



# Space product assurance

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## Cleanliness and contamination control

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## Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

The formulation of this Standard takes into account the existing ISO 9000 family of documents.

This Standard has been prepared by the ECSS-Q-70-01 Working Group, reviewed by the ECSS Technical Panel and approved by the ECSS Steering Board.

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## Introduction

The objective of this Standard is to ensure a successful mission by the definition of acceptable contamination levels for space system elements, their achievement, and maintenance, throughout

- performance assessment versus contamination,
- facilities and tools definition for contamination control and monitoring,
- materials and processes selection, and
- planning of activities.

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# 1

## Scope

This Standard defines the requirements and guidelines for the measurement and control of particulate and molecular contamination to be met by personnel, items, facilities and operations of space projects.

It covers mission definition, design, development, production, testing and operations of space products.

Moreover, it identifies the possible failures and malfunctions due to contamination, and provides guidelines for maintaining the required levels of cleanliness during ground activities, launch and mission.

This Standard does not address magnetic, electrical or electrostatic cleanliness.

This Standard applies to all types and combinations of projects, organizations and products, and during all the project phases.

It also applies to those ground systems that have a hardware interface to space systems, such as MGSE integration stands.

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## Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references the latest edition of the publication referred to applies.

ECSS-P-001	Glossary of terms
ECSS-Q-00	Space product assurance — Policy and principles
ECSS-Q-20	Space product assurance — Quality assurance
ECSS-Q-20-07	Space product assurance — Quality assurance for test centres
ECSS-Q-40	Space product assurance — Safety
ECSS-Q-60	Space product assurance — Electrical, electronic and electromechanical (EEE) components
ECSS-Q-70	Space product assurance — Materials, mechanical parts and processes
ECSS-Q-70-02	Space product assurance — Thermal vacuum outgassing test for the screening of space materials
ECSS-Q-70-05 <sup>1)</sup>	Space product assurance — Detection of organic contamination of surfaces by IR spectroscopy
ECSS-Q-70-50 <sup>1)</sup>	Space product assurance — Particulate contamination control in cleanrooms by PFO measurement
ECSS-E-10-04	Space engineering — Space environment
FED-STD-209E	Airborne particulate cleanliness classes in cleanrooms and clean zones

NOTE The ISO Technical Committee, ISO/TC 209, is currently preparing a range of ISO standards (six published as of June 1999) that expand on the requirements, along with new additions, of FED-STD-209E.

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1) To be published.

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## Terms, definitions and abbreviated terms

### 3.1 Terms and definitions

The following terms and definitions are specific to this Standard in the sense that they are complementary or additional to those contained in ECSS-P-001.

#### 3.1.1

##### **airborne particle**

particle suspended in air

#### 3.1.2

##### **airborne particle cleanliness class**

level of cleanliness specified by the maximum allowable number of particles per cubic metre (or cubic foot) of air

#### 3.1.3

##### **bakeout**

activity of increasing the temperature of hardware to accelerate its outgassing rates with the intent of reducing the content of molecular contaminants within the hardware

NOTE Bakeout is usually performed in a vacuum environment, but may be done in a controlled atmosphere.

#### 3.1.4

##### **bio-contamination**

contamination of materials, devices, individuals, surfaces, liquids, gases or air with micro-organisms

#### 3.1.5

##### **clean area**

general term that includes cleanrooms, controlled areas, good housekeeping areas, and other areas that have contamination control by physical design and specified operating procedures

#### 3.1.6

##### **cleaning**

actions to reduce the contamination level

**3.1.7****cleanliness (contamination) control**

any organized action to control the level of contamination

**3.1.8****cleanliness level**

quantitative level of contamination

**3.1.9****cleanliness verification**

activity intended to verify that the actual cleanliness conditions of the space system, the cleanrooms or the vacuum chambers are in conformance with the applicable specifications and other cleanliness requirements

**3.1.10****cleanroom**

area in which the airborne particulate concentrations, temperature, humidity, molecular species, pressure, activities, and other environmental parameters are controlled, as specified, to produce acceptable products

**3.1.11****clean work station**

workbench or similar work area characterized by having its own filtered air or gas supply

**3.1.12****clean zone**

defined space in which the contamination is controlled to meet specified cleanliness levels

**3.1.13****contaminant**

any unwanted molecular or particulate matter (including microbiological matter) on the surface or in the environment of interest, that can affect or degrade the relevant performance or life time

**3.1.14****contaminate, to**

act of introducing any contaminant

**3.1.15****contamination budget**

permissible contamination levels defined at different stages of the life of the instrument and satellite

**3.1.16****contamination potential**

potential amount of contaminant in the source which can produce contamination

**3.1.17****controlled area**

environmentally controlled area, operated as a cleanroom, with two pre-filter stages but without the final stage of HEPA (or better) filters used in cleanrooms

**3.1.18****fibre**

particle with a length to diameter ratio of 10 or more



**3.1.19****FTIR spectrometer**

analyser (chemical identification) of organic and inorganic contamination using infrared wavelengths

**3.1.20****HEPA particle filter**

throwaway, extended-medium, dry type filter in a rigid frame that has a minimum particle-collection efficiency of 99,97 % (that is a maximum particle penetration of 0,03 %) for 0,3  $\mu\text{m}$  thermally generated DOP or specified alternative aerosol

**3.1.21****induced contaminant environment**

environment created by the presence of contaminating items

**3.1.22****molecular contamination**

airborne or surface contamination (vapour, gas, liquid, or solid) without observable dimensions (i.e. with dimensions at molecular level)

**3.1.23****monitoring**

to perform routine, quantitative measurements of environmental parameters in and around cleanrooms, clean zones, and other clean areas, including contamination parameters

**3.1.24****non-volatile residue (NVR)**

quantity of residual soluble, suspended, and particulate matter remaining after the controlled evaporation of a volatile liquid at a specified temperature

**3.1.25****obscuration factor (OF)**

ratio of the projected area of all particles to the total surface area on which they rest

**3.1.26****offgassing**

evolution of gaseous products from a liquid or solid material into an atmosphere

**3.1.27****outgassed quantity**

total quantity of outgassed species expressed as a mass (e.g. gram or percent of the initial specimen) or as pressure  $\times$  volume (e.g. hPa  $\times$  m<sup>3</sup>)

**3.1.28****outgassing**

evolution of gaseous species from a material, usually in vacuum

NOTE Outgassing also occurs in a higher-pressure environment.

**3.1.29****particle**

unit of matter with observable length, width and thickness

**3.1.30****particle fallout**

accumulated deposit of particulate matter on a surface

**3.1.31****particle size**

apparent maximum linear dimension of a particle in the plane of observation as observed with an optical microscope, or the equivalent diameter of a particle detected by automatic instrumentation

NOTE The equivalent diameter is the diameter of a reference sphere having known properties and producing the same response in the sensing instrument as the particle being measured.

**3.1.32****particulate**

of or relating to minute separate particles

**3.1.33****particulate contamination (PAC)**

airborne or surface contamination due to particles

**3.1.34****plume**

exhaust (molecules or particles) of thrusters and engines

**3.1.35****purging**

supply of clean gas to protect the critical hardware from contamination

**3.1.36****quartz crystal microbalance (QCM)**

device for measuring small quantities of mass deposited on a quartz crystal using the properties of a crystal oscillator

**3.1.37****ram direction**

in the direction of velocity vector

**3.1.38****sensitive item**

item whose contamination may affect its performance or life time

**3.1.39****ULPA particle filter**

throwaway, extended-medium, dry-type filter in a rigid frame that has a minimum particle-collection efficiency of 99,999 % (that is, a maximum particle penetration of 0,001 %) for particles in the size range of 0,1  $\mu\text{m}$  to 0,2  $\mu\text{m}$

**3.1.40****venting**

conveying unwanted gaseous products through an aperture

**3.1.41****visibly clean**

absence of surface contamination when examined with a specific light source, angle of incidence and viewing distance using normal or magnified vision

**3.1.42****wake direction**

direction opposite to the velocity vector

**3.1.43****witness sample**

sample used to collect contaminants during exposure, usually in an environmentally controlled area, and then analysed or measured

**3.2 Abbreviated terms**

The following abbreviated terms are defined and used within this Standard:

<b>Abbreviation</b>	<b>Meaning</b>
<b>AIT</b>	assembly, integration and testing
<b>AIV</b>	assembly, integration and verification
<b>AO</b>	atomic oxygen
<b>BOL</b>	beginning of life
<b>CC</b>	contamination control
<b>C&amp;CCP</b>	cleanliness and contamination control plan
<b>CRS</b>	cleanliness requirement specification
<b>CVCM</b>	collected volatile condensable material
<b>DML</b>	declared materials list
<b>DOP</b>	dioctylphtalate
<b>ECLS</b>	environmental control and life support
<b>EGSE</b>	electrical ground support equipment
<b>EOL</b>	end of life
<b>EVA</b>	extra vehicular activity
<b>FTIR</b>	Fourier transform infra-red
<b>GSE</b>	ground support equipment
<b>HEPA</b>	high-efficiency particulate air filter
<b>ICC</b>	internal contamination control
<b>IR</b>	infra-red
<b>LEO</b>	low Earth orbit
<b>LVC</b>	leakage/venting control
<b>MBC</b>	micro-biological contamination
<b>MGSE</b>	mechanical ground support equipment
<b>MLI</b>	multi layer insulation
<b>MOC</b>	molecular contamination
<b>MRR</b>	manufacturing readiness review
<b>NVR</b>	non-volatile residual
<b>OF</b>	obscuration factor
<b>ORU</b>	orbital replaceable unit
<b>PAC</b>	particulate contamination
<b>PFO</b>	particle fallout
<b>PMP</b>	parts, materials and processes
<b>QCM</b>	quartz crystal microbalance
<b>RH</b>	relative humidity
<b>RML</b>	recovered mass loss
<b>TB</b>	thermal balance
<b>TML</b>	total mass loss

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<b>TRR</b>	test readiness review
<b>TV</b>	thermal vacuum
<b>UV</b>	ultra-violet
<b>ULPA</b>	ultra-low-particle airfilter
<b>VBQC</b>	vacuum balance quartz crystal
<b>VCM</b>	volatile condensable material

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# General cleanliness and contamination control aspects

## 4.1 General

Contamination control cannot be applied effectively without an understanding of the contaminant, the contaminant source and the detrimental effect that the contaminant has.

The known causes of failure and degraded performance of space elements attributed to contamination, including their sources, are given in this Standard. When they are not known, tests and analyses can be performed (e.g. outgassing rates as a function of time, chemical composition of outgassing products, condensation rates or degradation as result of radiation).

The results of these tests and analyses can be used to calculate expected contamination levels and their subsequent effects if other relevant parameters are known.

Preventive cleanliness control is becoming more important as space systems become more sophisticated and mission durations are extended.

A problem frequently encountered in space technology is the lack of data enabling a good correlation between contaminant levels and mission performance requirements. This kind of information should be available in the mass production areas of electronics and precision mechanical devices.

## 4.2 Contamination attributes

### 4.2.1 Main effects of contamination on space systems

The main effects of contamination are:

- failure of precision mechanisms due to particulate matter,
- light scattering by particle and molecular contaminants,
- electrical discharge or arcing in high voltage equipment due to high outgassing and other contamination,
- noise on slip rings and electrical contacts,
- results of certain experiments obscured by excessive molecular contamination (e.g. mass spectrometers and ion counters),

- degradation of optical elements (e.g. lenses, mirrors and windows) due to molecular contamination, especially X-ray and UV equipment and low temperature IR detectors,
- degradation of thermal control surfaces (absorptivity/emissivity ration,  $\alpha/\epsilon$ ) especially in the case of molecular contamination on optical solar reflectors at low temperatures,
- loss of efficiency in heat pipes,
- effects on conductive and non-conductive surfaces (leak paths in electronics),
- loss of efficiency in solar cell generators,
- corrosion of electrical contacts due to the presence of halogenated solder fluxes,
- space charge and discharge effects related to contaminants,
- thermal radiation from particles,
- disorientation due to erroneous reaction of star trackers to luminous particles,
- multipaction in waveguides,
- bad closing of a valve,
- explosion of a cryotechnic motor (Oil + O<sub>2</sub>),
- HF for a motor,
- disturbance of gas flux and combustion within thrusters, and
- disturbance and propagation within RF wave guides.

## 4.2.2 Typical contaminants and their sources on ground

### 4.2.2.1 Particulate contaminants

Many particulate contaminants, such as dirt, sand, industrial fumes, can, to a large extent, be excluded from cleanrooms by filtering, and the space system can therefore be protected from them right up to the final preparation at the launch site.

Nevertheless, a considerable quantity of particulate contaminants are produced or released during the life cycle of the space system. For example:

- hair cosmetics, 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, and
- bacteria, fungi, viruses and secondary products.

### 4.2.2.2 Molecular contaminants

Molecular contaminants can be produced by the following sources:

#### 4.2.2.2.1 Gases and vapours

These include:

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

#### 4.2.2.2.2 Liquids

Examples include:

- residues from cleaning agents,
- residues from adhesive masking tapes,
- machine oils,
- coolants,
- lubricants,
- solder fluxes,
- cosmetics,
- grease from human skin, and
- secondary products coming from micro-organisms.

#### 4.2.2.2.3 Other contaminants

These are usually:

- salt,
- acid,
- alkaline,
- corrosion products,
- oxidation products,
- finger prints, and
- stains.

### 4.2.3 Typical contaminants during operations and their sources

#### 4.2.3.1 Launch

Launch contaminants can come from the acoustic noise and mechanical vibrations. The contamination source is then the space system itself and the fairing and structural parts during the first minutes of the launch.

Redistribution of the released particles can occur so that clean surfaces are covered by particles.

