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Contamination and cleanliness control

Prepared by:
Product Assurance Division
European Space Research & Technology Centre
Noordwijk, The Netherlands

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ABSTRACT

This specification defines the criteria to be met by personnel, items and operations in clean rooms for spacecraft and associated equipment so that the strict levels of environmental cleanliness and contamination control required by ESA can be achieved and maintained . Furthermore, this specification details possible spacecraft failures or malfunctions due to contamination, and sets out guidelines for the production of the cleanliness requirement specification and the cleanliness control plan. Magnetic, electrical and electrostatic cleanliness is not covered by this specification.

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

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1. SCOPE

This specification defines the criteria to be met by personnel, items and operations in clean rooms for spacecraft and associated equipment so that the strict levels of environmental cleanliness and contamination control required by ESA can be achieved and maintained. Furthermore, this specification details possible spacecraft failures or malfunctions due to contamination, and sets out guidelines for the production of the cleanliness requirement specification and the cleanliness control plan. Magnetic, electrical and electrostatic cleanlinesses is not covered by this specification.

2. GENERAL

2.1 INTRODUCTION

(a) Cleanliness procedures and methods detailed herein shall be implemented to ensure that the required cleanliness levels are achieved for items, containers, packaging, clean rooms, work stations and facilities. The procedures concern the following specific areas:

- protection of the spacecraft from outgassing products, lubricants from bearings, wear particles from moving parts, terrestrial contaminants (e.g. dust) rocket plumes, boost motor and jet exhaust, leaks from sealed components, leaks from fuel systems, dumps, contaminants from nose fairings and equipment bays etc.
- provision of correct cleanliness levels for process/ manufacture areas, assembly, integration and test areas
- provision for protection from contaminants by proper preservation, packaging and storage
- provision of correct cleanliness levels of facilities (e.g. vacuum test chambers) in which equipment or spacecraft are to be tested
- provision for the protection of complete spacecraft, systems, subsystems and equipment during all operations.

(b) Procedures for the control of the clean-room environment, operations, cleaning techniques, personnel, regulations and clean-room monitoring of all environmental factors are also detailed in this specification.

(c) The most important point is that contamination control cannot be applied effectively without an understanding of what constitutes a contaminant, a contaminant source and a detrimental effect. The known causes of failure and degraded performance of spacecraft components attributed to contamination, including their sources, are given in Chapter 3. For these contaminants calculations to determine expected contaminant levels and their subsequent effects can be made if other relevant parameters are known. When they are not known, practical experiments and analyses must be performed (e.g. outgassing rates as a function of time, chemical composition of outgassing products, condensation rates, degradation as a result of radiation etc.).

Preventive cleanliness control is becoming more important as spacecraft become more sophisticated and mission durations are extended. A difficulty frequently encountered in space technology is the lack of data enabling a good correlation to be made between contaminant levels and mission reliability. This kind of information is available in the mass-production areas of electronic and precision mechanical devices, so it is desirable that these data should be collected and incorporated into the spacecraft "Cleanliness Control Plan". Even so, such requirements will remain a matter of coarse judgement until tests have yielded realistic data.

(d) Particular attention shall be paid to precautions/ hazards relevant to contamination and cleanliness control which are listed in ESA PSS-01-40.

2.2 RELATED DOCUMENTS

Some or all of the content of the documents listed below is directly related to this specification. The applicability of these documents is defined in the contract.

ESA PSS-01-20	Quality Assurance of ESA Spacecraft and Associated Equipment
ESA PSS-01-40	Safety Assurance of ESA Spacecraft and Associated Equipment
ESA PSS-01-70	Material and Process Selection and Quality Control for ESA Spacecraft and Associated Equipment
ESA PSS-01-202	Preservation, Storage, Handling and Transportation of ESA Spacecraft Hardware
ESA PSS-01-711	Product Assurance Requirements for Micro VCM-apparatus and Associated Equipment
ESA PSS-01-705	The Detection of Organic Contamination of Surfaces by Infrared Spectroscopy
ESA PSS-01-716	The Listing and Approval Procedure for Materials and Processes

2.3 DEFINITIONS

The definitions listed in Annex 'A' shall apply.

3. CONTAMINATION ATTRIBUTES

3.1 MAIN EFFECTS OF CONTAMINANTS ON SPACECRAFT

(a) Failure of precision mechanisms due to particulate matter.
(b) Light scattering by particulate and molecular contaminants.
(c) Electrical discharge or arcing in high-voltage equipment due to high outgassing and other contamination.
(d) Noise on slip rings and electrical contacts.
(e) Results of certain experiments obscured by excessive outgassing, e.g. mass spectrometers, ion counters etc.
(f) Degradation of optical elements (e.g. lenses, mirrors, windows) due to organic contamination, expecially X-ray and ultraviolet equipment and low-temperature IR detectors.
(g) Degradation of thermal-control surfaces (absorptivity/emissivity ratio, α/ε) especially in the case of organic contaminants on optical solar reflectors at low temperatures.
(h) Loss of efficiency of heat pipes due to contamination.
(i) Effects on conductive and nonconductive surfaces (leak paths in electronics).
(j) Loss of efficiency of solar-cell generators.
(k) Corrosion of electrical contacts due to the presence of halogenated solder fluxes or halogenated cleaning agents.
(l) Space charge and discharge effects related to contaminants.
(m) Thermal radiation from particles.
(n) Disorientation due to erroneous reaction of star trackers to luminous particles.

NOTE: Effects (c), (f) and (g) are aggravated by the presence of radiation, especially UV and low-energy protons.

3.2 TYPICAL CONTAMINANTS AND THEIR SOURCES

3.2.1 Particulate Contaminants

Many particulate contaminants, such as dirt, sand, industrial fumes etc. can to a large extent be excluded from clean rooms by filtering and the spacecraft can therefore be protected from them right up to the final preparation at the launch site. Nevertheless, a considerable quantity of particulate contaminants is produced or released inside the clean room; for example:

- bacteria, hair cosmetics, fingerprints, dead human skin cells;
- fibres and lint from clothing, dust carried in on hair and clothes;
- chips and burrs from machined surfaces, solder and weld spatters;
- particles produced by wear or shedding, corrosion products, flakes from coatings and air filters.

3.2.2 Gases and Vapours

These are of the following kinds:

- atmospheric gases, desorbed water, leaks in sealed units (e.g. freon, hydrazine, helium, neon, krypton);
- outgassing products from organic materials (e.g. monomers, plasticisers, additives, solvents);
- vapours from packing materials and test facilities (e.g. vacuum-pump oils);
- vapours from substances used in clean rooms (e.g. plasticisers, cleaning fluids).

