by one of the following techniques:

1. Flaming the surface;
2. Playing a Tesla discharge over the surface; or
3. Placing the surface in a glow discharge at reduced gas pressure.

The latter technique is most generally used on surfaces encountered in electron tube construction, and it is difficult to use under some circumstances. Although critical areas may be masked by necessary mounting jigs, there is the hazard of spluttering unwanted materials, and there are times when the use of such a vacuum process as a cleaning step is inconvenient.

Methods 1 and 2 are generally applicable only to refractory, nonmetallic surfaces which have no metallic parts in the vicinity of the area to be cleaned. Metallic parts will oxidize when flamed, or will divert a Tesla discharge from covering the area of interest.

NOTE: The need for cleaning small ceramic sub-assemblies with metal appendages was the initial reason for determining the effect of a stream of ionized gas directly on such a surface as a possible cleaning agent.

Even a cursory perusal of the principles discussed makes it obvious that surface cleaning is and can be a very complex process involving multiple considerations, differing conditions, and almost infinite variables. All surfaces cannot be cleaned with any one given compound or material, one method of application, or one type of equipment. It could well be that one all-powerful type of solvent, when put to work in an elaborate piece of cleaning equipment, would exert sufficient detergency to perform 90 percent of all the cleaning problems discussed. But how economic would it be? What hardships would it work on the operators of such a process?

Consequently, when the factor of efficiency is contrasted with the all-important factors of safety and economy, it is increasingly evident

that manufacturers of cleaning compounds must resort to a multiple line of products. Some of these may be general purpose for common metals or soils, but special purpose compounds are required for given metals and specific contaminants.

Some of the common metals and comments on cleaning them follow:

ALUMINUM:

A light metal that possesses considerable resistance to some acids, but etches readily in uninhibited alkaline cleaners.

BRASS AND BRONZE:

Copper-bearing alloys containing zinc and tin respectively. Both require uninhibited cleaners.

COPPER:

Copper may be cleaned with the same cleaners used for steel or brass.

LEAD:

Lead requires an inhibited cleaner. A fluoboric acid dip is best for pickling lead prior to plating.

MAGNESIUM:

A light metal that is safely cleaned with heavy duty steel cleaners. Magnesium will corrode in mild cleaners, but not in highly alkaline cleaners.

NICKEL AND STAINLESS STEEL:

Both are resistant to corrosion and can be cleaned with most products having the strength to attack the degree of soil present.

STEEL AND CAST IRON:

Corrode in acids, but resist most alkalies. Steel can be cleaned with alkaline cleaners if the heavy duty variety is used.

TERNEPLATE:

This is lead on steel, and should be cleaned like lead.

TITANIUM:

This material presents many problems and should be carefully checked out before defining a process.

ZINC:

This nonferrous metal requires an inhibited alkaline cleaner.

ZIRCONIUM:

Normally cleaned like steel, unless the alloy would dictate otherwise.

Bibliography

CLEANING METALS PRIOR TO ELECTROPLATING: ASTM B322-58T; American Society for Testing Materials, 1916 Race Street, Philadelphia, Pa. 19103.

DESCALING AND CLEANING STAINLESS STEEL SURFACES: ASTM A380-57, American Society for Testing Materials, 1916 Race Street, Philadelphia, Pa. 19103.

CHEMICAL CLEANING OF METALS: Linsley, H. E.; American Machinist/Metalworking Manufacture, pages 67 through 78; February 4, 1963.

ABRASIVE BLASTING METHOD OF CLEANING AND CORROSION REMOVAL: T.O. 1-1-5 Technical Manual; U.S. Air Force; February 20, 1964.

METAL CLEANING: Metals Handbook—8th Edition, Volume 2, pages 307 through 370; American Society Metals, Metals Park, Ohio; July 1964.

SURVEY OF CERTAIN NONTHERMAL METHODS OF DECONTAMINATION AND STERILIZATION: Silverman, Gerald; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 193; November 16, 1965.

PROCEEDINGS OF THE CLEANING CONFERENCE IN JANUARY 1966 AT GEORGE C. MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE.

THE PHYSICAL CHEMISTRY OF CLEANING: Krieger, G. L.; SC-TM-66-428, Sandia Corporation; September 1966.

CHAPTER 7

Liquids, Gases, and Solids

The methods required to control contamination vary with the type and amount of contaminant to be controlled, and the required level to which a liquid, gas, or solid is to be maintained.

Liquids and gases may be divided into two general groups:

1. Those used as a part of a system, e.g.:
 - Hydraulic fluids and actuating or control gases;
 - Fuels;
 - Coolants;
 - Lubricants; and
 - Refrigerants.
2. Those used in processing and support of system activities, e.g.:
 - Cleaning solvents;
 - Flush gases and liquids;
 - Cutting oils; and
 - Lubricants.

Liquid or gas used as part of a system may be recycled or reused repeatedly in the system. In such cases a method of maintaining the contaminant level of the liquid or gas at an acceptable level should be considered.

The storage, transportation, handling, and transfer of liquids or gases should not contribute to their contamination. This requires attention to containers, handling or transfer equipment (funnels, valves, pipes, etc.), and the techniques employed.

Liquids

Liquids may be contaminated by particles (suspended), dissolved matter (combinations, gases, solids) or other liquids as shown in Figure 2. Regardless of the contaminant involved, a level of cleanliness must be specified for a given liquid. Such a requirement should not be imposed unless an adequate method of measuring the contaminant level is available to assure a good contamination control program.

Clean liquids are either purchased to the required contamination level, or are cleaned after

receipt from the supplier. Economic factors usually dictate the course to pursue. If small quantities are involved, it is unlikely that the user can justify the cost of maintaining his own filtering or distilling system. The cost of equipment, maintenance, space, and manpower must be balanced against the cost of the liquid.

Particle control in liquids

Particles are usually removed from liquids by filtration, although centrifugal separation and settling are employed under specific circumstances.

Filters are normally chosen to remove most particles above a specific size from the liquid. A filter may be a screen, a membrane, fritted glass, sintered metal, or in some instances merely a slit opening. The most appropriate type of filter is dependent upon one or more of these factors:

- Liquid compatibility with the filter;

- Quantity of liquid to be filtered;

- Quantity of contaminant to be removed (a pre-filter may be necessary or economical);

- Permanence or disposability;

- Temperature of liquid; and

- Accessibility in system (for replacement).

Liquid pressure requirements to be considered should include:

- Restrictions of the filter to liquid flow;

- Absolute system pressure; and

- Pressure variations (due to pulsation).

The two preceding paragraphs point up the need to consider the effects of the system on the filter and the effects of the filter on the system.

Dissolved matter in liquids

Chemical separation, ion exchange, distillation, heating, or vacuum may be required to control dissolved matter in liquids. The same considerations apply as in the control of particles. Removal of dissolved matter may present

additional problems when the characteristics of the contaminant and the liquid are similar (vapor pressure, weight, etc.).

Detection of dissolved contaminants may be very difficult when their volume is small and when the contaminants have characteristics quite similar to the liquid.

The distillation technique is commonly used to obtain high purity water and to maintain the high purity requirements of some solvents (vapor degreaser fluids, solvent stills, etc.). Ion exchange is another widely used means of obtaining high purity water.

Gases

Particulate contamination in gases

Contamination of gases by small particles may be controlled by filtration. To remove large particles, centrifugal separators or the sedimentation method may be more practical. The other methods, electrostatic precipitators and several types of scrubbers, are not commonly used with the types of gases discussed in this section.