Also the co-passengers can be the source of contamination in the case of multiple launches.

During the initial lift-off, the pressure inside the fairing drops from atmospheric pressure to high vacuum within a few minutes, and the turbulence of the air can also redistribute the particles.

The contamination environment during launch can be severe and there is basically no control of the contamination during this period.

Next to the particle contamination, the molecular contamination is of importance, especially the outgassing of the materials, the release of contaminants by mechanisms, separation mechanisms, such as pyrotechnics and thermal knives, motors and thrusters.

The mechanism of molecular contamination is based upon outgassing under high vacuum; however, the period for which the space system is under high vacuum with other neighbouring hardware is very short.

Predictions of the molecular transfer during this period can be estimated assuming that the Micro-VCM data are known and that the contamination species have a certain activation energy.

This type of calculation can be made for co-passengers when the outgassing requirements are less stringent than those for the space system of interest.

#### 4.2.3.2 Mission (external)

##### 4.2.3.2.1 General

The main problem of contamination in space is that there is limited feedback on contamination levels, because contamination is seldom measured in orbit.

The observed performance losses are often due to contamination.

Lessons learned from space systems returned to Earth after quite a long exposure to space e.g. LDEF, Eureca and solar arrays from the Hubble Space Telescope, indicated visible contamination especially near venting holes and at locations where photodeposition and photopolymerization occurred due to solar radiation, or where atomic oxygen has converted the volatile contaminants into non-volatile contaminants.

##### 4.2.3.2.2 Natural environment

The natural environments described here affect the contaminants in the environment or on surfaces or affect the deposition of contaminants on surfaces.

Most of the natural environments mentioned in the following subclauses are described in detail in ECSS-E-10-04.

##### a. Vacuum and type of gases

The pressure of natural gases around the space system causes reflection of the outgassing molecules originating from the space system. This reflection is called “ambient scatter” and can result in a return of the space-system-produced contaminants to the space system itself.

This type of reflection depends on the level of vacuum and thus upon the orbital altitude. For low Earth orbits the ambient scatter can result in a return contamination flux of a few percent.

The gas composition of the Earth environment is such that only in cryogenic space system applications are contamination problems to be expected.

##### b. Radiation (solar and other electromagnetic radiation)

Solar radiation and especially the ultra-violet part can have effects such as polymerization and decomposition of already deposited contaminants.

The generally observed effects are a reduction in reflection and transmission of light for optical experiments and solar arrays. Another observed effect is the increase of solar absorptance of thermal control surfaces, which results in a temperature increase for those surfaces.

Solar radiation can also affect the contamination deposition mechanisms, and although this combined effect of contamination and electromagnetic radiation is theoretically difficult to describe, this phenomenon is well known.

Radiation ionizes the outgassed molecules in space and so can influence the amount of ionized particles.

Also, the ionized molecules are attracted by a negative charged space system and thus contaminate it.

##### c. Thermal aspects (thermal cycling)

Solar radiation, rotating space systems and planetary shieldings cause temperature cyclings and these temperature cyclings have effects on the outgassing of materials and on the condensation and evaporation of contaminants on surfaces whose temperatures vary.

##### d. Atomic oxygen (AO) (speed effects)

AO is the main constituent of the residual atmosphere in Earth orbit at between 200 km and 700 km altitude. The density is a function of altitude and of other parameters such as solar radiation. In most cases the effect of



thermal AO on deposited contaminants can be neglected. However, due to the relative velocity between AO and the space system (approx 8 km/s) the collisional energy in the ram direction is around 5 eV.

The items and surfaces in the ram direction of the space system can be attacked by thermal AO, whereas the items and surfaces in the wake direction are hardly attacked.

The effect of AO can be described as an oxidation and some materials can become resistant to AO, e.g. non-volatile oxides can be formed on some metals.

Organic materials can be oxidized to volatile products such as CO and H<sub>2</sub>O. The presence of silica contaminants on space system surfaces can be explained by the attack of condensed silicone species by AO and the formation of SiO<sub>x</sub>.

e. Charged particles (electrons, ions)

The effect of charged particles on outgassing and on already condensed contaminants is probably small, but no exact data are known at this moment.

f. Micrometeoroids (debris)

Micrometeoroids have no direct effect on outgassing and on condensed contaminants. Micrometeoroids can pierce some materials and can also result in partly destruction of some materials, which causes release of a large amount of new particles which escape into space or affect neighbouring items. Impacts can also cause evaporation of the micrometeoroid and of the impacted surface.

Redistribution of particles, which were already on space system surfaces by micrometeoroid collisions, have been reported, but the effects are very small.

Based upon this redistribution, the acceptable particle levels for space system surfaces at BOL can be specified.

g. Speed effects of space systems w.r.t. molecular speeds

The speed of a space system has no direct effect on the outgassing of materials or on the deposition mechanisms of contaminants on surfaces.

However, the return contamination flux via the ambient scatter is highly affected by the local pressure around the space system. This local pressure depends upon the actual space system speed with respect to the speed of the natural species. Because of the speed effects, the ram direction pressure can be orders of magnitude higher than the normal pressure for that orbit and the ambient scatter is then also orders of magnitude higher than the normal ambient scatter.

The same can be expected for the wake directions, i.e. orders of magnitude lower pressures and thus orders of magnitude lower ambient scatter than expected.

#### 4.2.3.2.3 Induced environment

The space system environment can be seen as being created by the space system itself or by its operation, by the human space activities and by the docking vehicles.

a. Gas and fluid leakage from pressurized systems

In space systems one can expect sealed pressurized units, such as batteries and gyros; for these units leak rates have been specified which do not result in unacceptable performance losses of those units. However, the level of their leak rate or their location in the space system can be such that the performances of sensitive items can be affected. Also the leaks from pressurized units such as containers holding propulsion gases or fluids (e.g. hydrazine) can affect contamination sensitive items.

Within long-term space (station) programmes a number of fluids are used, which potentially emerge from containments such as tanks, lines and pressure shells to the exterior by leakage, venting or purging.

All fluids contribute to contamination.

b. Cabin leakage of pressurized human habitation systems

Habitation units can have acceptable leak rates, which are related to safety aspects of the astronauts, the leakage of gases can upset the performance of contamination-sensitive items, and then the location of these items is important with respect to the possible cabin leaks.

c. Human waste dumps from habited space systems

Habited space systems generally have overboard dumping of disposals such as gases, liquids and particles.

As particular matter formed through chemical or physical processes, e.g. from solid propellant burning at launch, (human) wastes produced inside and removed by crew, respectively, can be deposited on surfaces or change, for example, ambient optical conditions. They also can lead, for example, to malfunctions of mechanical equipment.

d. Contaminants from release mechanisms and moving mechanisms

Release mechanisms such as cable cutters and mechanisms based upon sealed units with explosives, release particles from adjacent surfaces due to the mechanical shocks.

Mechanisms that are based upon cutting of cables using thermal knives release both molecular and particulate contaminants.

e. Contaminants from operating thrusters, engines or other propulsion systems

Solid booster engines produce particles as well as molecular contaminants, liquid gas rockets produce mainly gaseous contaminants, and hydrazine thrusters produce gaseous reaction products and some unburned fuels. Ion thrusters mainly produce not fully neutralized gaseous products such as xenon and a small amount of sputtered metal from the neutralizing grid material.

f. Contaminants from docking activities

Docking contaminants can be the release of particles by mechanical shocks in the space system as well as the docking system.

g. Environment created by extra vehicular activity (EVA)

The exterior materials of astronaut space suits produce molecular outgassing contaminants and in the selection of those materials basically the same outgassing criteria as for the space system materials are applicable.

Particulate contaminants can also be expected and their level depends upon the astronaut activities.

h. Release of contaminants that were collected during ground activities

During the ground life of the space system, both molecular and particulate contaminants can be deposited, mainly on the external surfaces. During launch especially particulate contaminants are released and during the mission itself their release is mainly caused by shocks. The release of these particulate contaminants from external surfaces by impingement of micrometeoroids and debris is small compared to the amount of particles released from the surface materials by the same impingements.

For molecular contaminants that collected on surfaces during ground activities, the same outgassing effect can be expected as from material outgassing.

i. Secondary products

Secondary products are generated by various intermolecular interactions and chemical or physical processes due to payload or experiment operations or interactions of the natural and induced environment constituents and the space system.

#### 4.2.3.3 Mission (inhabited space cabins)

##### 4.2.3.3.1 General

This subclause deals with the contamination control aspects relevant to the inhabited areas of space cabins.

Long-term effects of contamination significantly affect the lifetime and functionality of equipment. An accumulation leads to an impairment in performance and health status not only with respect to equipment but also for crew members.

The necessity of service or maintenance and restoration activities are obvious.

##### 4.2.3.3.2 Sources of contamination - natural environment

The sources of internal and external contamination originate from natural and induced environments and their interactions.

###### a. Enriched oxygen

With the internal oxygen content (e.g. up to 40 % O<sub>2</sub> in the MIR-station) oxidation processes (e.g. corrosion) occur. Consequently, the internal equipment environment is contaminated in shorter time periods by the corresponding corrosion products (e.g. particles and gases).

###### b. Reduced pressure (emergency case)

In the case of reduced pressure (e.g. 700 hPa in an emergency), the offgassing rates of some internal used materials increase. Respective gaseous products contaminate surfaces or environments especially when the temperature of material surfaces is below the nominal one.

##### 4.2.3.3.3 Sources of contamination - induced environment (internal)

###### a. Propellant leakage

Propellants potentially emerge from, for example, tanks, line fittings and flanges or other equipment by leakage or via internal valves.

Like all fluids, any propellant contributes to contamination.

Each individual application of each propellant is reviewed in the leakage analysis to ensure an optimum selection of the detection, location and isolation techniques.

###### b. Fluid leakage

A number of fluids other than propellants are used, which potentially emerge as contaminants from equipment to the exterior by leakage or via internal valves.

###### c. Contamination from experiments (payloads)

Besides fluids, other sources of contamination are caused by material impurities or are of a more particular nature.

Solid materials contain impurities from manufacturing or cleaning processes which diffuse (outgass) to the exterior already at ambient pressure, especially at elevated temperatures.

In addition to the already discussed diffusion process from the material, adsorbed and absorbed contaminants from contaminant environmental conditions, e.g. during manufacturing, cleaning, interaction, test and launch

phases, can be desorbed (offgas) from the surfaces. This applies to materials and equipment brought into the internal volume by extra-vehicular-activities (EVA suits, repair or servicing of orbital replaceable units) or through particles formed in chemical or physical processes.

System equipment can also be an important source of contamination, for instance, via its normal operation and maintenance. Typical payload sources are bio-contamination from life science experiments and venting from material science experiments.

d. Human waste

As mentioned before human wastes include:

- fluids released by crew activities (nutrients and waste),
- particles from cloths or tissues (fibres) and from the crew's biological processes (e.g. hairs, scales, faeces and urine).

Aside the "contamination standards" with respect to fluids and particles, some very special problem areas are associated with human waste, such as contamination by:

- micro-organisms (fungi, yeasts and bacteria) and
- bio-chemical products of human metabolism (urea).

All of these are extremely bio-corrosive with respect to materials surfaces, especially when (pre-)contamination (water or nutrients) processes are involved.

In addition, all such human wastes pose risks for the health of crew members in closed environments.

e. Bio-contamination

The organisms that are responsible for internal bio-contamination are microbes (fungi, yeasts and bacteria). They can be found in any environment. On the other hand viruses or prions are per se not alive and depend strongly on the presence of other host organisms, such as humans, animals or plants and other bacteria.

Micro-organisms generate contamination substances with their potential metabolic or biological capabilities. The fluids produced contribute to trace gas concentration levels and odour.

1. Fungi, spores

Fungi are introduced into internal volumes by sticking to or being present in living organisms, contaminated equipment, food and airborne particles. They exist as fungi or can develop from spores. They can be introduced during the manufacturing, interaction and test, transport and operational phases.

They grow predominantly in a humid environment, especially in water films or droplets.

Most living species (except spores) do not survive at elevated temperatures ( $> 80^{\circ}\text{C}$ ) or in dry environments ( $< 8\%$  water activity). However, after settling down and starting to grow in a wet environment, they can form colonies, draw humidity from the air and continue to live.

Micro-organisms are killed by UV light, elevated temperatures, starvation (lack of water and nutrients) and contact with toxic substances (disinfectants or detergents and certain metals such as chromium, silver, copper). Spores are much more resistant to all of these measures.

The characteristic population varies due to changes in the growth environment (e.g. crew and sun activity), decontamination activities and genetic mutations.

Fluid and air loops are favourable areas for microbial growth.

In the fluid loops, contamination control can be provided by adding biocides.

In the air loop (e.g. cabin air, avionics air and humidity removal), microbial control is very difficult, especially in areas inaccessible to inspection and maintenance because of limitations on using biocides due to their impact on crew health.

The areas in the environmental control and life support (ECLS) system containing condensed water (condensing heat exchanger, condense and air lines, water separator and condense tank) and cold air are the most vulnerable due to the existence of saturated air or water.

Outside of the ducting, cold spots with low temperatures and high relative humidity are prone to condensation, especially in areas with low air flow velocities (e.g. corners), although condensation is prohibited and ventilation is required, e.g. in areas accessible to the crew.

The air is filtered by screens, high-performance (HEPA) filters or even activated charcoal filters (for odour removal). Therefore, microbial contamination in the flow direction can be prevented behind the filter elements by killing microbes in a dry air stream. However, recontaminations from the downstream side and during maintenance activities require special attention.

## 2. Bacteria

Bacteria are introduced into internal volumes mainly by living organisms such as crew members, animals or plants (payloads) and associated food and can be released via body fluids and wastes. They develop in organic matter (rarely inorganic) and on or within the bodies of living organisms and lead primarily to the impairment of health and bio/corrosion on material surfaces.