3.2.3 Liquids

The following are examples: residues from cleaning agents, residues of adhesive masking tapes, machine oils, coolants, lubricants, solder fluxes, cosmetics, grease from human skin.

3.2.4 Launch Contaminants

Besides the contamination it may be subjected to on the ground, the spacecraft is also exposed to:

- particulate and gaseous products released by the nose fairing
- particles originating in the equipment bay
- particles and gases produced by rocket engines, boost motors, spin-up jets, retro-rockets, explosive bolts etc.

3.2.5 Inorganic Contaminants on Surfaces

These are usually the following: salt, acid, alkaline, corrosion products, oxidation, finger prints, stains, solder fluxes, exhaust products from rockets, boost motors, jets etc. (See Paragraphs 3.2.1 to 3.2.4.)

3.2.6 Organic Contaminants on Surfaces

Organic contaminants are covered in Paragraphs 3.2.1 to 3.2.4.

4. CLEANLINESS LEVELS

4.1 PARTICLE LEVELS

4.1.1 Acceptance Levels

(a) **Federal Standard 209B** divides clean rooms into four classes in which the levels of airborne particles larger than 0.5µm are 100, 1 000, 10 000 and 100 000 per cubic foot, respectively (see Table 1). The number and size of airborne particles are measured with light-scattering meters.

(b) **MIL-STD-1246A** gives a classification of surface cleanlines levels. There are nine classes ranging from (ten) 10µm particles per square foot to one 1 000µm particle/ft^2, and more particles of smaller size (see Table 2). Levels are measured by microsopic counting.

(c) Schneider (JPL) has published measurements in the Journal of Environmental Science (February 1975). These have been evaluated at ESA and a rough correlation (presented in Table 3) has been found. This fits the theory and has been verified down to class 30 000.

4.1.2 Interpretation

To facilitate interpretation, particle fall-out (PFO) on surfaces should be expressed as an obscuration factor (the area covered by particles in ppm).

NOTE: SAAB has developed a patented PFO photometer that gives direct ppm readings of dust levels on glass plates.

From the particle-fall-out point of view, the number of 5μm particles per volume of air is much more critical than the number of particles larger than 0.5μm, since the fall-out is mainly determined by particles of 5μm or larger. The required cleanliness level of a clean room can only be selected when the specified obscuration factors for critical spacecraft surfaces are known (See Table 4). The particle size 5μm is often used as a criterion, because for optical surfaces particles larger than 5μm are critical, whereas for bearings and gears, particles in the range 10 to 40μm are more harmful.

Sometimes, particle contamination is given in terms of mass per unit area. In order to correlate this with the obscuration factor, it is necessary to know the density and the average diameter, of the particles. Quite often, the term "visually clean" is stated as a requirement. Such a term is not strictly applicable, but may be considered as equivalent to an obscuration factor of 300 ppm.

4.2 ORGANIC CONTAMINATION LEVELS

4.2.1 Acceptance Levels

(a) **Condensable Contaminants** The normal acceptance limit for levels inside clean rooms and other spacecraft areas is that a critical surface in such an area is not contaminated by more than 2×10^{-7} g/cm^2 during a continuous period of one whole week (value based on the decrease in ultraviolet reflection of optical components in spacecraft). However, for some applications, this limit may be more stringent i.e. the acceptance level for "clean" vacuum test facilities is set at 1×10^{-7} g/cm^2 after a blank test of 24 hours duration.

The form in which the contaminants are present (i.e. droplets or continuous film) may have an important bearing on degradation effects. Measurement of contamination levels is described in ESA PSS-01-705.

(b) **Solvent Vapours** Acceptance limits for clean rooms depend upon the limits established by the national occupational safety and health office of a country. Further requirements may be derived from a spacecraft's particular application.

4.2.2 Levels Obtained on Space Hardware

The Organic-contaminant levels listed in Table 5 are based on experience acquired with ESA spacecraft TD-1, Meteosat and Geos. Measurements of contamination levels were made according to ESA PSS-01-705.

4.3 INORGANIC CONTAMINATION LEVELS (See Paragraph 3.2.5)

Contaminants acquired on the ground are generally detected by visual inspection. Special methods, such as pH measurements, may be useful on occasion. No acceptance levels can be specified for contamination of this type. Coarse judgement of acceptability can be made on the basis of visual inspection or on that of performance measurements.

4.4 CLEANLINESS LEVELS OF GASES

For certain experiments, very clean gases are required; for example, spark chambers on board spacecraft. During the planned duration of a mission, the purity of the gases in such a spark chamber should not change outside specific limits, so such criteria as system outgassing level assume considerable importance.

Cleanliness of gases is generally expressed in ppm contaminants; for water content, it may be expressed as the dew point. In the case of purge gases (as used for nose fairings, vacuum facilities, containers etc.), the particle and organic-vapour content should at most be the same as that of the clean-room air.

4.5 CLEANLINESS LEVELS OF LIQUIDS

Liquids on board a spacecraft may be subject to stringent cleanliness requirements (e.g. in view of the need to eliminate particles capable of blocking valves etc.). In Table 6, the levels laid down for ESA projects are compared with those set out in MIL-STD-1246A. A similar comparison is made in Table 7, in this case concerning the content of nonvolatile residues. The cleanliness of cleaning solvents is mentioned in Section 5.4.

4.6 CLEANLINESS LEVELS AROUND SPACECRAFT DURING MISSION

Star trackers may become unlocked through the illumination of particles by sunlight (light scattering), resulting in excessive consumption of control jet fuel.

Gaseous matter around the spacecraft may give rise to an unacceptably high background for particle detectors on board, such as ion detectors or mass spectrometers (see Paragraph 3.2.2). In some cases, experimenters may stipulate requirements concerning cleanliness levels of the "spacecraft environment".

5. CLEANING PROCEDURES

Once the materials and components have been selected and the processes and/or manufacturing techniques are known, cleaning procedures can be chosen that will ensure that required cleanliness levels are achieved. The choice of cleaning methods will depend on the type of contaminants to be removed and the physical/chemical nature of the item to be cleaned. Certain items may be too delicate to withstand cleaning and for such items preventive contamination control is of the utmost importance.

5.1 INTERMEDIATE CLEANING

The cleaning of parts is often particularly important during the course of manufacture or before processing, e.g. prior to bonding, painting, vacuum coating, welding, soldering etc. Procedures concerning cleaning of this type shall be mentioned in the process specification.

5.2 REMOVAL OF INORGANIC CONTAMINANTS

As no final cleanliness level can be fixed for contamination of this kind, the desirability of cleaning is a matter of judgement, based on practical experience or on visual inspection, unless a special surface finish is required. Various methods are employed to achieve this, e.g.:

(a) Mechanical cleaning, such as grinding, brushing, blasting etc.