Filtration requirements for gases are similar to those for liquids. Specific considerations for gas filters include:

- Efficiency for removal of specific size particles;
- Quantity of gas to be filtered;
- Compatibility of gas and filter;
- Pressure required to pass gas through filter;
- Temperature of gas at filter;
- System pressure requirements; and
- Need for pre-filtering due to volume of contaminants in the gas.

Gaseous contamination in critical or high purity gases

To maintain the purity of a gas, one must consider several special problems:

1. *Separation and removal of contaminants from gases:* This may require difficult and expensive procedures. This will often be caused by a similarity in the chemical and physical characteristics, or gases whose chemical reactions create a very difficult separation combination. It is a

very specialized problem, worthy of close scrutiny and analysis. The purity of the basic gas must be maintained, and the closed system must be adequately cleaned to preclude the creation or introduction of any contamination by physical or chemical action.

2. *Isolation of a critical gas from contaminating gases:* The possibility of contamination of a critical gas from surface-absorbed gases within the system must not be overlooked. The volume of absorbed gases will vary with the surface roughness and porosity of the materials comprising the system.
3. *Condensation of gases within a system:* Gases in their natural state may not be a problem, but when converted to a liquid or solid state they may cause problems in a system. Water vapor and certain soldering fluxes are examples.
4. *Control or avoidance of chemical reactions within a system generating contamination gases:* Another important consideration is the reaction of a contaminant present in a critical gas without adverse effect on the critical gas, but causing a reaction on other parts of the system.

Solids

Contamination in solids may be in the form of particles, dissolved matter, gases, and droplets. In many instances the solids have acquired this contamination while in a liquid state.

Contamination also may be absorbed directly into a solid, especially if it is porous (plastics, some metals, etc.). Exposure of a porous solid to gases or liquids (water or solvent absorption, penetration of active gases, etc.) may contaminate it.

Some of the effects of contaminants in solids are:

1. Altered mechanical properties (strength, hardness, brittleness).
2. Electrical characteristics (dielectric constant, conductivity).
3. Optical properties (light transmission and absorption).

In general, contamination control for solids

should include both the use of raw materials of a required and verified purity, and the observance of contamination control regulations during the processing. The protection of porous solids may be necessary during an entire manufacturing cycle if they are exposed to penetrating contaminants.

The possibility of contamination of a solid is normally the greatest during its processing as raw material, which is the reason for stipulating material purity. As stated in Chapter 4, the designer is responsible for indicating the material purity requirements. These should preclude difficulty during the fabrication of a product.

Bibliography

- PROCEDURE FOR THE DETERMINATION OF PARTICULATE CONTAMINATION OF HYDRAULIC FLUIDS BY THE PARTICLE COUNT METHOD: SAE-ARP-598, Society of Automotive Engineers, Inc., 485 Lexington Avenue, New York, N.Y. 10017.
- FILTER APPLICATIONS FOR SPACECRAFT STERILIZATION PROGRAM: Decker, Herbert M.; and Buchanan, Lee M.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 259; November 16, 1965.
- GASEOUS STERILIZATION: Phillips, Charles R.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 231; November 16, 1965.
- SPECIFICATION FOR GAS CLEANLINESS REQUIREMENTS FOR OPERATIONAL GASEOUS NITROGEN, HELIUM, AND HYDROGEN SYSTEMS AT COMPLEX 39: KSC-C-182; June 7, 1966.
- CONTAMINANT REMOVAL FROM CIRCULATING OIL SYSTEMS—I: Lubrication, Volume 52, Number 8, Published by Texaco, Inc., 135 East 42nd Street, New York, N.Y. 10017; November 8, 1966.

CHAPTER 8

Radiation

Radiation, as a contaminant, is energy in or near a material to which it might be detrimental, which energy can be in the form of either particle velocity or a wave phenomenon and be transmitted through certain gases, liquids, or solids. The effect of radiation upon materials depends on the energy and charge of radiated particles or upon the frequency and magnitude of the wave.

Radiation can (1) change the state of energy of a material, (2) result in a chemical reaction, (3) change a physical characteristic such as strength, or (4) change an electrical or magnetic characteristic. A change in the energy state of a material is usually observed as an increase in temperature, such as occurs when an object is subjected to infrared radiation. Some materials may undergo a change in phase (i.e., change from solid to liquid or from liquid to gas) if subjected to a sufficiently high level of radiation. Additionally, radiation can cause electrons to be emitted from solids, thus increasing electrical noise within an electronic system.

Some radiations form ions as well as free radicals which result from neutralization of the ions. Both the ions and the free radicals may be chemically reactive with materials in a system.

Fast charged particles (beta particles) ionize atoms in materials in their path. Some electrons released in this manner create additional ionization—perhaps sufficient to cause electrical

conduction—which can result in failure of an electrical system.

Heavy charged particles (such as alpha particles and protons) can accelerate nuclei in solids, causing them to leave their positions in a crystal lattice, thereby modifying the mechanical properties of the solids.

Radiation in the form of visible light, infrared, and X-ray contaminates photographic film and causes electrons to be emitted from some materials. The emitted electron can cause ionization or other effects.

Ultrasonic vibration, another form of wave energy, may have a frequency as high as 10^8 cycles per second. That vibration can subject particles suspended in a liquid to bombardment by molecules of the liquid, thereby breaking the particles up and placing them in colloidal suspension. On the other hand, ultrasonic vibration can cause small particles in gases to coagulate and precipitate.

Vibration in the audible range can cause parts to break up or rub together in such a way that they can generate heat and cause the materials to produce wear particles.

The effects of radiation can be minimized by shielding or by some isolation of the product from the source of radiation.

Products contaminated by radioactivity may be scrubbed, or stored in a suitably shielded location until the radioactivity has decayed sufficiently so as not to be a personnel hazard. Decontamination procedures may be found in appropriate publications.

CHAPTER 9

Microbial Contamination

The purpose of contamination control is to reduce or manage contamination at some desired level. Microbial contamination poses special problems, since living forms have the ability to reproduce and grow. A specialized form of control is needed to cope with microbial contamination. There is a need for control of bacteria, fungi, and viruses in hospitals, in space sterilization, and in the food processing and pharmaceutical industries. Problems associated with jet aircraft fuels, printed circuits, and electronic malfunctions also have been related directly to microbial contamination.

Microbial contamination may be defined as unwanted living micro-organisms in a specified environment. Microbial contaminants may vary in size from the protozoa, algae, and fungi on the large end of the spectrum, through the yeasts, to the bacteria and the rickettsiae, and finally to the smallest, the viruses. Microbial contaminants are similar to other particulate contaminants in that they have structure and mass, but differ from such particulate matter in that micro-organisms have the ability to reproduce, grow, and to carry on physical processes. The viruses and the rickettsiae are obligate intracellular parasites, i.e., they are dependent upon other living cells for their nutrition and replication. Algae and certain bacteria are photosynthetic and are able to grow and multiply when furnished with a few simple salts. Certain of the fungi are capable of growth in even such harsh environments as mineral acids and upon substrates such as wood, cloth, leather, and even glass. Certain bacteria and fungi form structures called spores which are highly resistant to deleterious conditions such as drying or the application of heat and chemical disinfectants.