If suitable living conditions are available (water and nutrients), the number of microbes can grow exponentially.

Cross-contamination among crew members can be reduced by good design, by adhering to certain hygiene procedures, and by medication of infected organisms (antibiotics).

Hygiene methods to prevent infections consist of preventive means (no direct contact with contaminated matter, periodic cleaning and disinfecting of all surfaces and subsystems prone to microbial contamination, safe disposal and chemical treatment of biologically active wastes) and corrective means (immediate cleaning or disinfecting of spoiled areas).

## 3. Viruses and others

Contrary to fungi and bacteria, viruses and prions need other living organisms (hosts) to stay alive and reproduce in a suitable environment (e.g. temperature and humidity).

## 4. Secondary products

Secondary products generated by microbial growth are fluids (liquids or gases), odour and (bio)reproduction products (e.g. spores, living cells and cell debris) originating from the microbes themselves or from bio/corrosion processes and chemical reactions of space system materials induced through microbial activities.

All of these secondary products are taken into account in the general internal contamination control concept.

#### 4.2.4 Effects of contaminants and failure modes due to contaminants in space

Most of the effects of contamination occur in space, especially when solar radiation is involved. Typical effects of contamination and failure modes are given in subclause 4.2.1.

For the space environment around the space system, the “column density”, local gas pressures and gas composition can be limiting factors for some experiments.

#### 4.2.5 Particle transport in space

Only the surfaces in direct view of other surfaces can be contaminated by particles originating from the other surface and there is no known mechanism during space missions, that can cause a return of released particles to the space system.

Depending on the mass of particles, return of charged particles to a charged spacecraft can be expected.

#### 4.2.6 Molecular contaminants transport in space

- Creeping

Liquid contaminants and also lubricants can contaminate adjacent items by the liquid creeping over surfaces, and silicone fluids especially are known to have a high creeping effect.

In order to reduce the creeping effect, anti-creep barriers made of special materials can be applied.

- Direct flux

Contaminants in space move in straight lines from the space system into deep space and sometimes contamination sensitive items can be located in the direct flux; however, a design provision is to avoid this location.

- Indirect flux

Contaminants from space systems can impinge on less contamination sensitive surfaces such as solar arrays and antennas and after reflection (specular) or re-evaporation (diffusive) these contaminants can affect contamination sensitive items or areas.

- Collision with natural gases

Contaminants coming from the space system can collide with the natural gases around the space system and after collision can return to the space system. This phenomenon is known as ambient atmospheric scattering and depends upon the density (and thus upon the altitude) of the natural gas.

- Collision with other outgassed molecules

Molecules released from space systems (e.g. outgassing via venting holes) can collide with other molecules from the same origin or from other origins (e.g. plumes). After the collisions, some molecules can return to the space system. This phenomenon is called self-scattering and the return flux strongly depends upon the intensities of the fluxes from the contaminant sources.

- Ionization of gaseous contaminants and the re-attraction by the negative charged space system

Contaminants emitted from the space system can be ionized in space by solar radiation (especially ultra-violet radiation, electrons, protons and ions) and these ions can be re-attracted by a negative charged space system. This phenomenon is well known, but has not yet been quantified.

One of the simple rules is that instruments that have deployable shutters or ejectable covers shall be deployed or ejected when the outgassing has dropped to a certain level or after a pre-determined time after the launch.

## 4.3 Cleanliness levels

### 4.3.1 General

The cleanliness levels concern basically molecular contaminants (MOC) and particulate contaminants (PAC).

The levels can be defined for surfaces as well as for the relevant environment.

The relevant environment can be a cleanroom, a test facility and the space environment.

### 4.3.2 Particulate levels on surfaces

#### 4.3.2.1 General

The way the particulate levels on surfaces are expressed depends very much upon the size and number of the particles per unit area. Two standard methods of measurement are given below.

The general concern in space system technology is for particle sizes from 1  $\mu\text{m}$  to 100  $\mu\text{m}$ . Besides the size and number, important parameters for particles interpretation and measurement are:

- shape,
- orientation,
- fluorescence,
- magnetic properties, and
- chemical nature.

The redistribution of particles on surfaces in any environment can occur due to turbulence (e.g. in vacuum chambers during pump down or during repressurization), and during vibration (acoustic, vibration and launch).

#### 4.3.2.2 Expression of levels for particles on surfaces

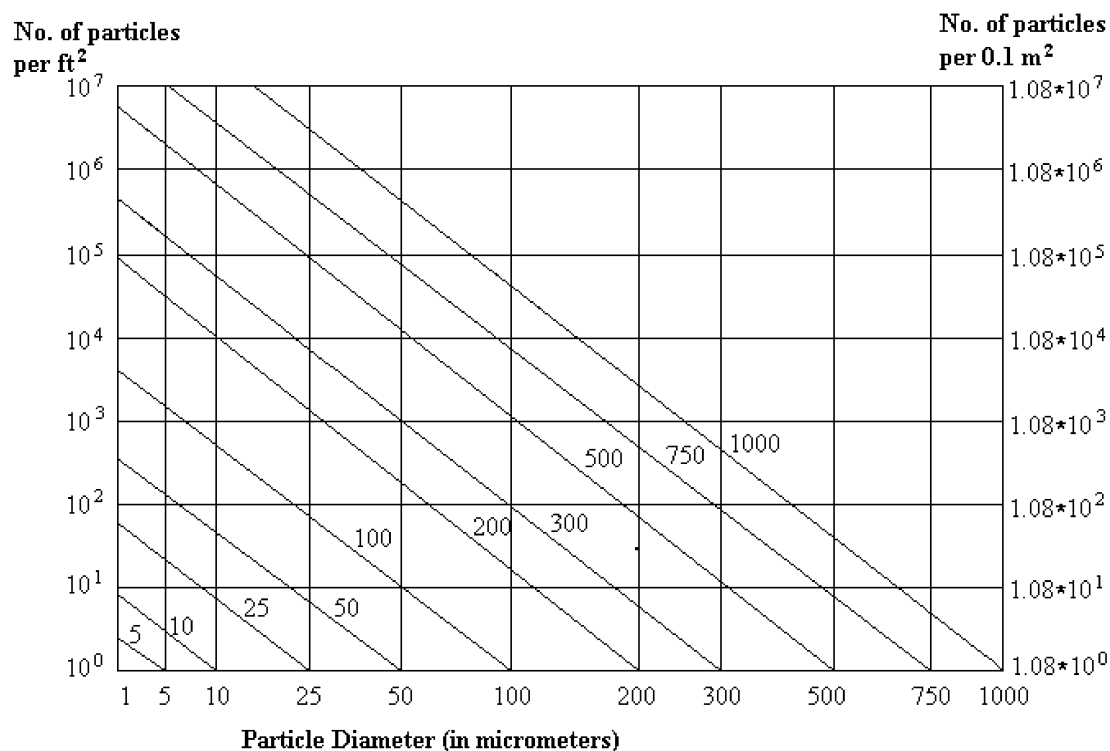
##### 4.3.2.2.1 Standard method 1 (MIL-STD-1246C)

The MIL-STD-1246C gives the size-number distribution function for particles on surfaces. Table 1 gives the classification in data terms and Figure 1 gives the same distribution function in the form of a graph.

Figure 1 gives the cleanliness levels for surfaces for particles from 1  $\mu\text{m}$  to 1 000  $\mu\text{m}$ .

NOTE Levels are measured by counting the number and sizes of the particles of at least three different sizes on a known surface area. The data are then plotted in the graph in Figure 1. A line parallel to those in the graph is then drawn such that all the measurement points are on the left of this line. The point in which this line meets the x-axis gives the actual cleanliness level.





**Figure 1: Product cleanliness levels according to MIL-STD-1246C**

**Table 1: Product cleanliness levels**

Cleanliness level (according to MIL-STD-1246)	Particle size (µm)	Max. allowable particle count per 0,1 m <sup>2</sup>	Max. allowable particle count per ft <sup>2</sup>	Max. allowable particle count per litre
1	1	1,08	1,0	10
5	1	3,02	2,8	28
	2	2,48	2,3	23
	5	1,08	1,0	10
10	1	9,07	8,4	84
	2	7,56	7,0	70
	5	3,24	3,0	30
	10	1,08	1,0	10
25	2	57	53	530
	5	24,8	23	230
	15	3,67	3,4	34
	25	1,08	1,0	10



**Table 1: Product cleanliness levels** *(continued)*

Cleanliness level (according to MIL-STD-1246)	Particle size (µm)	Max. allowable particle count per 0,1 m <sup>2</sup>	Max. allowable particle count per ft <sup>2</sup>	Max. allowable particle count per litre
50	5	179	166	1 660
	15	27,0	25	250
	25	7,88	7,3	73
	50	1,08	1,0	10
100	5	1 930	1 785	17 850
	15	286	265	2 650
	25	84,2	78	780
	50	11,9	11	110
	100	1,08	1,0	10
200	15	4 520	4 189	41 890
	25	1 340	1 240	12 400
	50	184	170	1 700
	100	17,3	16	160
	200	1,08	1,0	10
300	25	8 050	7 455	74 550
	50	1 100	1 021	10 210
	100	103	95	950
	250	2,48	2,3	23
	300	1,08	1,0	10
500	50	12 800	11 817	118 170
	100	1 190	1 100	1 100
	250	28,1	26	260
	500	1,08	1,0	10
750	50	105 000	95 807	958 070
	100	9 630	8 919	89 190
	250	231	214	2 140
	500	8,75	8,1	81
	750	1,08	1,0	10
1 000	100	46 100	42 658	426 580
	250	1 100	1 022	10 220
	500	42,1	39	390
	750	5,18	4,8	48
	1 000	1,08	1,0	10

## 4.3.2.2.2 Standard method 2 (Obscuration factor)

The obscuration factor (OF) is the ratio of the projected area of all particles to the total surface area on which they rest.

This OF is in principle independent of the number-size distribution of the particles and even independent of the shape and colour of the particles. In general the levels shall be expressed in parts per million ( $\text{mm}^2/\text{m}^2$ ) and the normal requirements should roughly be between  $10 \text{ mm}^2/\text{m}^2$  and  $10\,000 \text{ mm}^2/\text{m}^2$ .

The OF has the advantage that a number of performance loss parameters are directly related to the particle coverage of the critical item.

## 4.3.2.3 Correlation for particles on surfaces

The levels expressed in Table 1 and Figure 1 (MIL-STD-1246C) are according to the following equation:

$$\log n = 0,926 \{(\log C)^2 - (\log d)^2\} + 0,031\,97$$

where

$n$  is the number of particles per  $0,1 \text{ m}^2$ ;

$C$  is the class (e.g. 300);

$d$  is the particle diameter ( $\mu\text{m}$ ).

The factor 0,926 is a slope factor and is basically only valid for cleaned surfaces; in practice it is between 0,24 and 0,58.

Moreover, these levels are not linear and the interpretation of the real amounts becomes difficult, which in turn makes budgeting quite difficult.

The correlation between the ideal levels of MIL-STD-1246C (i.e. the slope factor of 0,926) and the obscuration factor for particles between  $1 \mu\text{m}$  and  $20 \mu\text{m}$ , is given in Table 2.

NOTE The definition of the actual slope factor depends basically on the surface characteristics. For this reason, values reported in Table 2 are given for reference and the method 2, based on obscuration factor, is preferred for the expression of particles on surfaces.

**Table 2: Correlation between ideal class of MIL-STD-1246 and obscuration factor**

MIL-STD-1246 (class)	Obscuration factor ( $\text{mm}^2/\text{m}^2$ )
50	0,3
100	3,3
200	54
300	329
400	1 274
500	3 814
600	9 619
700	21 469
800	43 707
900	82 799
1 000	148 025

### 4.3.3 Particle levels in environments

The environments concerned are cleanrooms (see annex F), test areas or test volumes and also space itself. The cleanliness levels for gases used for the relevant process or for purging are expressed in the same way.

### 4.3.4 Molecular levels on surfaces

#### 4.3.4.1 Sources of molecular levels on surfaces

This definition of MOC includes inorganic molecules (e.g. NaCl and residue of solder fluxes), as well as organic molecules on surfaces.

For organic molecules the space system contaminants are seen as, for example, hydrocarbon oils, ester types and silicones, mainly molecules coming from test facilities, and outgassing species from materials.

- a. For low temperature applications, the type of molecules can be different as, for example, water (under 0 °C) and even gases such as nitrogen can form a deposit on cold surfaces and as such shall be reflected on the CRS and C&CCP.
- b. The morphology of the deposit (e.g. smooth surface or droplets) can be important with regard to the actual performance loss.

Molecules can be deposited on surfaces during several critical phases on the ground as well as in space. On the ground, the critical periods are during manufacturing, activities in cleanrooms, tests (e.g. vacuum tests especially when critical surfaces are cold) and transport. Molecular contaminants can also be deposited during launch and in space and for this type of deposition special mathematical models have been developed.

#### 4.3.4.2 Acceptance levels for molecular contamination on surfaces

In general, the molecular levels on surfaces are expressed in terms of mass per unit area (i.e. g/cm<sup>2</sup>).