(b) Detergent cleaning (trade names: Decon-90, Contrad, RBS-50) for glass, rubbers, plastics, polyamide, ptfe, polypropylene, acrylates etc. and all ferrous metals, including stainless steel. Such detergents will also clean non-ferrous metals, such as aluminium and brass, but will have an oxidising effect on the surface.

(c) Chemical cleaning with acids, alkalines, salts etc. for metals.

(d) Electrochemical cleaning with acids, alkalines, salts, etc. for smoothing metal surfaces.

5.3 REMOVAL OF PARTICULATE CONTAMINANTS

For a number of substances, visibility of particles will be enhanced by the use of a special ultraviolet TL-lamp ("black light").

(a) Dust can be removed with the aid of an ordinary vacuum cleaner combined with a good brush. To avoid recontamination, the exhaust of the vacuum cleaner should preferably be outside the clean room.

(b) Wiping should be performed with extreme care; otherwise surfaces may be scratched and the "dust" may simply be wiped onto other clean items.

(c) Removal of particles by means of a jet of compressed gas is another method that must be employed with the utmost care, since contamination of the other clean items in the vicinity may result. Cleaning agents, such as brushes, wipe tissues or compressed gases, should not themselves contaminate the items to be cleaned and should not permit dust to scratch surfaces during cleaning.

(d) A form of wiping that may be effective is with tissues dipped in methanol.

5.4 REMOVAL OF ORGANIC CONTAMINANTS

(a) **Dry wiping.** This can be done with clean lint-free cloth or lens paper; it has the disadvantage that it may cause scratches on surfaces.

(b) **Wet wiping.** For this clean cloth, brush, paper etc. can be used in conjunction with organic solvents.

(c) **Solvent cleaning.** Examples are washing, dipping, spraying, vapour cleaning and ultrasonic cleaning.

(d) **Detergent cleaning.** See Paragraph 5.2(b).

(e) **Plasma cleaning.** This method is very successful if polymerised products have to be removed.

(f) **Devolatilising under vacuum.** This method is expecially successful for cleaning assembled units or when solvent cleaning is too delicate an operation.

(g) **Ultraviolet/ozone cleaning.** Molecules of an organic nature are activated by ultraviolet light, resulting in a dissociation, after which they react with the ozone produced in the air by the ultraviolet light.

5.5 CLEANING AIDS

(a) Cleaning aids should not increase the contaminant levels of the items to be cleaned. Therefore:

- wipe tissues, papers, cloth, brushes, foams, etc. should be non fluffing, lint free and dust free;
- damage to surfaces (scratches) should be minimal;

- organic contaminant content of cleaning wipe materials should be less than 25 ppm for wiping extremely clean surfaces.

(b) The organic contaminant content of some wipe materials measured in accordance with ESA PSS-01-705 is listed in Table 8. However, when cleaning wipe materials are selected, measurements should be made to determine their contaminant content. In principle, all wipe materials should be precleaned to obtain the required level. Precleaning requires extraction by solvents.

5.6 ORGANIC CLEANING SOLVENTS

(a) **Compatibility** . The cleaning solvent shall be compatible with the material or item to be cleaned (see Table 10: Compatibility of cleaning solvents with "plastics"). Moreover, the solvent shall not be corrosive to metals (see MIL-HDBK-406, Chapter 7, Sections 2 to 25, and NASA SP-5076, p. III-94), e.g. titanium shall not be cleaned with methanol, but with acetone, whereas solid-state detectors, which are liable to be affected by solvent vapours, must be cleaned with methanol only.

(b) **Solvency** . When the contaminant is known, the solvent best able to remove the contaminant shall be selected.

(c) **Toxicity and flammability** . Most solvents require precautions to be taken during the cleaning process (see MIL-HDBK-406, Table 7-2).

(d) **Residue of organic solvents** . For precision cleaning, solvents of high purity are required, otherwise contaminant levels will be raised rather than lowered. Typical figures for residue content of cleaning solvents are listed in Table 9, which is based on measurements performed in accordance with ESA PSS-01-705.

From Table 9 it can be seen that very clean solvents are commercially available. Consequently, when a cleaning liquid is selected it is only necessary to ensure that it is of "pro-analyse" quality or that the NVR is less than 2 ppm.

The two solvents included in Table 9 as "from aerosol bottle I" and "from aerosol bottle II" were produced by different manufacturers and were analysed because they caused visible contamination on critical surfaces.

In general, the cleaning agents with the best all-round performance are trichlorotrifluoroethane (trade names: Arklone and Freon TF), isopropyl alcohol and a 65%/35% mixture of trichlorotrifluoroethane and isopropyl alcohol. Solvents containing fluorine must evaporate completely, otherwise corrosion (e.g. of electrical contacts) may occur.

6. CLEANLINESS MONITORING

6.1 MONITORING PARTICULATE CONTAMINANTS

6.1.1 Clean Room Air

Clean room air is generally monitored with commercially available dust counters (e.g. ROYCO, Bausch-Lomb). Particle counts shall be taken at defined intervals during working periods and at locations which will yield the number of particles in the air as it approaches the work location. Monitoring techniques and routines shall be established to meet the requirements of a specific category of clean room or clean work station. Monitoring methods and equipment may be used only if demonstrated to be of adequate accuracy and repeatability.

Air monitoring of class 10 000 or better category shall be done by lightscattering equipment. Furthermore, tests shall be made to determine leaks:

- in the filter media themselves
- in the bond between filter media and the interior of the filter frame
- between filter frame gasket and filter bank supporting frames
- between supporting frames and walls or ceilings

6.1.2. Visual Inspection of Surfaces

Surfaces may be examined with the naked eye or with the aid of a microscope. An ultraviolet lamp increases the visibility of dust particles ("black light").

The "visibly clean" level depends very much on the circumstances in which the examination is made; it is better to express this level as an obscuration factor of 300 ppm (see Table 3).

6.1.3 Optical Methods on Surfaces

Typical methods are measurement of transmission or reflection loss and nephelometry. These methods are valid for all types of contaminants, both organic and inorganic. Photographic determination of dust particles on surfaces is also possible, as is automatic counting. SAAB has developed an automatic Particle Fall-Out Counter. Other particle monitoring methods are the tape lift method, using sticky tapes; microscopic counting and the Tapered Element Oscillating Microbalance (TEOM).

6.1.4 Internationally Recognized Tests

The following cleanliness tests have been established;
ASTM-F-24/D2427/D2391/D2390/F-25
SAE-ARD/598/743

6.2 MONITORING ORGANIC CONTAMINANTS

6.2.1 Visual Inspection

Experience with Micro-VCM tests has shown that, generally, levels of organic contamination above 1 x 10^{-6}g/cm^2 may already be visible to the naked eye.