When control of microbial contamination is desired, sterility is the only condition that can be considered stable or final. Sterility is an absolute term denoting the absence of all life. It either is or it is not. There can be no such condition as "almost sterile" or "nearly sterile." The companion word, "sterilization", refers to the process by which sterility is achieved. In some highly specialized requirements, the debris of dead organisms may be a contaminant and cause problems because of chemical action of the residue or because of the physical structure of the debris. Moreover, practical problems arise for anyone employing routine sterilization procedures; for example, heat is the most reliable means of killing micro-organisms, but it cannot be employed for the sterilization of heat labile materials. In such situations it often becomes necessary to resort to less reliable means of sterilization, or to accept something less than sterilization, such as decontamination. Decontamination means a reduction of the quantity of living material to a lower level but not necessarily to zero, which would be sterility. Decontamination is frequently a prelude to sterilization.

In controlling microbial contamination, the standards of control to be achieved must be defined: i.e., the goal of the control system must be defined in microbiological terms. If sterility is the aim, the criteria should specify what procedures are to be used in testing for sterility. If sterility is not the objective, the criteria should specify the maximum numbers and types of micro-organisms allowed in an environment, in a solution, on a surface, in a component, etc., and should indicate the test methods to be used. The testing of surfaces, solutions, and components for sterility or numbers of

residual micro-organisms is frequently destructive to the item being tested. Consequently, sterility itself often cannot be verified; instead proven methods of achieving sterility can be utilized and statistical techniques applied.

The most widely used physical and chemical means of sterilization and/or decontamination may be classified under one of the following six headings:

1. *Heat:*

Application of heat is the most effective method of inactivating micro-organisms. Whenever possible, heat should be used to sterilize materials because all organisms succumb to heat at some level of exposure. Moist heat is more effective than dry heat but is useful only when the moisture will penetrate to the micro-organisms and where the moisture will not have a deleterious effect on the material being treated.

Much of the work on kill rates for resistant bacterial spores has been expressed in D-values, or the time required to reduce a population by 90 percent, assuming logarithmic rates of destruction. It is necessary to use longer heating periods in order to sterilize when higher numbers of organisms are present. Therefore, if the total load of micro-organisms can be held to a low level the time of heating for sterilization can be reduced.

2. *Vapors and Gases:*

A variety of vapors and gases possess germicidal properties. Among these are ethylene oxide (ETO), formaldehyde, propylene oxide, betapropiolactone (BPL), methyl bromide. When these agents are combined with the proper conditions of temperature and humidity, excellent decontamination can result. Under controlled conditions, ETO is a highly penetrating and effective decontaminating gas, convenient to use, versatile, noncorrosive, and effective at room temperature; however, ETO is slow in killing micro-organisms and should be mixed with other gases to avoid explosion hazards. Formaldehyde and BPL are used primarily as decon-

taminants for rooms and building interiors. Formaldehyde, the slower acting of the two, has the undesirable property of leaving a difficult-to-manage residue. Betapropiolactone is much faster acting than formaldehyde and does not leave an undesirable residue after spraying. The toxicity to humans of BPL, however, is a serious deterrent to its use. Methyl bromide is about one-tenth as active against micro-organisms as is ETO. Methyl bromide has found widest application for decontamination of soil, especially to eliminate fungi.

3. *Liquid Decontaminants:*

The most frequently used liquid disinfectants include chlorine solutions, iodophors, alcohols, phenolic compounds, and quaternary ammonium compounds. There are many misconceptions concerning the use of liquid decontaminants. Chemical disinfection is time-concentration oriented. For example, at a given concentration a disinfectant solution may be bactericidal (lethal), while at another concentration it may be only bacteriostatic (inhibitory). Factors to be considered when liquid decontamination is to be used include: temperature, contact time, pH level, concentration, and the presence of organic material at the site of application. Small variations in these factors may cause a great change in the effectiveness of the chemical being used, and complete reliance should not be placed on liquid decontaminants.

4. *Radiation:*

Ultraviolet radiation, X-rays, gamma rays, high-energy electrons, protons, alpha particles, and neutrons are examples of forms of radiation capable of killing micro-organisms. The most common methods currently used for the sterilization of materials such as surgical and laboratory supplies, packaged foods, etc., are: (a) high-energy electrons from a particle accelerator, and (b) gamma radiation from a radioactive source. Micro-organisms vary

significantly in their resistance to radiation, and the dosage must be determined experimentally. Irradiation sterilization with gamma rays or high-energy electrons is used mostly with packaged goods and food products. Ultraviolet radiation is an effective means of decontaminating air and surfaces. It is also useful for reducing extraneous contamination in rooms. Ultraviolet radiation has limited penetrating power, and thus is most effective on exposed surfaces or in air. Proper concentration, contact time, and maintenance are also critical. Ultraviolet emission tubes must be kept clean or their effectivity will be greatly diminished.

5. *Filtration:*

Filtration is an effective means of removing viable or nonviable particles from air or liquids. The size range of the particles which are removed depends on the characteristics of the filter. Membrane filters may be used to filter small volumes of air and may also be used to filter fluids. Fluids should be clarified before being passed through such filters to avoid filter clogging.

Whenever filters are included in a contamination control system such as laminar flow, the filters must be tested to assure adequacy of operation. It is particularly important to test the complete filtration system *in situ* prior to beginning routine operation. In some instances microbiological tests with tracer micro-organisms will be appropriate, and in other instances temperature measurements and other tests are applicable.

6. *Isolation:*

Isolation of a part or device in a microbially clean area for extended time periods may allow organisms to die off and reduce the population. This is often an effective technique for decontamination, especially where vegetative cells are concerned; however, it is necessary that moisture and a food supply or source of energy for organisms be eliminated. The efficacy of such isolation techniques for decontamination of bacterial and fungal spores is not

known but it is certainly less efficient than for vegetative cells.

The success of any attempt to control microbial contamination depends largely on a combination of work techniques employed and the personnel involved. In general, "correct techniques" relate to the movements of people in the working environment when these movements influence the spread of contamination through the air or on surfaces. Techniques that involve violent movements, aspiration of fluids, spraying of materials, foaming or bubbling of liquids, and overflow or leakage of materials indicate a need for specifying exactly how the technique is to be carried out to achieve minimum spread of microbial contamination. Yet procedural and handling techniques cannot be depended upon for complete control of microbial contamination.

Engineering developments have provided devices for efficient microbiological and physical separation between environments. The most important type of containment and isolation equipment is the gas-tight, absolute barrier enclosure. Freon testing is the method of choice to validate the tightness of any absolute barrier system. Cabinets and enclosures have been designed for the control of microbial contamination by regulating the direction of air flow in or out of the critical areas. Some laminar flow cabinets or benches perform in this manner. Various engineering and performance standards can be established for any type of containment equipment, and the more commonly employed requirements include: (1) leak tests for the enclosure, (2) ventilation rates, (3) filtration or incineration of air supplies or exhausts, and (4) provisions for decontaminating or sterilizing the interior of the enclosure and the air filters.

The significance of man in any system where microbial contamination control is attempted deserves special consideration. Man is an extremely prolific source of micro-organisms. Unlike inanimate objects, he cannot be separated from a microbial population, and only with difficulty can he be enclosed in a ventilated garment to separate him from a controlled environment. Contamination control is simplified when man is isolated from the system.

The application of modern construction

criteria to the design of new facilities can do much to control microbial contamination. Some of the features suggested for inclusion in new or renovated facilities to control microbial contamination include:

1. Use of clean rooms to exclude micro-organisms from a particular environment.
2. Use of ventilated clean hoods, chambers, or cages to achieve an absolute or partial barrier to contain micro-organisms at their point of use, or to exclude them from a specific work area.
3. Use of differential air pressures within a facility to move air from clean areas toward areas of higher microbial contamination.
4. Use of effective microbial filtration of air supplied to and/or exhausted from clean rooms, clean hoods, chambers, or cages.
5. Room arrangement or layout to achieve traffic control within the facility along a clean-to-contaminated axis.