- a. The type of species (e.g. silicones) can be specified, as well as the total level.
- b. The expression in g/cm<sup>2</sup> generally varies between one monolayer and the visible level of  $3 \times 10^{-8}$  g/cm<sup>2</sup> and  $1 \times 10^{-6}$  g/cm<sup>2</sup>, respectively.
- c. The actual requirements depend upon the application and the temperature.
- d. Typical for optical instruments, the number of diopeters (number of optical surfaces) is important and it is generally known that for ultra-violet optics the requirements can be very stringent because of polymerization (mainly carbon) of the contaminants with incident radiation.
- e. Acceptance levels for the MOC are determined by analysis, which takes into account the above critical parameters and the acceptable performance loss.
- f. The specified levels are generally related to the method of measuring the organic contamination levels.
- g. Specifications can be based upon the amount of non-volatile residue (NVR), which is measured in real mass units per (large) area. Table 3 gives the NVR cleanliness levels according to MIL-STD-1246C.
- h. The acceptance level for NVR of liquid systems (cooling and propulsion systems) is generally  $\leq 1 \times 10^{-7}$  g/cm<sup>2</sup>.

**Table 3: NVR cleanliness levels, according to MIL-STD-1246C**

NVR level	NVR limit	
	Surface (mg/0,1 m <sup>2</sup> )	Volume (mg/l)
A/100	0,01	0,1
A/50	0,02	0,2
A/20	0,05	0,5
A/10	0,10	1,0
A/5	0,20	2,0
A/2	0,50	5,0
A	1,00	10,0
B	2,00	20,0
C	3,00	30,0
D	4,00	40,0
E	5,00	50,0
F	7,00	70,0
G	10,00	100,0
H	15,00	150,0
J	25,00	250,0

### 4.3.5 Molecular levels in environments

The environments that cause most concern for space systems are manufacturing areas, assembly areas, integration areas, test areas, transport containers, pre-launch areas, launch areas and space itself.

The contamination levels of natural environments in space (see ECSS-E-10-04) and the induced environment are to be dealt with. The induced environment is created by the space system itself and the actual processes. The space system induced environment is caused by, for instance, material outgassing, thrusters, mechanisms, dumps and the induced environment can be modelled when the contaminant sources are known and quantified (e.g. outgassing kinetic tests such as VBQC-tests) and when the distribution methods in space are known. The natural environment can have some effect upon the actual distribution of the space system contaminants.

Another effect is the speed of the space system and the speed of the contaminants. This effect can cause enormous contamination differences in the ram and wake areas of the space system.

A parameter that can be of importance is the column density of molecules in space.

## 4.4 Cleanliness monitoring

### 4.4.1 Particulate contamination monitoring

- Monitoring of the cleanroom air  
See annex F.
- Visual inspection of surfaces

Surfaces are examined with the naked eye or with the aid of a microscope. An ultra-violet lamp (395 nm) 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  $300 \text{ mm}^2/\text{m}^2$ .

This is independent of: colour of the surface, amount and wavelength of the inspection light and angle of vision.

- Optical monitoring methods on surfaces

Typical methods are the measurement of transmission or reflection loss and nephelometry (i.e. scattering of light).

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. There are commercially available instruments (e.g. PFO photometers) that automatically measure the particle fallout level on sensor plates, exposed during phases of interest.

The method for measuring of the PFO level is described in the ECSS-Q-70-50.

Other methods for the determination of the particle contamination are:

- the tape lift method, using sticky tapes (according to ASTM-E1216-87);
- microscopic counting;
- method of counting particles removed from a known surface by blowing and suction of air;
- washing of the surface of interest and counting the particles in the washing fluid either directly using a commercial instrument, or on a filter after filtration of the liquid.

#### 4.4.2 Molecular contamination monitoring

##### a. Visual inspection

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

##### b. Wipe techniques and visual inspection

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

NOTE If the lens tissue is carefully chosen, perfectly cleaned and accurately controlled, one can measure up to  $0,2 \times 10^{-7} \text{ g/cm}^2$ . Since with this method “false positives” can always be measured, indicating contamination where there is none, this wipe method should not be a “prime” detection method, but a “support” method, used to confirm a result. Good and reliable results depend greatly on lens tissue choice and pretreatment.

##### c. Wipe techniques and physical and chemical analysis

A surface of a known area is wiped with a clean tissue, the tissue is subjected to extraction with chloroform of spectral grade, and the residue of the chloroform is analysed by infrared techniques in accordance with ECSS-Q-70-05.

This method, applied to a wiped area of  $100 \text{ cm}^2$ , permits detection of organic contamination levels down to  $3 \times 10^{-9} \text{ g/cm}^2$ .

The results of this method depend very much on the surface roughness, on the type of tissue and on the method used to clean (and verify) the tissue.

The results depend also on the solvent used to wipe: if strong (e.g. chloroform), the surface can be damaged and the analyses biased; if soft (e.g. alcohol), the contaminant is not fully wiped and thus the pollution is underestimated. This is a strong limitation of the wipe method, which is, however, efficient for light molecular deposits (like hydrocarbide).

d. Non-volatile residue

The accuracy and detection limit of this method depend greatly upon the sensitivity of the balance, the substrate water absorption, the washing efficiency and the solvent background (see NVR-measurement according to ASTM-E1235M-95).

The levels should be expressed in mass per unit area and the measurements should be made using infrared spectroscopy (see measurements according to ECSS-Q-70-05).

Measurements in situ are quite often made using quartz crystal microbalances (QCM).

e. Direct analysis of the suspect item

Various analysing techniques can be applied, e.g. infrared analysis, gas chromatography, mass spectrometry, ultra-violet degradation, X-ray reflection loss.

f. Direct analysis of witness samples

Analysis of witness samples, exposed to the hardware concerned:

- Metal witness plates of 15 cm<sup>2</sup> area washed and analysed by IR techniques have a detection limit of  $6 \times 10^{-9}$  g/cm<sup>2</sup>.
- IR transparent disks (MgF<sub>2</sub>, CaF<sub>2</sub>, ZnSe) analysed directly by IR technique have a detection limit of  $2 \times 10^{-8}$  g/cm<sup>2</sup>.

NOTE 1 Even if measurements on metal witness samples seem to be more precise than measurements on IR transparent disks, they involve a lot of handling (cleaning, verification of background, exposure, recuperation of contaminants, transfer of concentrated solvent on a crystal and then analysis) and are thus less practical than the second method.

NOTE 2 The above detection limits were determined with sophisticated FTIR instruments (purged with dry air, against disturbance from humidity absorption, and regularly calibrated), based upon low signal-to-noise ratios and low NVR of solvents and wipes. Normally, worse detection limits need to be considered for routine measurements.

#### 4.4.3 Contamination monitoring in vacuum facility

Monitoring of organic contaminants in vacuum facilities can be achieved using one of the following methods:

- By means of clean metallic sensors placed on or near suspect places for a specified time and then subjected to one of the standard analyses. A combination of a QCM and a mass spectrometer can allow identification of the different condensed species after a controlled re-evaporation from the QCM.
- Mass spectrometer measurements can also be used to obtain information on outgassing products, and their origin if a position-scanning mechanism (NIPKOV disk) is employed.

- A QCM which can detect contamination levels down to  $1 \times 10^{-9} \text{ g/cm}^2$ , and can also be used to measure condensation rates. Such QCMs can operate down to liquid nitrogen temperatures. (QCM can be used under atmospheric conditions, but humidity shall then be controlled to close tolerances, since water sorption on the crystal affects the results).

NOTE: In general, the use of witness samples is the simplest and cheapest method for contamination monitoring in a vacuum chamber.

#### 4.4.4 Contamination monitoring during launch

Contamination measurements during launch are difficult to perform, especially those of particle levels.

- For the molecular contamination levels during launch, QCMs can be used, with the temperature either uncontrolled or kept constant.
- For the interpretation, the thermal fluxes and the solar fluxes can affect the QCM readings and corrections can then be required.

The QCMs can be installed on the launcher and the measuring time is limited to a few minutes; if the QCMs are installed on the space system, the measurements can continue during mission.

The measurement of particles during launch is extremely difficult and no specific method has been established for their detection.

#### 4.4.5 Contamination monitoring in space

Measurements of contamination in space are not often made because the policy of cleanliness control is based upon the basic principle of achieving the lowest possible contamination levels with existing knowledge and within the allocated financial budgets.

The manageable factors are then: a good materials and process selection, cleanliness oriented design, good preventive actions and good operations procedures.

- Particle measurements in space can be made by light scattering measurement, e.g. using the Sun or a laser as the a light source.
- Particles can also be measured by mass increase measurements using QCMs with a crystal having a surface to which particles stick.
- Molecular contaminants in space can be measured using mass spectrometers.
- Molecular contaminants on surfaces can be measured using a QCM as a witness sensor, which is located near a sensitive item and maintained at the same temperature as the item.

## 4.5 Cleaning

Various methods are employed to clean contaminated items; for example:

- Mechanical cleaning, such as grinding, brushing and blasting.
- Detergent cleaning (or soap cleaning) for, for example, glass, rubbers, plastics, polyamides, PTFE, polypropylene and acrylates and all ferrous metals, including stainless steel. Such detergents also clean non-ferrous metals, such as aluminium and brass, but have an oxidizing effect on their surface. A detergent or soap cleaning is followed up by a final cleaning with solvent to remove all traces of detergent.
- Chemical cleaning with, for example, acids, alkalines and salts for metals.
- Electrochemical cleaning with, for example, acids, alkalines and salts for smoothing metal surfaces.



### 4.5.1 Removal of particulate contamination

For a number of substances, visibility of particles can be enhanced by the use of a special ultra-violet lamp ("black light" - UV-A 365 nm).

- Dust can be removed with the aid of an ordinary vacuum cleaner, combined with a good brush. Having the exhaust of the vacuum cleaner outside the cleanroom is preferred to avoid recontamination. Clean air supply to the item to be cleaned is used, otherwise the contamination of items to be cleaned can be increased by the relative dirty air which is extracted from the environment (e.g. when electrostatic attraction can occur). Only vacuum cleaners equipped with HEPA filters are used in a cleanroom and checked with a UV lamp while working.
- Wiping is performed with extreme care, otherwise surfaces can be scratched and "dust" can simply be wiped onto other clean items in the vicinity.  
Since, in any case, solvent leads particles to the bottom of cleaned part, those particles shall be recovered with a vacuum cleaner at the end.
- Another method of removal of particles is the very careful use of a jet of compressed gas, since contamination of the other clean items in the vicinity can result. Cleaning agents, such as brushes, wipe tissues or compressed gas, can themselves contaminate the item to be cleaned and can lead to dust scratching the surface during cleaning. Ionized air is a good approach in the removal of particles by air blowing.
- An effective form of wiping can be used of tissues dipped in methanol.
- Larger particles can be removed by means of polyimide adhesive tape, eventually rolled around a metal or other appropriate tool (e.g. swabs).
- Cleaning with dry ice (e.g. CO<sub>2</sub> jet spray) can be very effective.
- The hardware to be cleaned can be coated with shrinkable polymer film and, after drying, the film can be removed with the contaminants. Use of this type of cleaning method needs to be carefully evaluated as it is known to have detrimental effects on some materials (e.g. gold coatings).

### 4.5.2 Removal of molecular contamination

Several methods exist for cleaning off molecular contamination, and for which the final cleanliness levels can be assessed based on experience and on the initial cleanliness level, as well as on the type of item contaminated.

- Dry wiping: clean lint-free cloth or lens paper is used, however, it has the disadvantage that it can scratch the surfaces.
- Wet wiping: a clean cloth, brush or paper is used in conjunction with organic solvents.
- Solvent cleaning: examples are washing, dipping, spraying, vapour cleaning and ultrasonic cleaning.
- Detergent cleaning or soap cleaning.
- Plasma cleaning (i.e. ionized inert low pressure gas) is very effective for the removal of polymerized products.
- Volatilizing under vacuum is especially successful for cleaning assembled units, or when solvent cleaning is too delicate an operation. See also sub-clause 6.4.3 "Bakeout".
- Ultra-violet-ozone cleaning: molecules of an organic nature are activated by ultra-violet light, resulting in dissociation, after which they react with the ozone produced in the air by ultra-violet light.
- Cleaning with dry ice (CO<sub>2</sub> jet spray): this is very effective for the removal of molecular layers.
- Use of shrinkable polymer film, peeled after drying, can also be very effective for the removal of molecules (not for optical surfaces).



## 4.6 Modelling

Known quantities of outgassing flux as a function of time and knowing the shape of the outgassing plume are essential for the modelling of contamination in an environment around the space system. It is assumed that the temperature of outgassing sources is known.

Knowledge of the outgassing fluxes as a function of time, the view factors and the residence times (as a function of surface temperature) of the contaminants on the surface of interest are indispensable for the modelling of the contaminants on surfaces.

For a worst case surface modelling, the Micro-VCM data (ref. ECSS-Q-70-02) can be taken. It is then assumed that all the contaminants released during the Micro-VCM test of 24 hours at 125 °C, are now released during the actual life time and the second assumption is that the view factor ( $V_f$ ) is estimated ( $V_f$  = part of the total outgassing amount which impinges on the surface of interest). The third assumption is that all the TML for surfaces at -100 °C or lower, all the RML for surfaces between -100 °C and +25 °C or all the CVCM for surfaces at 25 °C, is deposited permanently on the surface of interest. Knowledge of the outgassing rates as a function of time and temperature for realistic hardware is indispensable to achieve more realistic modelling. The same applies to the residence time of the contaminants on surfaces as a function of surface temperature.

Most modelling methodologies (like e.g. ESABASE outgassing) are based upon outgassing data obtained during outgassing kinetic tests (ref. ESA-QME-WI-F-03). The test data obtained from outgassing tests according to ASTM-E1559-93 can also be used for modelling space system contamination.

Based upon the modelling, contamination budgets are allocated for certain applications.

Detailed information on plumes and different modelling approaches is given in ECSS-E-10-04.

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## Cleanliness and contamination control programme

- a. The supplier shall establish a cleanliness and contamination control programme for each level of configuration item defined in the project, at the beginning of the project.