6.2.2 Wipe Techniques and Visual Inspection

Wiping certain areas with a clean tissue concentrates the contaminants. In practical cases, a concentration of ten times is possible. This means that, unless the surface wiped is abrasive (e.g. aluminium), contamination levels down to a few times 10^{-7}g/cm^2 can be detected in this way.

6.2.3 Wipe Techniques and Physical/Chemical Analysis

A surface of known area is wiped with a clean tissue, the tissue is subjected to extraction with chloroform spectral grade and the residue of the chloroform is analysed by infrared techniques in accordance with ESA PSS-01-705. This method, applied to a wiped area of 100 cm^2, permits detection of organic contamination levels down to a few times 10^{-8}g/cm^2.

6.2.4 Direct Analysis of the Suspect Item

Various analysing techniques can be applied, e.g. infrared analysis, gas chromatography, mass spectrometry, ultraviolet degradation, X-ray reflection loss etc. Such analyses are not standard practice and are performed only in special cases. Gaseous species can be monitored by means of the gas correlation spectrometer based on microwave absorption.

6.2.5 Sensor Techniques

Clean metallic sensors are placed on or near suspect places for a specified time and are then subjected to one of the forms of analysis mentioned above. This technique is widely used in the monitoring of clean areas, vacuum facilities etc. A combination of a quartz crystal microbalance and a mass spectrometer can give identification of different condensed species after a controlled re-evaporation from the QCM.

6.2.6 Vacuum Facilities

(a) During vacuum tests on experiment hardware or spacecraft, the contaminants emitted by the test pieces are generally detected by means of sensors (see Paragraph 6.2.5), placed preferably at cold locations around the test object.

(b) Mass-spectrometer measurements can also be used to obtain information on outgassing products and their origin if a position-scanning mechanism is employed (NIPKOV disc.).

(c) A quartz-crystal microbalance (QCM), which can detect contamination levels down to 1 x 10^{-9}g/cm^2, can also be used to measure condensation rates. Such QCM's can operate down to liquid-nitrogen temperatures. (They can be used under atmospheric conditions, but humidity must then be controlled to close tolerances, since water sorption on the crystal will affect the results.)

6.2.7 X-ray fluorescence

The thickness of the contaminant layer can be measured by X-ray fluorescence during proton bombardment.

6.2.8 Special techniques

Various other special techniques that can be employed include ellipsometry, nephelometry, SIMS, LEED etc.

6.3 MONITORING INORGANIC CONTAMINANTS

6.3.1 Visual inspection

This is the only practical method of checking for corrosion etc.

6.3.2 Other methods

For special applications, such methods as pH measurements, secondary-ion mass-spectrometer (SIMS) measurements and the like are available.

6.4 MONITORING OF GASES

Chemical analyses such as infrared spectrometry, gas chromatography, mass spectrometry or combinations of these can be employed.

Another method is ionisation by ultraviolet-light instruments, which are able to detect the presence of most organic vapours in concentrations down to 1 ppm.

6.5 MONITORING OF LIQUIDS

Recommended monitoring methods are detailed in ASTM-D2931/ D2390 and SAE-ARP-598.

7. QUALITY ASSURANCE CLEANLINESS CONTROL PLAN

7.1 GENERAL

To provide and maintain a system of efficient contamination control in clean rooms or working stations procedures must be established for:

(a) **Environmental Control** . Environmental conditions, such as temperature, humidity, pressure, differential radiation which may influence the contamination level, shall be controlled and recorded. Records shall be reviewed according to written specifications.

(b) **Personnel Control and Management** . Adequate regulations for control of personnel entering and working in environmentally controlled facilities shall be established and enforced to the degree required by the product concerned.
Training of operators shall precede their work in contamination controlled areas.
For the class 10 000 or better, a cleanliness-operations supervisor shall have continuous visible control of the clean rooms actually occupied in order to ensure that the operation procedures are fulfilled.

(c) **Clean-room Operations** . Procedures shall be established to produce the desired product control. Furniture and equipment for clean rooms shall be selected to minimise maintenance and cleaning. An effective preventive maintenance programme shall be established to eliminate unscheduled shut-downs.

(d) **Cleaning Techniques** . Methods shall be established for the detection, evaluation and effective removal of contaminants, and operators shall be familiar with the appropriate techniques for dealing with any specific type of contaminant.

(e) **A Cleanliness Plan** shall be prepared which sets out the ways in which it is intended to achieve and maintain the required cleanliness levels.

The plan shall include as a minimum:

- quality control on selected materials and components
- specification of stages at which cleanliness levels are to be verified
- specification of frequency with which cleanliness of clean rooms is to be checked
- requirements for the training of clean room operators.

7.2 SPACECRAFT CLEANLINESS CONTROL

The need for cleanliness control as a part of spacecraft technology is obvious. Since the construction of spacecraft is not a mass-production process, it is difficult to show the relationship between the cost of cleanlines control and the improvement in reliability achieved.

Spacecraft design is generally dominated by such overriding considerations as weight limitations and functional requirements; the problem of cleanliness is not given high priority. It is, however, essential that designers should attach to this factor the importance it deserves, as explained below.

7.2.1 Spacecraft Cleanliness-control Plan - See Chart 2

This document shall deal with the varius ways of achieving and maintaining the required cleanliness levels. Special attention shall be paid to the following:

(a) Material/process selecton shall be in accordance with ESA PSS-01-70 and ESA PSS-01-716.

(b) Criteria in the selection of materials may be outgassing rates or condensation rates at various temperatures, possibly in combination with electromagnetic and particulate radiation.

(c) Plans shall be stated for special tests to determine outgassing condensation or radiation rates, the effects of plumes, degradation etc., performed for the purpose of obtaining data to be used in the calculations referred to in Para. (d) below.

(d) Contaminant levels and/or the effects of contaminants on critical parts or experiments shall be calculated as a function of time.

(e) Calculations shall be made to determine acceptable leak rates from jets, hermetically sealed components or equipment etc. from the point of view of contamination.

(f) Pressures inside the spacecraft shall be calculated as a function of time, particularly in cases where high-voltage equipment could give rise to arcing effects (the pressure is a function of outgassing rates and the size of the venting holes).

(g) The position of critical parts/experiments with respect to the source of the contaminant shall be stated.

(h) The position of venting holes in the spacecraft and the nose fairing with respect to critical parts/experiments shall be stated.

(i) The design shall incorporate any permanent shields, temporary covers or hoods, and heaters on critical parts/ experiments if required for shielding during critical contamination phases.

(j) Consideration shall be given to cleanability as a design feature of critical parts/experiments; i.e. the possibility of accidental contamination shall be taken into account in the design phase.