The effective control of microbial contamination is the culmination of thorough and detailed planning coupled with effective personnel orientation in the important part they occupy in the overall effort.

Bibliography

PRELIMINARY REPORT ON MICROBIOLOGICAL STUDIES IN A LAMINAR DOWN-FLOW CLEAN ROOM: Arnold, V. E.; Jack, A. J.; King, J. G.; Marsh, R. C.; and Whitfield, W. J.; SC-RR-

65-47, Sandia Corporation; Confirmation Study by Beakley, Dr. John W.; January 1965.

NASA REQUIREMENTS FOR THE STERILIZATION OF SPACECRAFT: Hall, Lawrence W.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 25; November 16, 1965.

ENVIRONMENTAL MICROBIOLOGY AND THE CONTROL OF MICROBIAL CONTAMINATION: McDade, Joseph J.; Favero, Martin S.; Michaelson, George S.; and Vesley, Donald; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 51; November 16, 1965.

MICROBIOLOGICAL BARRIER TECHNIQUES: Phillips, G. Briggs; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 105; November 16, 1965.

DRY-HEAT STERILIZATION FOR PLANETARY-IMPACTING SPACECRAFT: Bruch, Carl W.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 207; November 16, 1965.

ENGINEERING PROBLEMS IN STERILIZATION OF SPACECRAFT: Magistrare, Victor J.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 285; November 16, 1965.

CLEAN ROOM AND WORK STATION REQUIREMENTS, CONTROLLED ENVIRONMENT: Federal Standard No. 209a; August 10, 1966.

CHAPTER 10

Monitoring for Contaminants

Methods of detecting the various types of contaminants are related directly to both the contaminant type and the environment in which it is located. Some of the methods mentioned in this section are not used as commonly as others—some are not as accurate as would be desirable for certain needs. Therefore, equipment and methods for monitoring contamination should be evaluated on the basis of the needs of the job to be done.

For data obtained from contamination monitoring to be meaningful, one must consider:

1. The type of monitoring equipment and its limitations;

2. The accuracy of the equipment and its calibration;
3. The care exercised during monitoring;
4. The location at which measurements are made relative to sources of contamination and the product; and
5. Other factors such as personnel activity, etc., which might affect the validity of the measurement.

The monitoring principles used in detecting contaminants are listed here according to the type of contaminant and the environment in which the contaminant is located:

<i>Type of contaminant</i>	<i>Monitoring principles in common use</i>
1-1 PARTICULATE----- In air In gas	a. Membrane filter/microscope: Particles are collected on a membrane filter surface and are counted with the aid of a microscope, which is a satisfactory method for particles of 5.0 microns and larger. Ref: SAE-ARP, "Procedure for the Determinations of Particulate Contamination of Air in Dust-Controlled Spaces by the Particle Count Method." b. Light scattering: Particles are forced through a high intensity light beam, and the light rays scattered from the particles are evaluated electronically, a method required for particles in the 0.5- to 5.0-micron size range. Refs: ASTM F-25, "Method for Sizing and Counting Airborne Particulate Contamination in Clean Rooms and Other Dust Controlled Areas Designed for Electronic and Similar Applications," and ASTM F-50, "Method of Test for Continuous Counting and Sizing of Airborne Particles in Dust-Controlled Areas by the Light Scattering Principle (for Electronic and Similar Applications)."
1-2 PARTICULATE----- In liquid	a. Membrane filter/microscope: This procedure is similar to 1a (in air) except that the sample is liquid. b. Light scattering: Similar to 1-1b (in air) except that particles are evaluated while suspended in liquid. c. Light absorption: This method varies from light scattering in the reflective technique, and although it is reasonably responsive for large particles, it is unreliable in the small micron range. d. Silting index: The basic use is to establish the presence of fine particulate in liquids, and if used as a monitor this method has value. The effective range is from 0.5 to 5.0 microns, an area in which microscopic counting of particulate matter is not recommended.
1-3 PARTICULATE----- In solids	Material purity: a. Chemical analysis. b. Nondestructive tests (ultrasonics, X-ray).

*Type of contaminant**Monitoring principles in common use*

- | | | |
|-----|---|---|
| | | <ul style="list-style-type: none"> c. Mass spectrography denotes apparatus for sorting streams of charged particles in accordance with their different masses by means of magnetic deflecting fields. The purpose of this preparation may be to detect various particles, to determine their relative proportions, or to separate them for investigation of their properties. d. Emission Spectroscopy: Especially suited for control analyses of minerals, metals, and alloys. |
| 1-4 | PARTICULATE.....
On surfaces | <ul style="list-style-type: none"> a. Visual: Except for clear and transparent materials, visual inspection is a widely used but ineffective means of identifying anything but gross contamination caused by fabrication, inadequate housekeeping, or operator incompetence. b. Microscopic: An improvement over the unaided eye depending upon whatever power lens is used, this method is limited to identifying size and quantity plus surface imperfections. Films are not detectable unless a discoloration is present, but then the quantity or type of contaminant is still unknown. c. Indirect method: <ul style="list-style-type: none"> (1) After flushing surface with a solvent, use solvent purity meter, plus standard chemical analysis for dissolved matter. (2) Use filtration/microscopic (1-1a) for nondissolved particulate. (3) Light scattering (1-1b). (4) Light absorption (1-2c). |
| 2-1 | GASES.....
In air
In gas | Gas monitor:
<ul style="list-style-type: none"> a. Mass spectrography (1-3c), a direct method. |
| 2-2 | GASES.....
Adsorbed
On surfaces | Gas monitor:
<ul style="list-style-type: none"> a. Mass spectrography (1-3c): When used on surfaces, the gas must be drawn off by vacuum or heating processes, which are indirect monitoring methods. |
| 2-3 | GASES.....
Adsorbed
In liquids | <ul style="list-style-type: none"> a. Chemical analysis—a direct method. b. Mass spectrography (1-3c)—an indirect method: <ul style="list-style-type: none"> (1) When vapor pressures of gas and liquid differ markedly, the gas is driven out of the liquid and analyzed. (2) When the vapor pressures are nearly equal, both the liquid and the gas are analyzed for contaminants. |
| 3-1 | LIQUID.....
In liquid | <ul style="list-style-type: none"> a. Chemical analysis, if both type and quantity of contamination are desired. b. Solvent purity meter, if the contaminant is a dissolved substance having a different volatility than liquid which it contaminates. This equipment will measure down to approximately 1 ppm, dependent on the solvent involved. c. Conductivity measurements, used for high purity water and some solvents. |
| 3-2 | LIQUID.....
In gases | <ul style="list-style-type: none"> a. Light scattering (1-1b): This technique is only used when droplets (i.e., oil, etc.) prevail. b. Membrane filter/microscope (1-1a): The results of this sampling technique should be subjected to microchemical analysis. |
| 3-3 | LIQUID.....
On surfaces | <ul style="list-style-type: none"> a. Water break. b. Rinse: Analyze the fluid by chemical analysis or the solvent purity meter. |
| 4-1 | SOLID (films).....
Adsorbed
On surfaces | <ul style="list-style-type: none"> a. Wetting of surface by liquid. The wettability of a surface by a given liquid is measured by the angle formed between the liquid bead and the surface. This procedure gives an indication of adherence of liquid to the surface under test. b. Visual: <ul style="list-style-type: none"> (1) Microscopic examination will reveal thin opaque films with discontinuities. (2) Some films and oxides discolor surfaces so as to be easily distinguished as contaminants. (3) Ultraviolet causes some film materials such as activated flux to glow. |