The objective of this programme is, starting from the mission performance requirements, to establish cleanliness and contamination levels to be achieved at different manufacturing, AIT and mission stages.

- b. This shall be documented in the cleanliness requirement specification (CRS).
- c. The programme shall implement methods to achieve the specified levels established and documented in the cleanliness and contamination control plan (C&CCP).
- d. Clear responsibility and authority shall be assigned for the implementation of the cleanliness and contamination control tasks.
- e. Adequate measures shall also be established for the coordination and resolution of cleanliness and contamination control issues among the parties involved in the project.

NOTE In general, the organization of regular workshops dedicated to cleanliness and contamination control for a specific programme is a good practice for the definition of the CRS. Surveys should also be made to determine what is really needed for contamination control, based on mission objectives and scenarios.

For complicated contamination items, the early preparation of a cleanliness policy document is of great value before the preparation of the actual CRS and C&CCP, because all relevant data are not available in the early stages of the project and not all possible steps, such as purging and bakeout, are defined.

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# Contamination control during the product life cycle

## 6.1 General design provisions

Contamination control activities during the design phase shall take into account the following points:

- a. selection of materials, mechanical parts and processes,
- b. cleaning aptitude of materials and mechanical parts,
- c. acquisition of outgassing data of organic materials,
- d. volume or quantity of each material used,
- e. application and location of materials,
- f. vent path or hole of outgassing,
- g. measurement of contamination,
- h. deployable aperture covers,
- i. flash-off heaters on passive radiative coolers, mirrors and detectors,
- j. covers over passive radiative coolers,
- k. in-bay purging (on-ground and at the launch),
- l. verification of the compatibility of the surface treatment with the cleanliness level,
- m. identification of the protection equipment,
- n. ground support equipment, and
- o. detailed design provisions for specific types of mission are addressed in 6.6, 6.7 and 6.8.

## 6.2 Manufacturing, integration and test

### 6.2.1 Manufacturing

- a. All elements manufactured in non-clean areas or under non-clean conditions shall be the object of a cleaning process until the required cleanliness level is achieved, before they are packaged for delivery.
- b. All materials and processes used shall conform to PMP requirements.

- c. Cleaning and packaging operations for all elements shall be processed according to applicable and validated procedures.

Two cases can be identified:

- Elements that can be cleaned after manufacturing

These elements shall be cleaned so as to guarantee the required cleanliness level. For a given initial pollution, the cleaning procedure is validated if it allows to guarantee that both particulate and molecular contamination are within specified levels.

- Elements that cannot be cleaned after manufacturing

Manufacturing and assembling areas for these different elements shall meet the required cleanliness level specifications.

In this case the manufacturing process shall be considered in the C&CCP, in particular for sensitive elements.

### 6.2.2 Assembly and integration

- a. For any contamination critical assembly, a cleanliness control flow chart should be established, showing, schematically, the stages at which specific cleanliness controls shall be undertaken.
- b. Assembling activities shall be performed only by specifically trained personnel.
- c. Critical and sensitive elements should only be exposed during essential operations and returned to their dedicated containers when not in work.
- d. A dedicated set of assembly tools and equipment shall be used and maintained in clean conditions.
- e. Dedicated procedures shall be established for critical item assembly.

NOTE From the particle point of view, the number of 5  $\mu\text{m}$  particles per given volume of air is much more critical than the number of smaller particles, since the fallout is mainly determined by particles of 5  $\mu\text{m}$  or larger. The required cleanliness level of a cleanroom can only be selected when the specified obscuration factors for critical spacecraft surfaces are known. The particle size 5  $\mu\text{m}$  is often used as a criterion, because for optical surfaces particles larger than 5  $\mu\text{m}$  are critical, whereas for bearings and gears, particles in the range 10  $\mu\text{m}$  to 40  $\mu\text{m}$  are more harmful.

- f. For the selection of the cleanroom, the allocated contamination budget and the duration of the integration shall be known. Furthermore, the type of cleanroom shall be selected when the integration takes place. The correlation between the airborne contamination and the particle fallout for normal cleanrooms is basically known (see annex F), and so a rough estimate can be made of the type of cleanroom required. Of course a practical contamination level for the cleanroom is required with representative activities and a representative number of operators. Also, the type of protection required for the critical hardware (e.g. covers, shields and purging) has an effect on the expected contamination levels.
- g. An audit of the integration and test facilities shall be performed on a regular basis. The suitability of the facilities shall be verified during MRR or TRR.

### 6.2.3 Testing

Space system testing generally involves:

- a vibration test,
- an acoustic test,

- an EMC test,
- a thermal balance test,
- a thermal vacuum test, and
- a solar simulation test;

and these tests can affect the cleanliness of the hardware to be tested, e.g. vibration and acoustic testing can loosen particles and cause their redistribution; EMC and acoustic test facilities can be inside cleanrooms, but are basically not clean.

- a. The centre where the testing activities take place shall be in conformance with the relevant requirements of the ECSS-Q-20-07.
- b. The test facilities shall be classified with the same cleanliness level as cleanrooms. The cleanroom requirements are also applicable to the test facilities. However, for certain conditions, the specified cleanliness level is not guaranteed, such as:
  - vacuum chambers during operation,
  - acoustic facilities during operation,
  - EMC chambers, and
  - vibration facilities.
- c. All the potential sources of contamination from the test facility to the test item shall be analysed and controlled, for example;
  - lubricants,
  - gases for purging, and
  - coating material on walls.

#### 6.2.4 Vacuum facilities

- a. Adequate procedures shall be available for:
  - cleaning the test facilities (e.g. solvent and bakeout),
  - cleanliness control during pump-down and recovery,
  - recovery of storage pumps, and
  - cleaning cold trap.
- b. For a test in a vacuum facility, it shall be ensured that the material of the test item does pose any risk of contamination of the facility. If contamination has occurred, the contaminants are released during the warm phase of the facility to the test item.
- c. The following should be available and verified:
  - An approved declared material list (DML).  
The DML shall consider the test item in the “test configuration”, i.e. including the test adapter and all connections (e.g. mechanical, electrical).
  - For a flight, hardware may be accepted only having the reference to the already approved material list.  
In such a case the DML shall be provided only for the materials used in addition to the flight configuration (test configuration).
- d. For “clean” vacuum systems, a sensor (or a critical surface) shall not be contaminated by more than  $1 \times 10^{-7}$  g/cm<sup>2</sup> during a blank test of 24 hours duration. The sensor is normally at room temperature, but, more stringent requirements can be imposed, depending upon the budget allocation for the

equipment. In fact, for sensitive equipment,  $0,3 \times 10^{-7} \text{ g/cm}^2$ , 24 hours (or  $0,5 \times 10^{-7} \text{ g/cm}^2$ , week) for a blank test should be specified.

- e. The blank test shall be representative of the actual test (inclusive of test equipment and cabling) and include a pump down and a repressurization.

## 6.3 Budgets, prediction and modelling

### 6.3.1 General

- a. A contamination budget shall be established in order to determine:
  - the on-ground molecular and particulate contamination levels;
  - an estimate of the in-orbit molecular contamination, for contamination-sensitive systems.
- b. The contamination budget at different stages in the life of the instrument and satellite (e.g. end of instrument AIT, end of satellite AIT, beginning of orbital life, end of orbital life) shall be compared to the cleanliness requirements.
- c. If the estimated contamination budget is higher than the specified level, then precautions to minimize contamination shall be investigated and implemented.

### 6.3.2 On-ground contamination budget

- a. This budget shall be elaborated to evaluate the molecular and particulate contamination levels generated by the cleanroom and test site environments on the sensitive surfaces exposed inside.
- b. The budget planning for integration of the instrument and satellite shall be elaborated from the integration and test plan.
- c. For each activity, the sensitive surfaces, the duration of the exposure during each activity, the cleanroom criteria, and the potential means of protection shall be identified.
- d. The consolidation of the budget planning with the results of the witness samples (molecular contamination levels as a function of time) and the particulate formula shall give the estimated ground contamination budget (in terms of  $\text{g/cm}^2$  and parts per million or in terms of transmittance losses) for each sensitive exposed surface.
- e. The linear dependency of MOC and PAC as a function of time is not always valid for longer periods.

### 6.3.3 In-orbit molecular contamination budget

The in-orbit molecular contamination results from the outgassing of organic materials; molecules outgas from the different materials and can condense on sensitive surfaces.

- a. The temperatures of the surfaces and the view factors between a potential outgassed surface and a sensitive surface shall be taken into account in the elaboration of this budget. For sensitive instruments, such as optical instruments, modelling methodologies are used to make an estimate of the superficial density of contaminants ( $\text{g/cm}^2$ ) condensed on the surfaces as a function of time.
- b. Complementary experimental tests on the outgassed materials should be proposed to evaluate the transmittance losses induced by the molecular contaminants in the spectral bands of the instrument. The molecular levels calculated in the modelling as per a. above are then associated to these transmittance losses.



### 6.3.4 Launch contamination budget

A budget for contamination during the launch phase shall be allocated, based on the type of launcher, the co-passengers and other relevant aspects.

This budgeting shall be performed at least for contamination sensitive systems.

## 6.4 Cleanliness verification

### 6.4.1 General

- a. The cleanliness verification shall include all the activities intended to ensure that the actual cleanliness conditions of the space system, the cleanrooms or the vacuum chambers conform to the applicable standards or the applicable CRS (specific to the a certain project).
- b. The cleanliness verification shall make use of recognized methods for the determination or the monitoring of the contamination levels.
- c. The cleanliness verification activities shall be specified in the C&CCP.
- d. The cleanliness verification of cleanrooms shall also include the verification of the environmental parameters such as temperature, relative humidity and the overpressure.
- e. The cleanliness verification shall take place under one or more of the following conditions:
  - at predetermined intervals, independently of the current activity, to confirm the efficiency of the established cleanliness control measures;
  - after the occurrence of an incident or anomaly that can have influenced the cleanliness conditions of the space system or cleanroom;
  - before the beginning of the ground (e.g. test campaign) or launch activities, to confirm that the facilities and cleanrooms are conform to the relevant C&CCP;
  - before and after a test in a vacuum chamber.

### 6.4.2 Cleaning procedures

#### 6.4.2.1 General

- a. Once the materials and components are selected and the processes or manufacturing techniques are known and established, suitable cleaning procedures shall be chosen in order to ensure that the required cleanliness levels, expected in the contamination budget, and the final product cleanliness level are achieved.
- b. Cleaning procedures shall be validated by tests on representative samples, or by experience from previous and similar projects, in which they were validated.

The choice of the cleaning method obviously depends on the type of contaminants to be removed and the physical or chemical nature of the item to be cleaned.

For those items that are too delicate to withstand cleaning, preventive contamination control is of the utmost importance.

The cleaning of some parts is particularly important during the course of manufacture or before processing (e.g. prior to bonding, painting, vacuum coating, welding and soldering).

- c. The procedures concerning cleaning of this type shall be mentioned in the process specification. In this case, the desirability of cleaning is a matter of judgement, based on practical experience or on visual inspection, unless a special surface finish is required.

#### 6.4.2.2 Cleaning aids

- a. Cleaning aids shall not increase the contaminant levels of the items to be cleaned. Therefore:
  - the aids, such as wipe tissues, papers, cloths, brushes and foams shall be non-fluffing, lint free and dust free;
  - damage to surfaces (scratches) shall be minimal;
  - organic contaminant content of cleaning wipe materials shall be less than  $25 \text{ mm}^2/\text{m}^2$  for wiping extremely clean surfaces.
- b. The molecular contaminant content of some wipe materials, measured in accordance with ECSS-Q-70-05, is reported in Annex C. However, when wipe materials are selected for cleaning, measurements should be taken to determine their contaminant content. In principle, all wipe materials should be precleaned to achieve the required level of cleanliness. Precleaning requires extraction by solvents.

#### 6.4.2.3 Cleaning solvents

The following are the basic rules for the selection of the correct solvent to be used for molecular contamination removal.

- a. Compatibility
 

The cleaning solvent shall be compatible with the material or item to be cleaned (see annex D). Moreover, the solvent shall not be corrosive to metals (see MIL-HDBK-406 and NASA SP-5076), e.g. titanium shall not be cleaned using methanol, or with chlorocarbon or chlorofluorocarbon, but with acetone, whereas solid-state detectors, which are liable to be affected by solvent vapours, shall 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
 

For most solvents particular precautions shall be taken during the cleaning process (see MIL-HDBK-406).
- d. Residue of organic solvents
 

For precision cleaning, solvents of high purity shall be used, otherwise contaminant levels are raised rather than lowered. Consequently, when a cleaning liquid is selected, it is only necessary to ensure that it is of a "pro-analyse quality", or that NVR is less than 10 mg/l (measured with gravimetric method). Typical figures for the residue content of cleaning solvents are listed in annex E, which is based on measurements performed in accordance with ECSS-Q-70-05. From this list it can be seen that very clean solvents are commercially available.

#### 6.4.3 Bakeout

The aim of the bakeout process is:

- to improve the outgassing behaviour of a material;
  - to reduce the level of surface contamination collected during processing or testing.
- a. Bakeout should be applied for all materials that can be warmed, and more specifically to:
    - harness,
    - MLI,
    - carbon and glass fibre components, and

- glued, coated or potted materials.
- b. During the bakeout process, the following relevant parameters shall be monitored:
  - vacuum conditions ( $< 10^{-2}$  Pa),
  - temperature ( $\geq 60$  °C),
  - duration ( $\geq 72$  h).

The temperature shall be linked to the outgassing material and the cleaning effect, but the lower the temperature (with given minimum of 60 °C) the longer the duration.

- c. In addition, the outgassing rate should be monitored.