(k) The choice of manufacturing sequences, techniques and processes shall be governed by considerations concerning compatibility with desired cleanliness levels, unless the article can readily be cleaned afterwards (e.g. mirrors to be bonded to a substrate before vacuum coating, since otherwise the coating can be damaged by corrosive vapours released by the adhesive during bonding).

(l) The cleanliness levels shall be stated that are required for the process/manufacturing areas and for the assembly, integration and test areas. Warning must be given of special precautions to be taken to exclude contaminants from the clean article. Section 7.3 deals in general with clean room operation and handling guidelines. Table 4 indicates the particle fallout to be expected on spacecraft surfaces. When a clean room is being selected, exposure time shall be taken into account. Moreover, it shall be borne in mind that certain critical surfaces can be cleaned after being contaminated.

(m) In general, cleanliness control during final launch preparations is extremely difficult, particularly as regards defining precautions to be taken to prevent contamination of the spacecraft.

(n) The acceptable cleanliness levels for facilities (e.g. vacuum test chambers) in which experiment hardware destined to be placed aboard spacecraft is to be tested shall be specified. Vacuum facilities may give rise to contamination attributable to the pumping system (e.g. diffusion pumps) or to the presence of previous contaminants (memory effects).

Another reason why test facilities shall be subject to qualified operation procedures is that there is otherwise a danger that the test object will become recontaminated, especially during the warm-up period of the shrouds. Liquid-nitrogen-cooled shrouds used in vacuum facilities do not in practice form a perfect molecular sink, so a small proportion of the contaminants leaving the spacecraft will return - this is known as self contamination (chamber scattering). This return of contaminants to the spacecraft also occurs in orbit, where, especially in low orbit, molecules leaving the spacecraft collide with other molecules from the same source (self scattering) or with molecules in the environment (the ambient scattering for shuttle orbits is in the order of 15%).

In general, tools, test equipment, cables, connectors and other hardware employed in vacuum facilities shall have a low contamination potential.

(o) As regards preservation, packaging and storage, the following points are important. Clean items shall be protected from contamination by proper preservation, packaging or storage prior to such further handling as assembly and integration (see ESA PSS-01-202).

Packing materials shall not release corrosive vapours (such as those from polyvinylchloride, neoprene, vinyl and polysulphide) or contain corrosive constituents (e.g. sulphur if present in paper will attack silver). The requirement regarding packing materials is that the contamination level of the packed item shall not increase the specified level. Selection criteria have so far been based on low outgassing figures. A reasonable guarantee that packing materials are safe is that they have passed the "Micro-VCM" test.

(p) It is desirable that drawings contain the following information:

- required cleanliness level
- intermediate cleaning methods prior to such further treatment as painting, bonding, vacuum coating etc.
- final cleaning method
- preservation, packing and storage methods

7.2.2 Task of Spacecraft Designers

It is recommended that the following documents be prepared for each spacecraft:

- Cleanliness requirements specification (chemical and particle)
- Cleanliness control plan
- Cleaning procedures
- Cleanliness monitoring procedures
- Product assurance plan for cleanliness control.

7.2.3 Cleanliness Requirement Specification - See Chart 2

This document may be prepared in collaboration with experimenters, thermal-control engineers, power-supply engineers and others and should contain:

(a) Definition and identification of spacecraft parts, equipment or areas sensitive to contamination and a description of the effects of such contamination.

(b) Definition of the acceptable contaminant levels on these parts etc. before launch and during the mission, or of the acceptable degradation. In principle, the acceptable degradation is the difference between the design performance and the required performance.

(c) Environmental factors, such as solar-radiation, electron and proton fluxes, together with the planned mission duration.

(d) Expected temperatures to which contaminant-sensitive parts will be subjected.

(e) Pressures inside spacecraft required in connection with voltage breakdown, arcing, corona etc.

(f) Identification of contaminant sources and an evaluation of the source parameters in general, such as outgassing from materials, lubricants escaping from bearings, wear particles from moving parts, terrestrial contaminants (e.g. dust), rocket plumes, boost-motor and jet exhausts, leaks from sealed components, leaks from fuel system, dumps, contaminants from nose fairing and equipment bay etc.

7.3 CLEAN ROOM CONTROL

7.3.1 General

Written operational guides shall be established to avoid contamination and degradation of the cleanliness level of the area. These guides shall include, but not necessarily be limited to, the following requirements:

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

(b) Smoking and eating shall not be permitted in the clean room area or the anteroom.

(c) Racks and/or cabinets for street clothing must be separated from those used for clean room clothing.

(d) Local clean-room procedures shall specify amount of protective clothing to be worn and shall assist minimum contaminant transfer.

(e) If air showers are used, only properly clothed personnel shall be allowed to enter.

(f) All personnel shall wear lint-free smocks or coveralls in the area.

(g) Head covers and other apparel shall be used as needed to enclose loose particles of hair and skin flakes.

(h) Entering paper shall be limited. Special non-shedding papers for the necessary records or paperwork shall be made available.

(i) Only ballpoints shall be used for writing. Lead pencils and erasers shall not be used.

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

(k) Fingernail polish shall not be permitted in the area.

(l) Hand lotions, creams or soap containing lanolin to tighten skin particles shall be used as appropriate.

(m) Contact of hands with solvents shall be avoided, as many solvents remove natural oils and cause excessive skin peeling or flaking.

(n) Gloves, finger cots (of approved types), tweezers or clean handling methods and equipment shall be used while working with or handling sensitive parts to avoid contamination of those parts by loose skin or natural skin oils.

(o) Exhaust systems for grinding, welding or soldering, machining or other related operations shall be installed.

7.3.2 Environmental conditions

(a) **Temperature** . Clean room temperatures shall be maintained at nominally 22°C. Temperature variations of ± 3°C at the control point are acceptable for most operations, but special conditions may be imposed in case of critical operations. The temperature distribution inside clean rooms shall be controlled to ensure that a nominal temperature is achieved throughout the room. Automatic devices may be used for temperature monitoring. If items being worked on are extremely sensitive to temperature changes, it may be necessary to equip automatic devices with a warning system that comes into operation when a temperature change occurs. In practice, it is difficult to maintain a constant temperature to very close limits in environmentally controlled areas. Therefore, specified temperatures shall include the widest tolerances permitted by product requirements.

(b) **Pressure** . A positive pressure differential shall be maintained between the clean room and the outside. Pressure shall decrease successively between the clean room, entrance lock, anteroom and surrounding. The positive minimum pressure differentials to be maintained shall be:

Between clean room and surrounding area: 6 mm H_2O
Between clean room and entrance lock : 2 mm H_2O

Pressure in all areas shall be monitored.