*Type of contaminant**Monitoring principles in common use*

- c. X-ray or electron diffraction: X-ray and electron beams are diffracted differently by different crystalline structures, allowing contaminants to be identified.
- d. Electrical conductivity: Conductivity of a metal at its surface is measured. An insulating film which is not penetrated by a small contact force between conducting materials will provide a high surface (contact) resistance, which is an indication of the film's presence.
- 5-1 DISSOLVED-----
In liquid
- 5-2 DISSOLVED-----
In solids
- 6-1 RADIATION-----
(Without reference to type
of environment.)
- a. Chemical analysis.
- b. Solvent purity meter.
- c. Conductivity (see 3-1 a, b, c).
- a. Chemical analysis.
- b. Physical characteristics:
- (1) Strength.
 - (2) Stress.
 - (3) Appearance.
- c. Electrical characteristics.
- a. Light, X-ray, infrared:
- (1) Film: Changes upon exposure to light. Effectively integrates intensity and time of exposure. Film may be color sensitized, i.e., made sensitive to bands of wavelengths.
 - (2) Photoelectric cells: Photoemissive elements of alkali metal oxides (such as sodium, potassium, cesium) are sensitive from deep ultraviolet to infrared. Photoconductive cells such as those utilizing lead sulfide respond to radiation with wavelength to 3 microns or more.
 - (3) Bolometer: Radiation raises temperature, thereby increasing resistance which is used as measure of radiation.
- b. Particles (alpha particles, electrons, etc.):
- (1) Proportional counter: A gas tube in which particles with sufficient energy to ionize gas cause electron flow with each ionization. Current pulses are fed to pulse amplifier and counters. Neutrons require different tube fill gases than are required for charged particles (H_2 for fast neutrons, BF_3 for slow ones). Photons (gamma rays) cause electrons to be emitted from metallic wall of counter, thereby creating gas ionization.
 - (2) Geiger counter: Similar to proportional counter, except higher voltage is used. Single ion pair produced by one particle can be detected. Large constant output pulse requires simple associated circuits. Geiger counter gives no information concerning energy of particle.
 - (3) Scintillation counter: Particle or photon produces internal secondary electrons in luminescent crystal or plastic. (Photocathode of photomultiplier tube.)
 - (4) Semiconductor: Electron-hole pairs created by particle (in p-n junction beneath surface) causes current to flow.
 - (5) Dosimeter: Deflection of charged plates change with loss of charge due to ionization, indicating integrated radiation.
- c. Sound and vibration:
- (1) Microphone: Sound pressure deflects diaphragm which either exerts a force on a crystal to generate an electrical voltage, or moves a coil in a magnetic field to generate a voltage. Both frequency and amplitude of the sound can be measured with microphone and associated equipment. Microphones are used in air or gases.
 - (2) Transducers (accelerometers): Crystal (barium titanate or similar crystal) has its crystals deformed by inertia of a mass undergoing acceleration during vibration. The deformation creates an electrical voltage across the crystal.
 - (3) Visual: Measurement of a gage displacement of object being vibrated. Acceleration can be computed after determining displacement if the frequency of vibration is known.

*Type of contaminant**Monitoring principles in common use*

- (4) Velocity pickup: A mass with a coil attached to it is accelerated through a magnetic field, inducing a voltage in the coil proportional to the velocity of the relative motion between coil and magnetic field. This method is best for low frequencies (above about 10 cps).
- 7-1 MICROBIAL-----
- In air
- In gas
- a. Filtration/culturing:
- (1) Contaminants are collected on the surface of a filter through which air is forced, and are cultured either directly on the filter surface or with the filter overlaid with a nutrient agar medium and incubated for growth of organisms. Colonies of growths are then counted. This method is suited for assay of only those organisms resistant to drying. Filters may be membrane filters with pore size down to 0.01 micron, chemical corps type 6 filter paper, or Mine Safety Appliances 1106BH glass filter paper.
 - (2) Same as a (1), except filters are placed in a broth, shaken in a mechanical shaker, and the broth plated. This method has a high collection efficiency but there is biological decay of some organisms so collected.
- b. Impingement on solid surfaces: The microbial particles impinge upon a surface from which they are cultured and colonies counted.
- (1) Settling plate: Particles precipitate onto or impact against a stainless steel or other sterile plate. The plate is sonicated in sterile water and mixed with agar, then colonies are grown and counted. This is the least expensive of all sampling methods; however, it has the disadvantages of providing no measure of the quantity of air sampled and of being most reliable for large particles.
 - (2) The Anderson sampler is efficient for the collection of small concentrations of organisms one micron and larger in diameter. It collects particles and sorts them into six size ranges. Particles are collected on agar plates so no diluting or plating of particles is required.
 - (3) The Reyneir slit sampler provides a time-concentration relationship with particles being impacted onto an agar surface on a rotating disk which is turned by a clock motor. No diluting or plating procedure is required. This method is not suited for collection of large concentrations of organisms.
- c. Impingement in liquids:
- (1) The all glass impinger (AGI) is a standard instrument which has an air flow rate of about 6 to 12.5 liters of air per minute at near sonic velocity. Organisms are impinged in the liquid of the AGI. The liquid is later diluted and plated, and the clusters of organisms counted. The shearing action of the high flow rate breaks up clusters of organisms so that a better count can be obtained. The high flow rate will destroy many organisms and spores unless they are protected by an appropriate collection fluid. The AGI is useful only for collecting aerosols which are fairly heavily laden with viable particles.
- d. Light scattering (Ref. 1-1b): In clean environments such as laminar air flow rooms and devices, the light scattering particle monitoring method may be used to advantage, since it can be assumed that the quantity of viable particles will always be less than the total number of particles detected by the monitoring instrument.
- 7-2 MICROBIAL-----
- In liquid
- a. Filtration/culturing: The principle is similar to that of 7-1a(1), except liquid instead of air is passed through the filter. Filters have pore sizes of 0.01 micron to 10 microns or more, with flow rates of 0.5 ml/min/cm² to 1000 ml/min/cm², depending upon pore size.
- b. Aliquot sampling: Samples are subjected to aliquot sampling and samples are tested for viable contamination. Statistical analysis can be made by the most probable number (M.P.N.) technique (Ref. A.P.H.A. 19 standard methods for the examination of water and sewage) to determine estimates of microbiological loading.

*Type of contaminant**Monitoring principles in common use*

- 7-3 MICROBIAL-----
On surfaces
- a. Rodac plates: Rodac plates are pressed against smooth flat surfaces. Upon removal from the surface being tested, particles adhere to the nutrient. The plates are cultured and the colonies are counted. A problem with this method is that the Rodac plates leave small residuals of the nutrient on the surface—the residue being capable of supporting growth of micro-organisms under certain conditions.
 - b. Coupons: Sterile coupons (strips of material such as stainless steel with an adhesive backing) are placed on a sterile surface and remain on it until an assay of microbial loading is desired. The coupons are removed periodically and are treated as settling plates (see 7-1b(1)). The contamination on the coupons is assumed to be the same as that on other portions of the surface from which the coupon was removed.
 - c. Cotton swabs: The surface is rubbed with a sterile cotton swab which is then sonicated in sterile water. The contaminated water is then mixed with agar and incubated. Growth colonies are counted to provide an indication of the microbial loading on the surface.