#### 6.4.4 Purging

The aim of the purging is to avoid external contaminants being deposited on sensitive equipment, such as optics, by injecting a non-ionized high-purity dry gas inside a cavity.

- a. The purging shall be performed inside a cavity to maintain a constant exchange of the gas present in the cavity. This exchange depends on the entry flow rate of the gas and the total surface leaks.

The purging can be implemented at instrument or satellite level during functional and performance tests at ambient conditions, during repressurization after TB/TV and TV tests, during all the phases without activities and during storage and transport phases.

- b. The purity of the gas and the cleanliness of all the pipes shall be verified before the first use of the purging system.
- c. Filtering systems (both for MOC and PAC) shall be provided before the gas comes into contact with the hardware.
- d. The filtering capabilities shall be compatible with the relevant cleanliness requirement.

NOTE A good solution, for chamber repressurization, is to add an HEPA filter to the repressurization piping and to collect the air for repressurization in a clean area (preferably class 100).

### 6.5 Packing, containerization, transportation and storage

- a. To maintain the cleanliness levels achieved at any point from initial precision cleaning to delivery to the launch site, provisions shall be taken for packing, containerization, transportation and storage.
- b. For that, cleanliness protection shall be provided prior to leaving the controlled areas, or whenever a storage period is planned.
- c. The container for clean item shall maintain the cleanliness levels specified for the product.
- d. Storage areas shall provide adequate protection to the package and the product for the intended storage period.
- e. When sensitive items are packaged, containers for long-term storage or transportation, shall include adequate provision for internal flushing with dry high-purity nitrogen and over-pressurization (100 hPa minimum), except if units are put in sealed bags as per bullet h.
- f. In the above case, an inlet valve and an outlet valve shall be installed and clearly identified.
- g. The design of the container shall facilitate easy cleaning and inspection of its surfaces, avoiding any kind of dirt traps.

- h. Small clean parts shall be double bagged in airtight envelopes during storage or transportation outside controlled clean areas.
- i. Bags for contamination-sensitive items shall be flushed with dry nitrogen and then sealed.
- j. Only approved materials that were procured as cleaned films shall be used (e.g. polyethylene, polypropylene and polyimide).
- k. Static sensitive items shall use metallized films.
- l. Outer bags shall not enter controlled clean areas.
- m. When desiccants are used, they shall be in bags that are clean and do not produce particulate contamination.
- n. Desiccants and humidity indicators shall be placed in the external envelope.
- o. Adequate procedures shall be provided for packing, containerization, transportation and storage.
- p. PVC (polyvinyl chloride) shall be avoided for optics protection.

## 6.6 Launch

### 6.6.1 General

It is assumed that the space system is shipped to the launch base under clean conditions and that potential contamination during launch preparation is also controlled.

A final cleaning of external surfaces should take place in order to meet the BOL requirements.

The moment of a final cleaning is generally just before the entry of the space system into the fairing, or a final cleaning can even be done just before closing the fairing.

Purging of the contamination-sensitive instruments should take place until final closure of the fairing.

Special constructions can be provided, e.g. a purge connection such that purging can take place until just before launch.

Under normal conditions, purging cannot be re-installed in the case of an aborted launch.

NOTE There is hardly any contamination control, or even measurements, during the launch, and contamination of the hardware is predicted based upon the possible release of contaminants and the view factors of the sensitive items with respect to contamination sources.

### 6.6.2 Specific provisions

#### 6.6.2.1 Launcher level

- a. Launcher parts, such as fairings and mechanical systems for double or multiple launches, shall be clean in order not to contaminate the clean items of the space system.
- b. The materials of the hardware in the vicinity of the space system shall meet the same outgassing and surface-cleanliness requirements as the space system itself.
- c. The building environment in which the spacecraft is put inside the fairing shall be compatible with the spacecraft characteristics.

### 6.6.2.2 System (payload) level

- a. Specific design provisions can be protection mechanisms to be used to limit the launch contaminants, especially the “unknown” figure of particle transfer during launch.
- b. A second design aspect is the location of the contamination-sensitive items with respect to the position of thrusters and of pyrotechnics (or other contamination sources).
- c. Also the reflection by atmospheric molecules (i.e. atmospheric scattering) or by outgassing molecules (i.e. self-scattering) can take place and some form of modelling is of interest.

## 6.7 Mission (external)

### 6.7.1 Molecular outgassing from materials

The materials used for space systems shall be selected based upon low outgassing criteria. The outgassing criteria are based upon the Micro-VCM test (ECSS-Q-70-02), and shall take into account the location of the outgassing source and its mass.

- a. The general requirement for materials outgassing is:  $RML < 1\%$  and  $CVCM < 0,10\%$  as per ECSS-Q-70.
- b. An overall outgassing budget should be allocated per equipment or box. This should be calculated by adding the outgassing contribution of each constituent of the equipment.
- c. For applications around sensitive items (e.g. optics and detectors) more stringent values should be used, along with performance of bakes on the relevant hardware. The definition of the outgassing requirements shall take into account the quantity of material concerned, and the specific environmental conditions (e.g. available volumes and temperatures).

NOTE Table 4 provides an example of the definition of outgassing requirements based on good design practice.

- d. Some metals such as cadmium and zinc have high vapour pressures and deposit metallic films on adjacent surfaces. The application of these volatile metals shall not be used especially when the temperatures are above room temperatures.
- e. Each individual application of any fluid shall be reviewed in the leakage analysis to ensure optimal selection of detection, location and isolation techniques.
- f. The location of the dump lines with respect to the contamination-sensitive items is critical and during dumping the very critical items should be shielded.

**Table 4: Material outgassing criteria values**

Mass of material concerned (grams)	CVCM(%)	RML(%)
> 1 000	< 0,01	< 1
100 – 1 000	< 0,01	< 1
10 – 100	< 0,01	< 1
1 – 10	< 0,03	< 1
< 1	< 0,1	< 1

### 6.7.2 Design aspects

- a. The sensitivity to contamination shall be one of the drivers in the initial design of the space system and its instruments.
- b. The design shall be cleanliness-oriented and such that the lowest possible contamination levels can be achieved on-ground as well during the launch and mission.

In order to achieve the lowest contamination levels, attention shall be paid to the following:

1. Locate contamination sensitive items far away from the contaminant sources.
2. Position the sensitive items so that the view factors with respect to contaminant sources (e.g. solar arrays, antennas and thrusters) are as low as possible.
3. Locate the vent holes of the space system and the instruments away from the sensitive items (= backdoor venting).
4. Manufacture the hardware in such a way that venting (of, for example, thermal blankets) is directed towards the backdoor.
5. Design baffles or shields for the sensitive items or even for the contaminant sources.
6. Design temporary covers (red-tag covers) or hoods to reduce contamination during ground life. (Optically transparent covers can be used for calibration, alignment or functional testing of optical instruments without removing the covers.)
7. Design deployable covers for very sensitive instruments, that are operated only in space.
8. Design cleaning mechanisms for the removing of contaminants by, for example, heating the sensitive hardware, manoeuvre the space system in such a way that in low orbit the AO can perform a cleaning.
9. Selection of materials, processes, mechanisms and components with low particulate and molecular contamination potential. In this respect low outgassing materials shall be chosen, and zinc and cadmium (or cadmium plating) should not be used because of the relatively high vapour pressures of these materials.
10. If the contamination potential of selected materials is still too high, bake-out of the hardware shall be considered before assembly or even during tests.
11. The design, manufacturing order and assembly shall be such that bakeout can still be performed (sometimes baking is carried out before further assembly is done because of the temperature limitations of certain hardware or because the products released during the bakeout can have effects on other items).
12. Where sensitive items are expected, the design of the instruments or space system shall be such that purging is feasible in the periods of assembly, integration, tests and launch preparations or even up to launch.
13. Based upon these effects, the venting holes and other contaminant sources should be located in the wake side of the space system.
14. On the other hand, the wake side of a space system can be used for special experiments for which extremely low pressures in relatively low Earth orbit are required.

### 6.7.3 Mission (inhabited space cabins)

A number of fluids other than propellants are present, that can emerge to the exterior by leakage or intentional use of valves.

- a. All fluids shall be considered, whether originating from thermal, environmental or life support systems or subsystems or released due to crew activities (nutrients, wastes), during maintenance and repair and from experiments or payloads.
- b. Each individual application of each fluid shall be reviewed in a specific analysis to ensure an optimum level of detection, location and isolation techniques.
- c. Design measures shall comprise the usage of easily cleanable surfaces (shape, materials), safe disposal of wastes in concealed bags or compartments, and removal of airborne microbial contamination by filters.

These aspects shall be considered in the design and operational requirements of system and equipment hardware.

## 6.8 Mission (internal)

### 6.8.1 System level

The flight configuration tasks related to contamination, leakage and venting of internal fluids, particulates and microbiological matter, comprise the following activities:

- analyse and specify internal contamination control requirements;
  - analyse and specify leakage and venting control requirements;
  - define and develop methods and analysis tools;
  - define and perform analyses and tests;
  - coordinate and supervise the lower level tasks.
- a. The ICC and LVC flight configuration level requirements shall be analysed and completed as a basis for analyses and task planning.
  - b. If the evolving programme contamination and LVC requirements are changed due to unresolvable conflicts between design and contamination and LVC constraints, then the impact of the requirement change shall be assessed and its acceptability verified at top (system) level.
  - c. For ICC/LVC, the effort shall be limited as much as possible.
  - d. ICC shall be achieved by material selection and analytical verification and optimization of design and operations.
  - e. If the ICC requirements cannot be met, decontamination equipment shall be developed.
  - f. In ICC/LVC, all interfaces to other subsystems and design elements where contamination and leakage are expected shall be investigated based on information obtained from the respective subsystem involved.
  - g. The ICC and LVC shall be achieved by proper material selection (in close cooperation with PMP), with design optimization and possibly with operations and maintenance guidelines and constraints based on analytical predictions and on-ground tests where necessary.
  - h. The design information and analysis and test results shall be compiled to ensure transparency and allow analyses with respect to contamination and the leakage/venting interface, which, in iterative procedure, shall be considered in the flight configuration level.



### **6.8.2 Lower levels**

- a. Based on overall system knowledge with respect to requirements, design and operations, support shall be given to the subsystem levels to identify and evaluate unacceptable contamination loads due to in-orbit operations and contingency cases and consequent design and operational measures. This should include the definition of maintenance activities of internal areas and equipment where restoration or replacement is required prior to EOL of the flight configuration.
- b. Inputs shall also be given to operations to define flight operational ICC tasks.
- c. Special attention shall be paid to microbial contamination control.
- d. If the baseline design is incompatible with ICC requirements, the design changes shall be identified and corrective actions shall be taken in close cooperation with all levels involved.
- e. The subsystem level tasks related to internal fluids, particular and microbiological contamination and leakage or venting comprise activities to analyse and specify requirements, define and perform analyses, integrate and test ICC and LVC hardware, coordinate and supervise the lower level tasks and support the higher level.
- f. All subsystem parts, materials and processes shall also be in accordance with the ICC and LVC concept of this C&CCP.
- g. The design data and other subsystem information relevant for ICC and LVC shall be compiled and given to the higher levels to conduct IC and LV analyses (e.g. performance of decontamination device and filters, mass and volume of outgassing materials and equipment and related outgassing rates and types and IC risk information).
- h. The component level tasks related to internal fluids, particulate and microbiological contamination and leakage or venting comprise activities to analyse requirements, perform analyses, develop and test ICC and LVC hardware and support the higher level.
- i. All components, materials and processes shall be in accordance with the ICC and LVC concept of the C&CCP (see above).
- j. The contamination control and monitoring hardware (e.g. filters and sniffing lines) shall be designed, developed, tested and verified according to the requirements of the associated subsystem.

### **6.8.3 Monitoring**

- a. In the operational phase, contamination levels shall be monitored. Appropriate sensor elements shall be applied to guarantee the predicted design life-times at system, subsystem, component or equipment level.
- b. Monitoring for particulate and molecular and microbiological contamination shall be considered only for internal environments.