(c) **Humidity** . The relative humidity shall be maintained at 55 ± 10% for general applications and 55 ± 5% for humidity-critical applications and shall be monitored continuously. Hygrometers shall be calibrated at least once every six months.

Corrosion, dimensional variations and loss of electrical properties are caused by changes in relative humidity. High humidity increases the risks of corrosion and fungus growth. Low humidity produces static electricity, thereby attracting particles to charged surfaces. The surfaces of most metals, if clean, will not corrode below 65% R.H., but, if contaminated, corrosion can begin at 55% R.H., particularly on mild steel, aluminium alloys, magnesium and copper alloys (see Table II: Guide to humidity level selection).

(b) **Other Environmental Factors** . Other environmental factors, such as light level, electromagnetic radiation, ionising radiation and radioactive particles, shall be taken into due consideration.

7.3.3 Facility Design Criteria

(a) **Clean room shell, entrances, anterooms.** Clean room shell, floor, walls and ceiling shall be low-shedding and the finish readily cleanable. Floor covering shall consist preferably of one piece or, if this is not possible, shall have the minimum number of joints necessary. It shall have low-shedding characteristics and be sufficiently durable to withstand wear by personnel and operations within the room. The room shall be designed in such a way that only one door or entrance can be opened at a time, except in cases of emergency. Such entrances shall provide an air lock to allow a maintained pressurisation of the area.

Anterooms shall be provided as needed for changing clothes, clothing storage, personal belongings and cleaning equipment.

(b) **Air Supply** . Air supply and filtration equipment shall have adequate capacity to filter all new and recirculated air entering the room. Air-conditioning equipment for prefiltering, cooling, heating, humidification and dehumidification of the clean-room air supply shall be supplied as required.

In laminar-flow clean rooms, the air-flow velocity through the cross-section of the room shall be maintained at 27m per minute with a uniformity within plus or minus 20% throughout the undisturbed room. Airflow patterns shall be uniform with minimum turbulence.

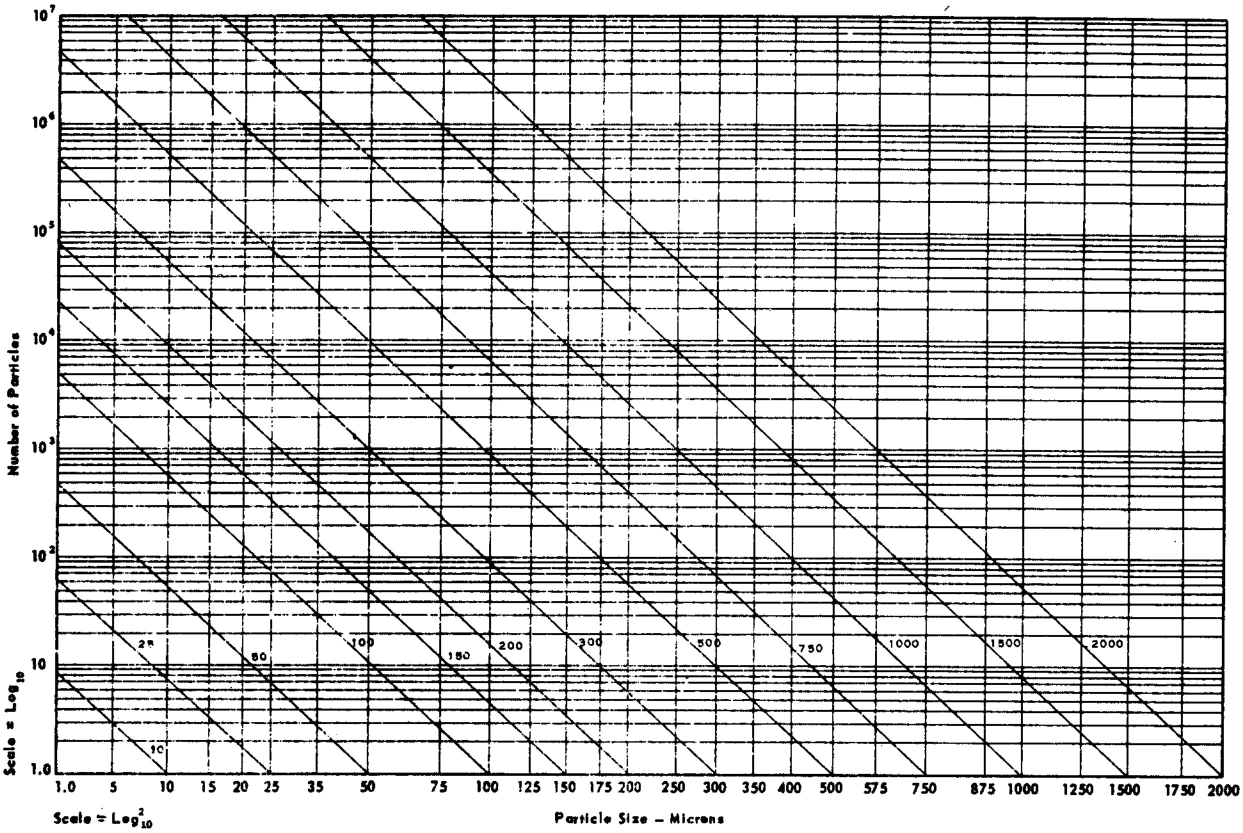
(c) **Filters** . In laminar-flow clean rooms high-efficiency particle air (HEPA) filters shall cover either one entire wall or the entire ceiling, except when diffusion ceiling or wall systems are used or when built-in benches are included in the incoming air end of the room. In the latter case, the wall filter may cover only the area extending from the work bench surface to the ceiling. Pre-filters shall be used to prolong the life of HEPA-type final filters.

CAUTION

After changing of filters, airborne contamination (gas and vapour) may be initiated by the new set of filters. Monitoring shall be effected and any work with highly sensitive equipment after installation of new HEPA filters shall be avoided until contamination has decreased to the specified acceptable level.

(d) **Containers** . Transport and storage containers shall be made of low particle-shedding materials which do not evolve contaminants. They shall also have as rigorous a cleaning schedule as the parts themselves. Care shall be taken that containers used for transporting clean parts do not transfer contamination from surface to surface within the clean room itself.

CHART I
PRODUCT CLEANLINESS LEVELS



Research shows that naturally occurring particulate contamination follows a log-normal distribution with a geometric mean of near one (1) micron particle. This distribution follows a straight line when plotted on a log x $\log^2$ scale graph. The grid is derived from the log-normal or Gaussian distribution function which provides a close fit to real contamination data. The lines on the chart represent the maximum contamination permitted for each level and the plot point is the number of particles above given size versus particle size. The curves can be expressed as $\log n = 0.9260 (\mathrm{Log}^2 X_1 - \mathrm{Log}^2 X)$, where n is the number of particles, 0.9260 is the tangent of the angle, X is the particle size, and X_1 is the cleanliness level.