Bibliography

SIZING AND COUNTING AIRBORNE PARTICULATE CONTAMINATION IN CLEAN ROOMS AND OTHER DUST-CONTROLLED AREAS FOR ELECTRONIC AND SIMILAR APPLICATIONS (5.0 MICRON AND LARGER): ASTM F 25-63T, American Society for Testing Materials, 1916 Race St., Philadelphia, Pa. 19103.

METHOD OF TEST FOR CONTINUOUS COUNTING AND SIZING OF AIRBORNE PARTICLES IN DUST-CONTROLLED AREAS BY THE LIGHT-SCATTERING PRINCIPLE (FOR ELECTRONIC AND SIMILAR APPLICATIONS): ASTM F 50, American Society for Testing Materials, 1916 Race St., Philadelphia, Pa. 19103.

PROCEDURE FOR THE DETERMINATION OF PARTICULATE CONTAMINATION OF AIR IN DUST CONTROLLED SPACES BY THE PARTICLE COUNT METHOD: SAE-ARP-743A, Society of Automotive Engineers, Inc., 485 Lexington Ave., New York, N.Y. 10017.

INSTRUCTION MANUAL FOR THE INSTALLATION, OPERATION, AND MAINTENANCE OF PENETROMETER, FILTER TESTING, DOP, Q 107: 136-300-175A, Quality Assurance Directorate, U.S. Army, Edgewood Arsenal, Md.

A COMPARISON OF DUST COUNT DATA OBTAINED FROM DIFFERENT MEASURING METHODS: Marsh, R. C.; SCR-656, Sandia Corporation; April 1964.

STANDARD TESTS FOR LAMINAR FLOW DEVICES (U): Marsh, R. C.; Whitfield, W. J.; Neitzel, W. E.; Mashburn, J. C.; and Trujillo, L. C.; SC-TM 64-637, Sandia Corporation; June 1964.

MICROBIAL PROFILE OF LAMINAR FLOW CLEAN ROOMS: Powers, Edmund M.; X-600-65-308, Laboratory for Atmospheric and Biological Sciences, Goddard Space Flight Center, Greenbelt, Md.; September 1965.

SAMPLING SUBMICRON T1 BACTERIOPHAGE AEROSOLS: Harstad, J. Bruce; Applied Microbiology, Volume 13, Number 6 (Published by American Society for Microbiology); November 1965.

VISUAL MONITORING AS AN ASSAY TECHNIQUE: Drummond, D. W.; Angelotti, R.; and Lewis, K. H.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 137; November 16, 1965.

SURVEY OF MICROBIOLOGICAL TECHNIQUES FOR RECOVERY FROM SURFACES: Vesley, Donald; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 147; November 16, 1965.

CONTAMINATION ANALYSIS AND MONITORING: Johnson, Jack D.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 293; November 16, 1965.

CLEANLINESS METER AND ITS APPLICATION TO SOLVENT CLEANING: Marsh, R. C.; and Oswalt, F. C.; SC-R 66-865, Sandia Corporation; March 1966.

MODIFICATIONS FOR IMPROVING THE RESPONSE CHARACTERISTICS OF THE ROYCO MODEL PC200A PARTICLE COUNTER: Marsh, R. C.; Oswalt, F. C.; Trujillo, L. C.; Neitzel, W. E.; Mashburn, J. C.; and Whitfield, W. J.; SC-TM 66-155, Sandia Corporation; April 1966.

STANDARD PROCEDURES FOR THE MICROBIOLOGICAL EXAMINATION OF SPACE HARDWARE: NASA; June 1966.

CLEAN ROOM AND WORK STATION REQUIREMENTS CONTROLLED ENVIRONMENT: Federal Standard No. 209a; August 10, 1966.

MONITORING A CLASS 100 CLEAN ROOM: Whitfield, W. J.; SC-R-956, Sandia Corporation; October 1966.

DEVELOPMENT OF AN INCREASED SAMPLING RATE MONITORING SYSTEM: Mashburn, J. C.; and Whitfield, W. J.; SC-RR-66-585, Sandia Corporation; NASA Contract No. R-09-019-040; October 1966.

AIR FILTRATION OF SUBMICRON VIRUS AEROSOLS: Harstad, J. Bruce; Decker, Herbert M.; Buchanan, Lee M.; and Filter, Melvin E.; U.S. Army Laboratory, Fort Detrick, Md.; paper presented at San Francisco to the American Public Health Association, November 1, 1966.

CHAPTER 11

Packaging, Transport, and Storage

In controlling contamination, one of the more difficult tasks is to maintain cleaned parts and assemblies in an acceptable condition until they are placed in service. Clean packaging requires materials especially selected for non-shedding characteristics, and performance of the function in an adequately controlled environment.

Clean packaging films as we know them today have both desirable and undesirable traits, some of which are discussed below:

1. *Resistance to Sloughing.* Particles may slough off from a film if it is flexed or if the part rubs against the film during handling or transport. This results in recontamination of the once-clean part. Sloughing is a very important limitation, to varying degrees, of all films. Of those currently available, Nylon 6 is the least likely to produce particles which will contaminate the product.
2. *Transparency.* Transparency provides ready identification of the part, and to a limited degree, allows for gross inspection without removal from the package.
3. *Sealability.* To assure a tight closure of the bag or package, the film must be heat sealable. Sealability may be expressed as a "coefficient of heat sealability," which is the ratio of the tensile strength of the heat-sealed film to that of the original film. The effectiveness of heat-sealed seams is described in considerable detail as Procedure METHOD B, METHOD 1013 of Federal Specification L-P-406. A strong seal is important especially when large heavy items are being packaged.
4. *Cleanability.* A film must be adaptable to being cleaned with solvents such as trichlorotrifluoroethane without being softened or chemically attacked.

5. *Strength.* Transparent, clean packaging films are usually quite thin to reduce the cost and to improve transparency and flexibility. The material must, therefore, be strong enough to resist rupture.

Plastic Film Properties

The Packaging Laboratory, U.S. Army Rock Island Arsenal, has conducted extensive evaluations of the physical properties of plastic films—including tensile strength, elongation, tear strength, and puncture resistance.

In general, their findings were:

1. *Tensile Strength:* High for the polyesters, polycarbonate, polyvinyl fluoride, polyvinylidene chloride, and the cellophanes; very low for the rubber hydrochlorides and the polyolefins.
2. *Elongation:* High elongation capability was found in conventional polyethylene, unoriented polypropylene, and polyurethane. Lower elongation qualities (associated with brittleness) were found in cellophane, cellulose, and the oriented or linear plastics.
3. *Tear Strength:* High tear strength is normally (but not always) associated with materials having low tensile strength and high elongation. Tear strength of some composites is higher than the sum of the tear strengths of the components.
4. *Puncture Resistance:* Two of the polyesters, oriented polypropylene and polyvinyl fluoride, have outstanding resistance to puncture.
5. *Low Water-Vapor-Transmission Rate (WVTR).* (Also known as moisture-vapor-transmission (MVTR).) This factor is related to the protection of parts from corrosion. No highly accurate test procedures are presently available for this

test, but the Rock Island findings show low WVTR's for polyolefins, polyvinylidene chloride, some rubber hydrochlorides, cellophane, the polyesters, and fluorocarbon films. Some of the fluorocarbons, such as Aclar have exceptionally low values.