## Annex A (normative)

### Document requirements list

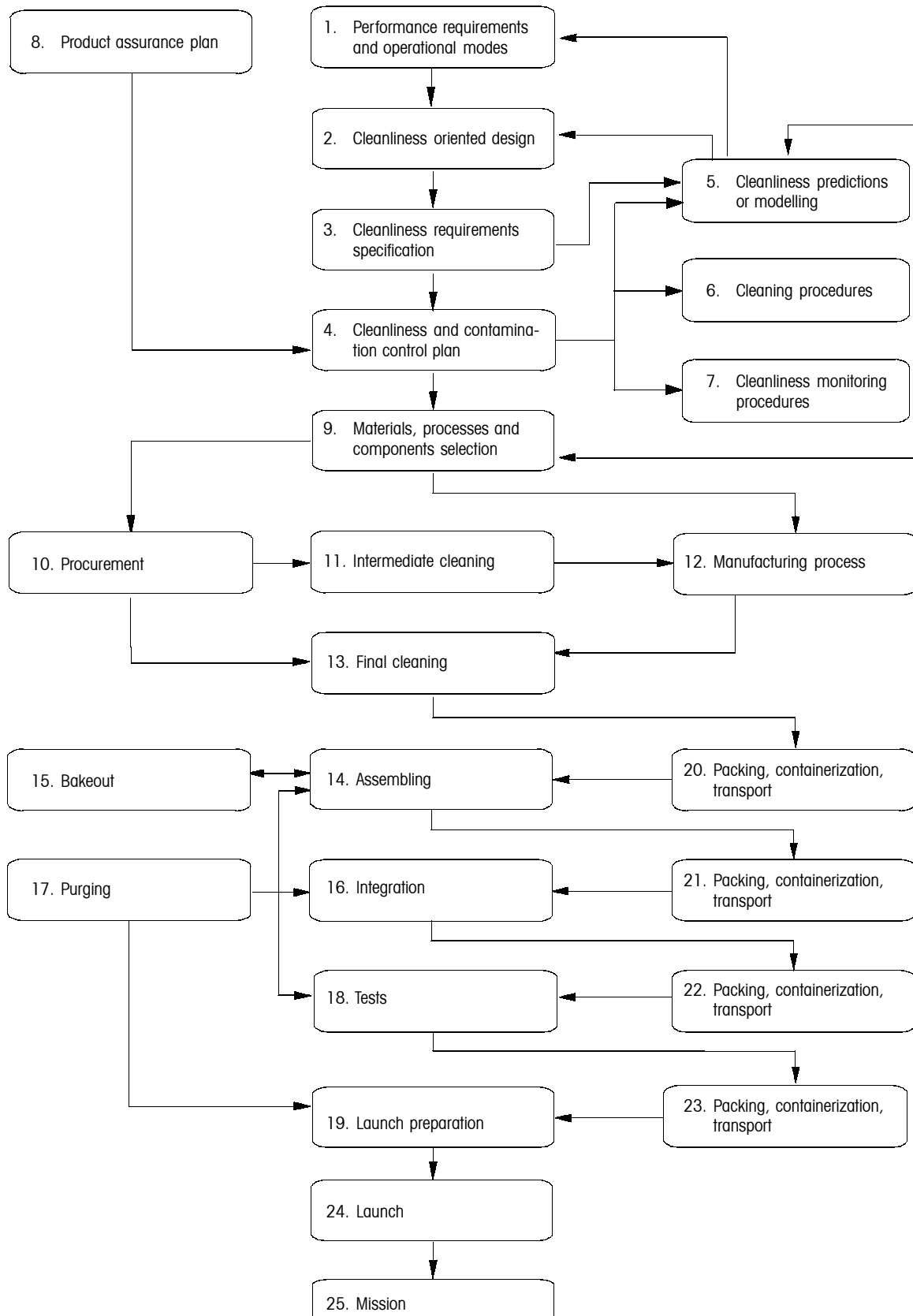
DRD number	DRD title (Grouped by discipline)	Applicable to (phase)							Deliver at (frequency or milestone)	Remarks
		0	A	B	C	D	E	F		
Q-70-01A Annex G	Cleanliness requirement specification									
Q-70-01A Annex H	Cleanliness and contamination control plan									

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## **Annex B (informative)**

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### **Space system cleanliness control flow chart**



**Figure B-1: Space systems cleanliness control flow chart**

## Annex C (informative)

### Molecular contaminant content of some wipe materials

The data in this table are a result of single tests and are simply illustrative.

**Table C-1:**

<b>Material</b>	<b>Molecular contaminant content (mm<sup>2</sup>/m<sup>2</sup>)</b>
Cotton wool	140
Kim <sup>™</sup> wipes	46
Kleenex <sup>™</sup>	88
Garby <sup>™</sup>	23
Greem 105 <sup>™</sup> lens tissue	34
Velin non-fluff tissue	47
Lens tissue (SS-2478 <sup>™</sup> )	14
Filter paper SS-595 <sup>™</sup>	29
Filter paper SS-1575 <sup>™</sup>	21
Filter paper SS-1505 <sup>™</sup>	22

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## **Annex D (informative)**

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### **Compatibility of various solvents with listed materials**

**Table D-1:**

Materials	Solvent					
	Aliphatic	Aromatic	Ethers, ketones	Alcohols	Strong acids	Strong bases
Polyvinyl chloride (plasticized)	++++	---	---	---	++++	++++
Polyvinyl chloride (hard)	++++	+	+	-	++++	++++
Polyethylene	---	---	---	-	++++	++++
Polystyrene	---	---	---	+++	----	++++
Polyester	++++	++++	+++	?	----	-
Epoxy	++++	++++	+++	--	+	+++
Polyvinylidene fluoride	++++	++++	++	+++	++++	++++
Chlorinated polyester	++++	++++	+++	+++	+++	+++
Fluran	++++	++++	++++	?	++++	++
Polymethyl methacrylate	----	----	----	---	----	+
Polycarbonates	++++	----	--	+	+	--
Polyamides	++++	++++	++	++++	++	++
Polyphenylene oxides	++++	----	--	++++	++	++
Polysulphides	++++	--	--	++	++++	++++
Vinyl esters	++++	----	----	?	+	++++
Polyurethane (paints)		----	----	++		
Phenolics	++++	++++	++++	++++	++++	++++
Polytetrafluoroethylene (PTFE)	++++	++++	++++	++++	++++	++++
Perchlorotrifluoroethylene (PCTFE)	++++	++++	++++	++	++++	---
Diallylphthalate silicone elastomer	---	---	-	+++	+++	?
Ethylene propylene	---	---	++	+++	+++	?
Butadiene styrene	--	---	-	+++	--	-
Chlorosulphonated polyethylene	+	---	-	+++	++	?
Polychloroprene polyethylene	++	---	-	+++	+	?
Fluorocarbon polyethylene	++++	+		+++	+++	?
Acrylate ester polyethylene	+++	---		---	---	?
Butadiene acrylonitrile polyethylene	+++	---		+++	?	?
++++	Very good	-	Average	? Not known		
+++	Good	--	Average			
++	Average	---	Bad			
+	Average	----	Very bad			



## Annex E (informative)

### Non-volatile residue of commercially available solvents, measured by infrared techniques

**Table E-1:**

<b>Product</b>	<b>Non-volatile residue (NVR) (mm<sup>2</sup>/m<sup>2</sup>)</b>
Acetone	0,4
Ethyl alcohol	1,6
Isopropyl alcohol	0,8
Chloroform, spectral grade	0,3
Methanol	0,7
Tetrachlorocarbon	0,2
“from aerosol bottle I”	35
“from aerosol bottle II”	50

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## Annex F (informative)

### Cleanroom requirements

#### F.1 Particle levels and cleanroom classification

The number of particles per  $\text{m}^3$  as a function of the diameter from  $0,1 \mu\text{m}$  to  $5 \mu\text{m}$  as classes is reported in Table F-1 (derived from FED-STD-209E). This classification depends upon the ideal number-size distribution and is given graphically in Figure F-1.

NOTE 1 The document FED-STD-209E is fully applicable to the airborne particulate cleanliness classes in cleanrooms and clean zones. The information reported below is included for information and is in conformance with this document.

NOTE 2 Table F-1 gives the particle numbers per  $\text{m}^3$  and conversion to the number per cubic foot can be achieved by multiplying the above numbers by: 0,0283. (The old classes 100, 1 000, 10 000 and 100 000 are now, respectively, Classes M3.5, M4.5, M5.5 and M6.5).  
Concentration limits are calculated by means of the following formula:

NOTE 3  **$\text{particles}/\text{m}^3 = 10^M(0,5/d)^{2,2}$**

where

M is the numerical metric class designation (e.g. 3,5);  
d is the particle size (in  $\mu\text{m}$ ).

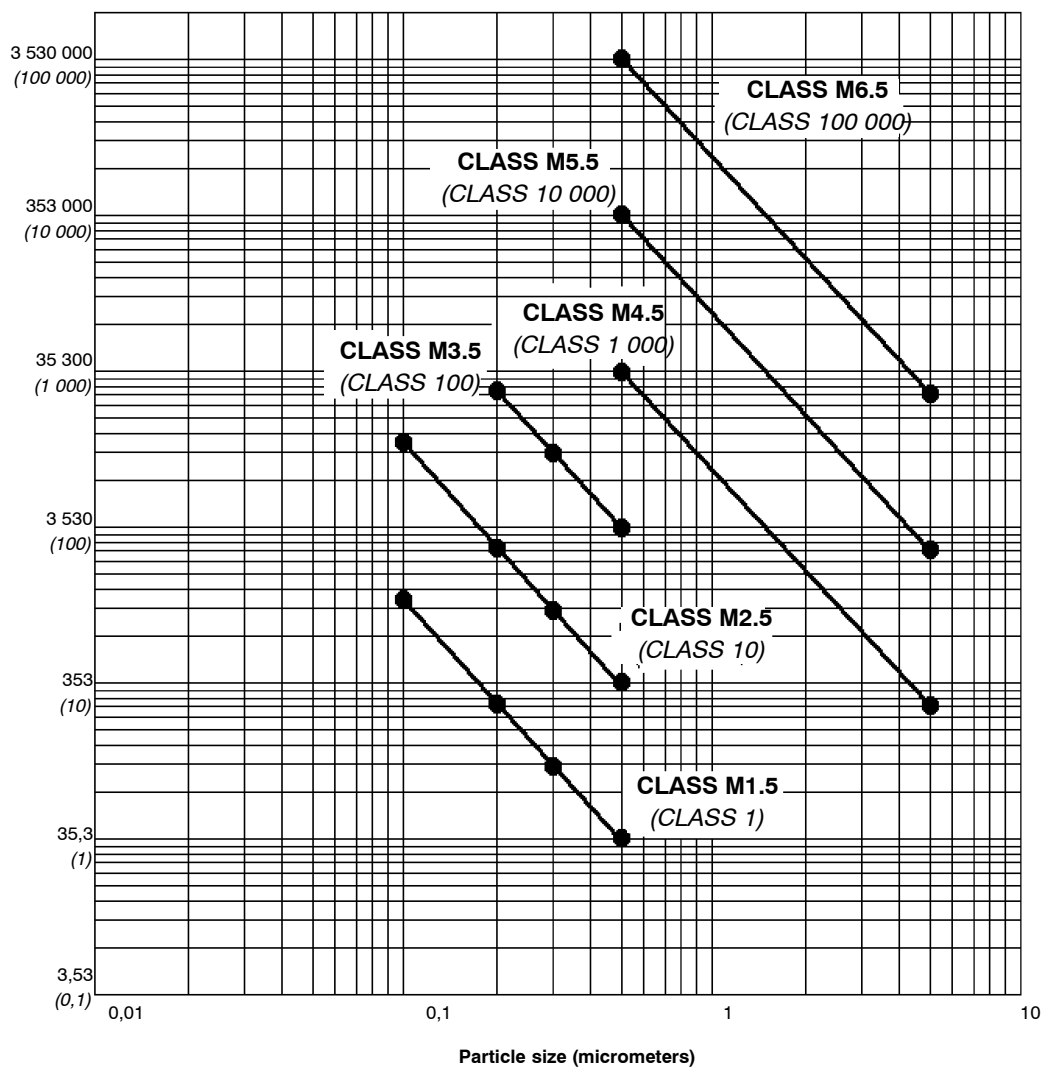
or, alternatively, by means of the following formula:

**$\text{particles}/\text{ft}^3 = N_c(0,5/d)^{2,2}$**

where

$N_c$  is the numerical designation of the class, in the old system (e.g. 100, 10 000).

Particles per m<sup>3</sup>  
(Particles per ft<sup>3</sup>)



**Figure F-1: Ideal particle-size distribution**

**Table F-1: Airborne particulate cleanliness classes (taken from FED-STD-209E)**

Class Name		Class Limits									
		0,1 µm		0,2 µm		0,3 µm		0,5 µm		5 µm	
		Volume Units		Volume Units		Volume Units		Volume Units		Volume Units	
Metric Class	Old Class	m <sup>3</sup>	ft <sup>3</sup>	m <sup>3</sup>	ft <sup>3</sup>	m <sup>3</sup>	ft <sup>3</sup>	m <sup>3</sup>	ft <sup>3</sup>	m <sup>3</sup>	ft <sup>3</sup>
M1		350	9,91	75,7	2,14	30,9	0,875	10	0,283	-	-
M1.5	1	1 240	35	265	7,5	106	3	35,3	1	-	-
M2		3 500	99,10	757	21,4	309	8,75	100	2,83	-	-
M2.5	10	12 400	350	2 650	75	1 060	30	353	10	-	-
M3		35 000	991	7 570	214	3 090	87,5	1 000	28,3	-	-
M3.5	100	-	-	26 500	750	10 600	300	3 530	100	-	-
M4		-	-	75 700	2 140	30 900	875	10 000	283	-	-
M4.5	1 000	-	-	-	-	-	-	35 300	1 000	247	7
M5		-	-	-	-	-	-	100 000	2 830	618	17,5
M5.5	10 000	-	-	-	-	-	-	353 000	10 000	2 470	70
M6		-	-	-	-	-	-	1 000 000	28 300	6 180	175
M6.5	100 000	-	-	-	-	-	-	3 530 000	100 000	24 700	700
M7		-	-	-	-	-	-	10 000 000	283 000	61 800	1 750

## F.2 Interpretation for particles in environments

The disadvantages are that in practice the slope of the actual curves can be different from the slopes in Figure F-1.

- The classes can be interpolated to classify a cleanroom or an environment, other than conventional, when special conditions dictate their use (e.g. M2.2, M4.3 and M6.4, corresponding to the old classes 5 600 and 70 000).
- The labelling for an alternative class shall be based on the concentration limit specified for particles 0,5 µm and larger, in the same manner as the classes listed in Table F-1 above.
- Concentration limits for the other particle sizes shall be in the same proportions as those in the next cleaner class in Table F-1; these limits can be calculated by using the appropriate equation reported under Figure F-1.
- Similarly, for classes cleaner than class M1, or class 1, the concentration limits at particle sizes other than 0,5 µm shall be in the same proportion as those of class M1, or class 1.

## F.3 Monitoring of cleanroom air

The cleanroom air is generally monitored with commercially available dust counters.