MIL-STD-1246A
18 August 1967

CHART 1 - Product cleanliness levels

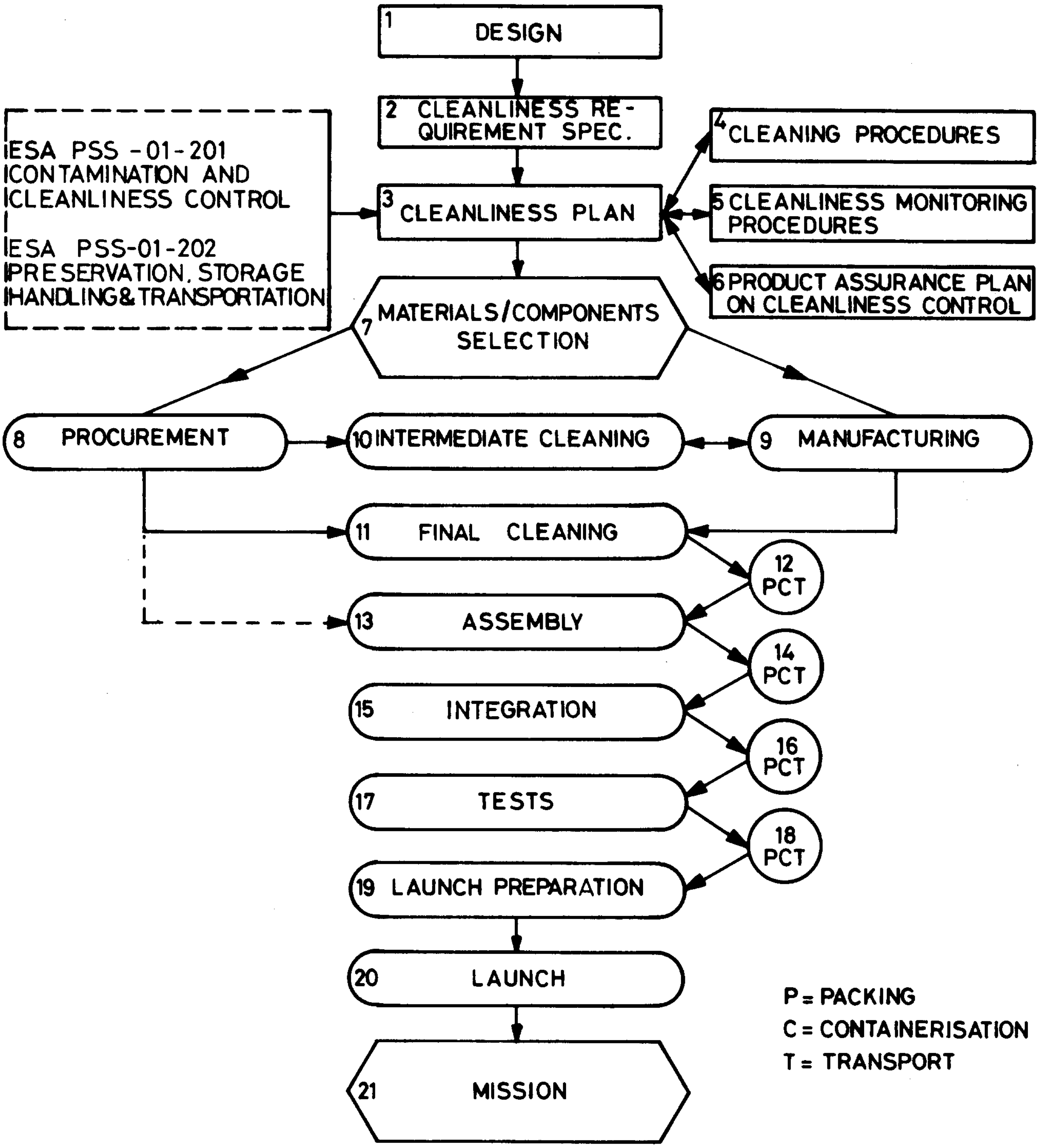


CHART 2 - Spacecraft cleanliness-control flow chart

TABLE 1

AIR CLEANLINESS CLASSES (Federal Std. 209B)

Clean room class	Maximum number of particles			
	> 0.5 µm		> 5 µm	
	per cubic foot	per litre	per cubic foot	per litre
100	100	3.5	*	*
1 000	1 000	35	6.5	0.23
10 000	10 000	350	65	2.3
100 000	100 000	3 500	700	25

* Counts of less than 10 (0.35) particles per cubic foot (litre) are unreliable unless the number of samplings is large.

TABLE 2
(from MIL-STD-1246A)

CLASSIFICATION OF PRODUCT CLEANLINESS LEVELS

Table 1 A

Cleanliness level	Range Surface and Fluids	Quantity of particles
10	5	less than 3
25	5	21
	15	less than 4
	25	1
50	5	180
	15	25
	25	7
	50	1
100	15	280
	25	75
	50	11
	100	1
200	15	4100
	25	1100
	50	180
	100	16
300	25	7000
	50	1000
	100	90
	250	less than 3
500	50	11000
	100	950
	250	25
	500	1
750	100	6500
	250	170
	500	7
	750	1
1000	250	1000
	500	45
	750	7
	1000	1

Table 1B
Nonvolatile residue

Level	Quantity NVR
A	less than 1.0 mg
B	1.0 mg to 2.0 mg
C	2.0 mg to 3.0 mg
D	3.0 mg to 4.0 mg
E	4.0 mg to 5.0 mg
F	5.0 mg to 7.0 mg
G	7.0 mg to 10.0 mg
H	10.0 mg to 15.0 mg
J	15.0 mg to 25.0 mg

TABLE 3
CLEANLINESS LEVELS IN CLEAN ROOMS

Clean-room class[x] (particles/ cubic foot) > 0.5 μm	Cleanliness level after 24h*	Obscuration factor ppm after 24 hours
100	class 85	1.5
1 000	class 145	12
10 000	class 210	60
100 000	class 300	225

[x]) Federal Standard 209B

* MIL-STD-1246A

TABLE 4
PARTICLE-CLEANLINESS LEVELS

Particle fall-out	MIL-STD-1246A	
ppm	Particles > 5 μm/sq.ft.	Cleanliness level
0.1	60	32
1	600	77
10	6 000	138
100	60 000	240
1 000	600 000	410
10 000	6 000 000	630