6. *Resistance to Grease.* Resistance to grease is a characteristic of most films, although the polyolefins, polystyrene, and ethyl cellulose are not resistant to grease.
7. *Resistance to Blocking.* The blocking test ascertains the maximum temperature to which material may be subjected without sticking together or to the product. Films should not block at temperatures below 200° F. Nitrocellulose-coated cellophane and some coated polyolefins were found to block at normal storage and transportation temperatures.
8. *Resistance to Outgassing.* Plastic films contain plasticizers, and the user should determine whether outgassing of the plasticizer will not be deleterious to the product.

Because of the multitude of attributes required of ideal clean-packaging materials, no available films rate very high. More research is being done; it is generally in the direction of composites of the existing films.

A brief synopsis of the five most commonly used materials follows:

Nylon 6 (polyamide): This film scores the highest in abrasion and flex resistance, and thus, creates the least self-contamination problems among films in common use. In recent tests Nylon C (a type of Nylon 6) surpassed four other materials tested (polyethylene, Mylar, Aclar, and Capran) in resistance to abrasion. A limitation of Nylon C is that it does not provide a good moisture barrier. This characteristic can be used to advantage when thin gage Nylon 6 is used to package a desiccant to prevent corrosion without permitting the desiccant particles to escape.

Aclar (fluorochalocarbon): Of seven films tested (Capron, polyethylene, Mylar, Aclar, Teflon, Nylon C, and Film-O-Rap), Aclar 33C and Teflon are the only ones compatible with LOX. Aclar 33C and Teflon meet the requirements of MSFC-SPEC-456 for packaging all pneumatic components requiring LOX compatibility. Aclar has the disadvantage that it abrades more readily than nylon, and therefore has more tendency toward selfcontamination.

Polyethylene: This film is widely used because it is available very economically in many types, sizes, and thicknesses. The disadvantages to its use are that it has

lower strength than most films and a higher degree of sloughing. It distorts readily when in contact with oils.

Mylar (polyester): This film has high resistance to abrasion, but less resistance than Nylon 6. It is very strong and oil has little affect upon it, but it seals poorly and has only moderate MVTR.

Aluminum foil: Ordinary household grade aluminum foil has an oil film which if present in sufficient quantity may destroy its LOX compatibility. Clean (oil-free) aluminum foils are obtainable which are LOX compatible, but the high rate of aluminum particles that slough as a result of flexing and abrasion makes the foil less desirable as a packaging material. Other disadvantages of aluminum foil are that it cannot be heat-sealed; it is not transparent; and when used in contact with dissimilar metals it can contribute to electrolytic corrosion.

No one film has all of the desired characteristics for clean packaging. Much work has been done, and more is being done to develop laminates and composites of films.

To meet specific needs a search of the entire field is recommended.

Transport Problems

Parts, subassemblies, and assemblies which have been cleaned to a specified level must be kept in an environment equal to that level until encapsulated, sealed, packaged, or deposited in an approved receptacle or container. This may be difficult during transport between work positions, temporary storage, curing time, drying time, and other stages after the actual cleaning process. One must consider both: (1) transport or progression within the manufacturing complex, and (2) storage and protection of a product after it is completed and ready for shipment.

Many costly handling and recleaning operations may be avoided by steps taken when the product process and physical floor layout are defined. The need for methods of protecting the product in the drying areas, in the next assembly, during encapsulation, in curing ovens, during temporary storage prior to assembly, and during packaging should be considered.

Factory layout, existing facilities, and conflicting product requirements may make it economically sound to transport the parts through contaminated areas. In such a case, the wheeled vehicles used in uncontrolled

areas should be excluded from the clean room if possible. Products in containers should be introduced into the clean room via a pass-through, after the exterior of the container has been cleaned.

Containers of gases and fluids should be excluded from the clean room if possible, by piping and connections from outside the actual clean room. This not only eliminates extra cleaning of containers, but also precludes the generation of contamination during disconnect and connect actions.

Storage Facilities

The product drawings and specifications should define the environmental limitations, and the conditions under which a product is stored should conform to these definitions.

Selection of facilities for storing of products should be based on such considerations as:

The allowable temperature extremes;

The humidity levels which must be maintained;

The pressure differentials applicable;

Freedom from insect and rodent infestation; and

Proper shelving or receptacles for storage to eliminate undue handling.

Poorly planned storing and inadequate storage facilities can nullify expenditures for packaging materials, expert handling during packaging, and crating or boxing.

Bibliography

METHODS AND PROBLEMS OF PACKAGING AEROSPACE HARDWARE: Pilcher, J. Mason; Proceeding of NASA Cleaning Conference, page 265; January 1966.

CHAPTER 12

Personnel Control and Management

Man is directly and indirectly the cause of more harmful contamination than any other single source. His skin flakes and scales; his clothing sheds fibers and lint; his hair falls out or breaks off; he smokes and creates ashes, air-borne tars, and particulate matter.

To control contamination we must train this basically unclean human being to follow new behavior patterns. Positive, logical, even common-sensical directions are more effective than a list of don't's.

Each employee being considered for placement on a job in a clean room, or critical environmentally controlled area, should have a physical examination to ascertain (1) the degree of dryness of his skin or the sloughing rate of epidermal scale, or (2) the presence of asthma, emphysema, or catarrh (which induces mouth breathing or exhaling and coughing).

The supervisory personnel of any contamination control facility, room, or bench must spend more time watching workers for inadvertent infractions than they would in normal work areas. Lapses may cause rejects, malfunctions, or functional failures.

Training of operators should precede their first work experience under contamination control rules. Re-training should be scheduled as needed, and the first re-training should be within 3 months. Subsequent re-training requirements can be determined in large part from the observations of supervisors.

Adequate regulations for the control of personnel entering and working in environmentally controlled facilities should be established and enforced to the degree that the product requires. Such actions as smoking and eating; entering the controlled area without prescribed garments, caps, and associated accessories; wearing sweaters; using lead pencils

and crayons; cosmetics; and uncleaned tools are examples of considerations for control through operational regulations.

Supervisory Management

Because of widely divergent degrees of self-motivation among even the most conscientious workers, the clean room supervisor has a far more demanding task than his counterpart in a non-environmentally controlled area.

Man begins each day's tasks with less dexterity than he displays after a period of repetitive activity. Conversely, as his manual dexterity improves, his mental alertness begins to wane, and he becomes increasingly susceptible to surrounding distractions.

At the beginning of each work period (before and after both morning and afternoon breaks) it is normal for an operator to begin somewhat slowly and build or accelerate to a plateau, and then decelerate rather sharply as the work period draws to a close. It is during these deceleration or relaxation periods that most human errors (both omission and commission) occur. A supervisor must be watchful and alert to this human foible, and counteract by paying closer attention himself and alerting inspection personnel to this potential source of rejects.

Bibliography

SKIN CARRIAGE OF BACTERIA IN THE HUMAN: Ulrich, John A.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 87; November 16, 1965.

QUANTITATIVE ASPECTS OF SHEDDING OF MICRO-ORGANISMS BY HUMANS: Riemensnyder,

Dick K.; Proceedings of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 97, November 16, 1965.

SPACECRAFT CONTAMINATION RESULTING FROM HUMAN CONTACT: Vesley, Donald; Ruschmeyer, Orlando R.; and Bond, Richard G.; Proceedings

of the National Conference on Spacecraft Sterilization Technology, NASA SP-108, page 275; November 16, 1965.

CLEAN ROOM AND WORK STATION REQUIREMENTS, CONTROLLED ENVIRONMENT: Federal Standard No. 209a; August 10, 1966.