TABLE 5
ORGANIC-CONTAMINANT LEVELS

Level	Organic-contaminant level	Remarks
I	$\leq 1 \times 10^{-7}$	PSS-01-705
II	1×10^{-7} to 3×10^{-7}	PSS-01-705
III	3×10^{-7} to 1×10^{-6}	PSS-01-705
IV	1×10^{-6} to 3×10^{-6}	visible
V	$> 3 \times 10^{-6}$	visible

TABLE 6
CLEANLINESS OF LIQUIDS

Number of particles > 5 µm per 100 ml	level according to MIL-STD-1246A
10	16
100	40
1 000	80
10 000	160
100 000	270
1 000 000	450

TABLE 7
CLEANLINESS OF LIQUIDS

(NVR)

	Nonvolatile residue (NVR) g/ml	Level according to MIL-STD-1246A
I	$< 1 \times 10^{-6}$	-
II	$1 \times 10^{-6} \rightarrow 3 \times 10^{-6}$	-
III	$3 \times 10^{-6} \rightarrow 1 \times 10^{-5}$	A
IV	$1 \times 10^{-5} \rightarrow 3 \times 10^{-5}$	B + C
V	$3 \times 10^{-4} \rightarrow 3 \times 10^{-4}$	D + E + F + G
VI	$1 \times 10^{-4} \rightarrow 3 \times 10^{-4}$	H + I

TABLE 8

ORGANIC-CONTAMINANT CONTENT OF WIPE MATERIALS

Material	Organic-contaminant content (ppm)
Cotton wool	140
Kim wipes	46
Kleenex	88
Garby	23
Greem 105 lens tissue	34
Velin non-fluff tissue	47
Lens tissue (Scheischer & Schüll - 2478)	14
Filter paper SS - 595	29
Filter paper SS -1575	21
Filter paper SS -1505	22

The data in Table 8 are results of single tests and are simply illustrative.

TABLE 9

CLEANING-SOLVENT RESIDUES

Product	Nonvolatile residue (NVR) (ppm)
Acetone	0.4
Ethyl alcohol p.a.	1.6
Isopropyl alcohol p.a.	0.8
Trichlorotrifluoroethane	0.3
Trichloroethane	0.5
Chloroform, spectral grade	0.3
Methanol p.a.	0.7
Tetrachlorocarbon	0.2
"from aerosol bottle I"	35
"from aerosol bottle II"	50

TABLE 10

EFFECTIVENESS OF VARIOUS SOLVENTS ON LISTED MATERIALS

Solvent materials	aliphatic	aromatic	ethers, cetones	chlorinated solvents
Polyvinyl chloride (Plasticised)	++++	---	---	----
Polyvinyl chloride (hard)	++++	+	+	++
Polyethylene	---	---	---	----
Polystyrene	---	---	---	----
Polyester	++++	++++	+++	++++
Epoxy	++++	++++	+++	++++
Polyvinylidene fluoride	++++	++++	++	++++
Chlorinated polyester	++++	++++	+++	++++
Fluran	++++	++++	++++	++++
Polymethyl methacrylate	----	----	----	----
Polycarbonates	++++	----	--	----
Polyamides	++++	++++	++	++++
Polyphenylene oxides	++++	----	--	----
Polysulphides	++++	--	--	----
Vinyl esters	++++	----	----	----
Polyurethane (paint)		----	----	----
Phenolics	++++	++++	++++	++++
Polytetrafluoroethylene (ptfe)	++++	++++	++++	++++
Fluorochlorotrifluoroethylene (pctfe)	++++	++++	++++	-
Diallylphthalate				
Silicone elastomer	---	---	-	---
Ethylene propylene	---	---	++	---
Butadiene styrene	--	---	-	---
Chlorosuphonated polyethylene	+	---	-	---
Polychloroprene polyethylene	++	---	-	---
Fluorocarbon polyethylene	++++	+		+++
Acrylate ester polyethylene	+++	---		---
Butandiene acrylonitrile polyethylene	+++	---		--

++++ very good	++ average	- average	--- bad	? not known
+++ good	+ average	-- average	---- very bad	

TABLE 10 (CONT'D)
EFFECTIVENESS OF VARIOUS SOLVENTS ON LISTED MATERIALS

Solvent materials	trifluorotrichloroethane	alcohols	strong acids	strong bases
Polyvinyl chloride (plasticised)	+	---	++++	++++
Polyvinyl chloride (hard)	+++	-	++++	++++
Polyethylene	+++	-	++++	++++
Polystyrene	+++	+++	----	++++
Polyester	-	?	----	-
Epoxy	++++	--	+	+++
Polyvinylidene fluoride	++++	+++	++++	++++
Chlorinated polyester	-	+++	+++	+++
Fluran	++++	?	++++	++
Polymethyl methacrylate	?	---	----	+
Polycarbonates	+++	+	+	--
Polyamides	++++	++++	++	++
Polyphenylene oxides	?	++++	++	++
Polysulphides	?	++	++++	++++
Vinyl esters	?	?	+	++++
Polyurethane (paint)	+++	++		
Phenolics	++++	++++	++++	++++
Polytetrafluoroethylene (ptfe)	++++	++++	++++	++++
Fluorochlorotrifluoroethylene (pctfe)	-	++	++++	---
Diallylphthalate				
Silicone elastomer	-	+++	+++	?
Ethylene propylene	?	+++	+++	?
Butadiene styrene	++	+++	--	-
Chlorosuphonated polyethylene	?	+++	++	?
Polychloroprene polyethylene	?	+++	+	?
Fluorocarbon polyethylene	+++	+++	+++	?
Acrylate ester polyethylene	+++	---	---	?
Butandiene acrylonitrile polyethylene	++	+++	?	?

++++ very good ++ average - average --- bad ? not known
+++ good + average -- average ---- very bad

TABLE 11
GUIDE TO HUMIDITY LEVEL SELECTION

% R.H. RANGE	EFFECT
0 - 30	Serious static charge problems
30 - 50	Safe for highly polished metal surfaces or closed components
50 - 65	Marginally safe for humidity-sensitive products. Contaminated metal surfaces start to corrode
65 - 80	Corrosion rate increases largely. Some plastics swell
80 - 100	Fungus growth. Rapid corrosion. Reduced electrical resistivity

ANNEX 'A'

DEFINITIONS

CLEAN ROOM

A clean room is an enclosed area, designed, equipped, maintained and controlled in such a way that the degree of contamination of a product can be controlled.

CLEAN WORK STATION

A clean work station is a work bench or similar work area characterised by having its own filtered air or gas supply.

VISUALLY CLEAN

Visually clean to the normal unaided eye (except corrected vision) when examined under oblique white light (50 - 150 ft. candles) and from a distance of 30 to 60 cm.