Glossary

Absorb To engulf wholly; to take in and incorporate; assimilate.

Adsorption Adhesion of the molecules of a gas, liquid, or dissolved substance to a surface.

Agglomerate The combining, joining, clumping, or clustering of two or more particles of matter by any means.

Air cleanliness class Each class of air cleanliness is determined by the particle count per unit volume, based on tabulation of particles 0.5 micron and larger or 5.0 microns and larger. Examples of standard air cleanliness classes are described and illustrated in Paragraphs 5.1, 5.1.1, 5.1.2, and 5.1.3 and Tables I and II in Fed. Std. No. 209a. Special classifications may be used for particle count levels where special conditions dictate their use. Such classes will be defined by the intercept point on the 0.5-micron line in Table II with a curve parallel to the three established curves.

Air lock A chamber with doors functioning to maintain pressure during entry to and exit from a contamination controlled area.

Air shower A chamber with interlocked doors and equipped with an exhaust system, having numerous air nozzles arranged in a predetermined pattern, for the purpose of forcibly blowing loose particles, fibers, dust and other particulate matter from the person and garments.

Ambient condition Environments such as pressure, temperature, humidity, etc., which are normal for one specific location.

Assembly Two or more parts, subassemblies or any combination thereof, joined together to perform a specific function.

Clean-down capability The time required for a clean room to recover and return to its normal level or class of air cleanliness, after introduction or generation of any unusual quantity of particulate matter.

Clean room A clean room is an enclosed area providing control over the particulate matter

in air with temperature, humidity, and pressure control as required. To meet the requirements of a "clean room," it must meet the particulate count as specified in Fed. Std. 209, Paragraph 5.1.3, as a minimum or other specified standard.

Cleanliness level An established maximum allowable distribution of contamination of a size or quantity in a stipulated area or volume.

Clean work station A work bench or similar working enclosure characterized by having its own filtered air or gas supply. The filters must be capable of providing the required air cleanliness level.

Component A series of two or more parts, subassemblies, assemblies, or any combination thereof, which in turn becomes a piece of functional equipment or assembly.

Contaminant (contamination) Any undesirable material in or on the material of interest.

Contaminate To make impure or unclean; to pollute, defile, sully, taint; said of something dirty; soil; the act of introducing any unwanted material.

Contamination control Planned and organized action to maintain the degree or level of contamination in, on, or around any object or product.

Controlled area Any enclosure which has a degree of control of contaminants in the atmosphere, gases, and fluids (may include temperature, humidity, and pressure) and which will not qualify as a clean room. This may encompass access and handling areas.

Cross-flow clean room See *Horizontal laminar air flow clean room*.

Down-flow clean room See *Vertical laminar air flow room*.

Environment All the conditions, circumstances, and influences surrounding and affecting the temperature, humidity, air cleanliness level, surface cleanliness, pressure, microbial, and illuminating conditions associated with a specific location.

Fiber A particle whose length is at least ten times its width.

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

First work location The work location that is first in the path of the airstream.

Flush A rinsing cleaning action applicable to a part, component, system, etc., which employs a liquid as a medium.

Flux A substance, as borax or rosin, used to help metals fuse together (as in soldering).

Gas A state of matter in which the molecules are practically unrestricted by cohesive forces. A gas has neither shape nor volume, and in form is neither liquid nor solid.

High efficiency particulate air filter (HEPA) Mil.-F-51068A specifies filters with minimum efficiency of 99.97% determined by the homogeneous DOP method at air flows of 100% and 20% of the rated flow capacity of the filter. It is referred to as the HEPA filter.

Horizontal laminar air flow clean room A room equipped with one entire vertical wall of HEPA filters, through which the air passes at a predetermined speed to an exhaust wall directly opposite the HEPA filter wall. The entire body of air moves horizontally across the room with uniform velocity along essentially parallel flow lines.

Hydrocarbon A chemically identifiable compound of carbon and hydrogen.

Laminar air flow Air flow in which the entire body of air within a confined area moves with uniform velocity along parallel flow lines.

Laminar air flow clean work station A work station in which the laminar air flow characteristics predominate throughout the entire air space, with a minimum of eddies.

Laminar air flow room A room in which the laminar air flow characteristics predominate throughout the entire air space, with a minimum of eddies.

Light-scattering A technique for detecting, counting, and sizing fluid-borne particulate matter passing through a high intensity light beam, the distorted light beams being converted to electrical impulses by a photo-

multiplier tube and registered on appropriate counters and tapes.

Liquid A state of matter in which the molecules are relatively free to change their positions with respect to each other but restricted by cohesive forces so as to maintain a relatively fixed volume.

Membrane filter Porous membrane composed of pure and biologically inert cellulose esters, polyethylene, or other materials.

Microbe An organism of microscopic or sub-microscopic size, generally including viruses, rickettsiae, bacteria, algae, yeast, and molds.

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

Non-laminar flow clean room A room characterized by non-uniform air flow patterns and velocities.

Non-laminar flow clean bench A work station characterized by non-uniform air patterns and velocities. This includes work stations which have constricted air exhaust or ports.

Non-volatile residue (NVR) Soluble (or suspended) material and insoluble particulate matter remaining after temperature controlled evaporation of a filtered volatile liquid, usually measured in grams.

Organic Designating or of any chemical compound containing carbon.

Orifice A fixed restriction in a fluid passage which established the rate of fluid flow.

Oxide A binary compound of oxygen with some other element or with a radical.

Oxidizer A substance that supports the combustion reaction of a fuel.

Particle A piece of matter with observable length, width, and thickness, usually measured in microns.

Particle counters Automatic electronic devices designed to electronically separate, size, and count individual particles.

Particle size Particle size is expressed as the apparent maximum linear dimension or diameter of the particle. The linear dimension is implied unless otherwise specified.

Particulate matter The general term applied to matter of miniature size, with observable

length, width, and thickness, and contrasted to non-particulate matter without definite dimension.

Plenum An enclosed space in which the pressure of the air is greater than that of the outside atmosphere.

Pre-cleaning That cleaning which is accomplished outside of a controlled area, for the purpose of removing contaminants, such as rust, oxidation, grease, oil, heavy scale or soil deposits in an effort to control the amount of contaminating matter brought into the clean room zone. This is synonymous with *rough cleaning*.

Purge To flow an inert gas or system media through a system (or line, tank, etc.) for the purpose of ridding the system of a residual fluid or for providing a positive flow of gas from some opening in the system.

Rough cleaning See *Pre-cleaning*.

Silt Particulate matter settled from fluid, generally in particle size range greater than 0.5 micron.

Silting An accumulation of minute particles, in the size range normally not counted, but of sufficient quantity to cause a haze or

partial or complete obscuring of either grid lines or any portion of the grid on a test filter membrane, when viewed visually or under 40 power (maximum) magnification.

Solid A state of matter in which the relative motion of the molecules is restricted and they tend to retain a definite fixed position relative to each other, giving rise to crystal structure.

System Any combination of parts, assemblies, and sets joined together to perform a specific operational function or functions.

Test Examination, investigation, and evaluation of inherent properties, functionability, environmental reaction, variances, and reliability of any product, system, sub-system, vehicle, equipment assembly, part, material, and process.

Vertical laminar air flow room A room equipped with a ceiling of HEPA filters, with a grated or perforated metal floor for the exhausting of the air issuing from the ceiling filters; the airflow is vertical, and moves within the walled area along essentially parallel lines at uniform velocity.