- Particle counts shall be taken continuously or at predetermined intervals during working periods and at locations that yield the number of particles in the air as close as possible to the work location.
- Monitoring techniques and routines shall be established to meet the requirements of a specific category of cleanroom or clean work station.
- The monitoring methods and equipment can be used only if demonstrated to be of adequate accuracy and repeatability; frequency, sampling air volume and position shall be established on the basis of the airborne particulate

- cleanliness and the degree to which contamination is controlled for protection of processes and products.
- d. For monitoring purposes only, determining the extent to which particles are deposited on surfaces can be achieved through the exposure of test surfaces or samples to the environment and counting the settled particles by appropriate methods.
  - e. Air monitoring of class M6.5 or better shall be achieved by means of light scattering equipment.
  - f. Furthermore, tests shall be performed to determine if leaks exceed the specified limits:
    - 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, and
    - between supporting frames and walls or ceilings.
  - g. The cleanrooms shall be provided with a monitoring function for the contamination levels and the environmental parameters (i.e. temperature, relative humidity and differential pressure) as well as an alarm function which is initiated when certain levels (set well below the “out of specification limits”) are exceeded.
  - h. Adequate and planned corrective actions shall be initiated to re-establish the nominal conditions in the shortest possible time and to prevent recurrence.

## F.4 Indicative correlation between particles in air and particle fallout

An exact mathematical correlation between particles in air and PFO cannot be given (mainly due to operative conditions).

The data contained in Table F-2 are based on several measurements performed in different cleanrooms and are thus indicative of the expectable PFO.

**Table F-2: Correlation airborne and PFO for cleanrooms**

Metric class	PFO (mm <sup>2</sup> /m <sup>2</sup> /24 h)
3,5	2,0
4,5	10
5,5	52
6,5	275

$$\text{PFO} = 0,069 \cdot 10^{(0,72M-1,08)}$$

where M is the metric numerical class (e.g. 3,5)

or:

$$\text{PFO} = 0,069 N_c^{0,72}$$

where N<sub>c</sub> is the old numerical classification (e.g. 100 or 100 000)

## F.5 Molecular levels

- a. For ground facilities the normal requirements for cleanrooms are that a critical surface inside that area is not contaminated by more than  $0,5 \times 10^{-7} \text{ g/cm}^2$  during a continuous period of one week.

- b. In case of contamination sensitive equipment, a lower level can be required, based on the contamination budget (including exposure time).

NOTE 1 In a normal cleanroom (without charcoal filters) levels can be achieved that are 10 to 100 times better.

NOTE 2 For those hardware items where the cumulation from the air becomes a major issue (e.g. coated mirrors), the use of charcoal filters as molecular contamination trap should be considered.

NOTE 3 Charcoal is an efficient, but dangerous filter. It is important, on installation, to know exactly (by analysis) the charge in contaminants. Moreover, in some specific cases, it can release its charge in contaminants trapped. Hence, it is essential to know the initial charge, on installation, and to analyse it regularly in order to be able to monitor the evolution and when a failure occurs.

## F.6 Measurement of molecules in environments

For actual measurements it is advisable to have an overlap, so that accidental contamination can be measured twice.

- a. Sensors shall be exposed during two weeks and one sensor shall be analysed every week.
- b. This measurement shall be performed at two different locations within the area.
- c. These locations shall be selected in order to measure molecules in significant points of the environment.

## F.7 Design

### F.7.1 Cleanroom shell, entrances and anterooms

- a. Cleanroom shell, floors, walls and ceiling shall be low-shedding and the finish readily cleanable.
- b. The floor covering shall consist preferably of one piece or, if this is not feasible, it shall have the minimum number of joints necessary.
- c. It shall have low shedding characteristics and be sufficiently durable to withstand wear by personnel and operations within the room.
- d. The room shall be designed such that only one door or entrance can be opened at one time, except in case of emergency.
- e. Such entrances shall provide an air lock to allow a maintained pressurisation of the area.
- f. Anterooms shall be provided as required for the changing of clothes, and the storage of clothing, personal belongings and cleaning equipment.

### F.7.2 Air supply

- a. Air supply and filtration equipment shall have adequate capacity to filter all new and recirculated air entering the room.
- b. Air conditioning equipment for prefiltering (particular and molecular), cooling, heating, humidification and dehumidification of the cleanroom air supply shall be supplied as necessary.
- c. In laminar flow cleanrooms, the air flow velocity through the cross section of the room shall be maintained at 27 m/min with a uniformity within  $\pm 20\%$  throughout the undisturbed room. Airflow patterns shall be uniform with minimum turbulence.

### F.7.3 Filters

- a. In laminar flow cleanrooms, 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. Prefilters shall be used to prolong the life of the HEPA type final filters.

In cases where a uniform and controlled molecular environment is required the filtering system should be equipped with additional charcoal filters positioned after the HEPA filters.

Charcoal filters can be used to filter the make-up air or even to filter all the air that is circulating in the cleanroom (installation shall be done before filters).

After filters are changed, airborne contamination (gas and vapour) can be initiated by the new set of filters.

- b. Monitoring shall be effected and any work with highly sensitive equipment after the installation of new filter sets shall be avoided until contamination has dropped below the specified acceptance level.

Similar problems recur also when the air flow is stopped and then it is reactivated; due to the transitory pressure gradients, this operation can cause the release of contamination previously trapped by HEPA filters, together with a reduction in the operating life of the filters themselves.

- c. As general rule, the air flow inside cleanrooms shall be maintained also during “at-rest” periods, except for the normal maintenance operations.
- d. The same attention shall also be paid to the independent HEPA filtering systems, such as those equipped for the laminar flow tents and benches, except if they can work with a reduced air flow rate during stand-by periods.

### F.7.4 Cleanroom containers

- a. Transport and storage containers shall be made of low particle shedding materials that do not evolve contaminants.
- b. Containers carrying sensitive items (optical units and payloads) shall be pressurized with gaseous nitrogen.
- c. They shall also have as rigorous a cleaning schedule as the parts themselves.
- d. Care shall be taken that containers used for transportation of clean parts do not transfer contamination from surface to surface within the cleanroom itself.

## F.8 Environmental control

### F.8.1 Temperature

- a. Cleanroom temperature shall be maintained at nominally 22 °C. Temperature variations of  $\pm 3$  °C at the control point are acceptable for most operations, but special conditions can be imposed in case of critical operations.
- b. The temperature distribution inside a cleanroom shall be controlled to ensure that a nominal temperature is achieved throughout the room. Automatic devices may be used for temperature monitoring.
- c. If items being worked on are extremely sensitive to temperature changes, automatic devices with a warning system that comes into operation when a temperature change occurs can be used.



In practice, it is difficult to maintain a constant temperature to very close limits in environmentally controlled areas; hence, specified temperatures should include the widest tolerances permitted by the product requirements.

### F.8.2 Pressure

- a. A positive pressure differential shall be maintained between the cleanroom and the outside. Pressure shall decrease successively between the cleanroom, entrance lock, anteroom and the surroundings.
- b. The positive minimum pressure delta to be maintained shall be:
  - between cleanroom and surrounding area; 1,2 mm H<sub>2</sub>O (12 Pa);
  - between cleanroom and entrance lock; 0,5 mm H<sub>2</sub>O (5 Pa).
- c. Pressure in all areas shall be monitored, in order to take timely corrective actions in case of a pressure drop.

### F.8.3 Humidity

The relative humidity shall be maintained at  $(55 \pm 10)\%$  for general applications and shall be monitored continuously.

Humidity becomes detrimental due to electrostatic charging or surface corrosion (see Table F-3).

**Table F-3: Guide to humidity level selection**

% RH 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	Rapid corrosion Reduced electrical resistivity

### F.8.4 Other environmental factors

Other environmental factors, such as light level, electromagnetic radiation, ionizing radiation and radioactive particles shall be taken into due consideration.

## F.9 Maintenance and cleaning

- a. All maintenance and cleaning activities shall be listed in a dedicated logbook.
- b. A maintenance and cleaning procedure or document shall be available, along with a planning.
- c. Maintenance shall comprise regular inspections of the cleanroom, its control facilities and its operating equipment, including calibration of all inspection and monitoring devices (as per ECSS-Q-20).
- d. Regular inspections shall be performed of the cleanroom to determine the quality of the clean facility and to identify any contamination production or events that are detrimental to the cleanroom cleanliness (e.g. repairs, system modifications, replacements, filter resistance measurements, leak checks or air speed measurements).
- e. Data shall be recorded in the control documentation.

- f. All other cleanliness inspections shall be performed as required.
- g. When the level of contamination becomes higher than allowed (as defined in the cleanliness requirements specification), corrective actions shall be taken. The decision as to whether or not to clean depends on the integration flow of the unit within the cleanroom. Procedures shall cover the cleaning of the following areas by gross cleaning (dust wiping, or vacuum cleaning):
  - cleaning of personnel air lock;
  - cleaning of equipment air lock;
  - cleaning of cleanroom walls, floors, furniture, crane lifting devices and GSE.
- h. The cleanliness after the cleaning actions shall be verified by inspection (e.g. with UV or halogen lamp).
- i. Any personnel involved in cleaning actions shall be instructed by QA about the criticality of a cleaning action within a cleanroom.
- j. For any further (precision) cleaning activity within the cleanroom, due consideration shall be given to the detrimental effect of the cleaning on the hardware within the cleanroom.
- k. Cleaning tools, solvents and gases that are used for cleaning purposes shall not have a detrimental effect.
- l. The frequency of inspections and cleaning processes for a cleanroom shall be optimized since the inspections and cleaning can themselves be the source of contamination.

NOTE Cleanroom air of better than class M6.5 is transported in a close loop. Since only a limited percentage of fresh air is fed to the loop, excessive use of solvents outgassing into the air, even if not flammable or toxic, can cause health problems.

## F.10 Access control

- a. An access control system shall be available independently for cleanrooms, storage area and equipment airlock.
- b. The access to the areas shall be controlled by a permanently operating access control or door lock system.
- c. Only authorized personnel shall have access to the cleanroom (security lock at the entrance). Visitors and personnel without a direct work order shall not be allowed to enter the cleanroom.
- d. Visitors, who work in the clean area, shall wear the complete clothing, shall be identifiable as such and shall be instructed about the behaviour in a cleanroom.

## F.11 General requirements for a cleanroom

### F.11.1 Equipment and hardware requirements

- a. Racks or cabinets for street clothing shall be separated from those used for cleanroom clothing.
- b. Lint-free clothing shall be available and worn by all personnel within cleanroom area.
- c. Head covers or other garments shall be used as required to trap loose particles of hair or skin flakes.
- d. 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.

- e. Exhaust systems for grinding, welding or soldering, machining or related operations shall be installed.
- f. Equipment items with cooling fans are potential contamination sources and thus appropriate actions shall be undertaken to avoid contamination of critical hardware.

### **F.11.2 Procedural and behaviour aspect requirements**

- a. Written operational guides shall be established to avoid contamination and degradation of the cleanliness level of an area. These guides shall include, but not necessarily be limited to, the following requirements:
  - 1. All equipment shall be cleaned by dusting, vacuum suction, washing, or other means suited to the equipment involved before being brought into the area.
  - 2. Smoking, eating and drinking shall not be permitted in the cleanroom, including the entering areas and air locks.
  - 3. Local cleanroom instructions shall specify the amount of protective clothing to be worn and shall assist in minimum contaminant transfer.
  - 4. If air showers are used, only suitably clothed personnel shall be allowed to enter.
  - 5. Paper, pencils or erasers shall be kept outside the clean facilities. Only special non-shedding papers and ball-points shall be used.
  - 6. Cosmetics and medicaments that can produce contamination shall not be used by any personnel. In particular, eye make-up, rouge, face powder and hair spray shall be avoided.
  - 7. Fingernail polish shall not be permitted in the area.
  - 8. Hand lotions, creams or soap containing lanolin to tighten skin particles shall be used as appropriate.
  - 9. Contact of hands with solvents shall be avoided, as many solvents remove natural oils and cause excessive skin peeling or flaking.
  - 10. Personnel movements to and from the cleanroom shall be kept to a minimum.

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## Annex G (normative)

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# Cleanliness requirement specification — Document requirements definition (DRD)

## G.1 Introduction

As required by ECSS-Q-70-01, this document requirements definition (DRD) establishes cleanliness and contamination levels to be achieved at different manufacturing, AIT and mission stages.

## G.2 Scope and applicability

### G.2.1 Scope

This DRD establishes the data content requirements for the cleanliness requirement specification. This DRD does not define format, presentation or delivery requirements for the cleanliness requirement specification (CRS), which can vary depending on product level (i.e. equipment, subsystem and system), and specific contractual requirements.

### G.2.2 Applicability

This DRD is applicable to all projects using the ECSS standards.

## G.3 Terms, definitions and abbreviated terms

### G.3.1 Terms and definitions

For the purposes of this DRD, the definitions given in ECSS-P-001 and ECSS-Q-70-01 apply.

### G.3.2 Abbreviated terms

The following abbreviated terms are defined and used within this DRD.

<b>AIT</b>	assembly, integration and test
<b>AIV</b>	assembly, integration and verification
<b>AO</b>	atomic oxygen
<b>BOL</b>	beginning-of-life
<b>C&amp;CCP</b>	cleanliness and contamination control plan
<b>CRS</b>	cleanliness requirement specification

<b>EOL</b>	end-of-life
<b>EVA</b>	extra vehicular activity
<b>MOC</b>	molecular contamination
<b>PAC</b>	particulate contamination

## G.4 Description and purpose

Based on system or subsystem contamination budget, a CRS shall be established and agreed by all parties involved.

The CRS shall define and identify the spacecraft items and the environmental areas that are sensitive to contamination; a description of the effects of contaminants on performance shall also be given.

The CRS shall give the acceptable contamination levels at BOL and at EOL, and identify the required contamination level at delivery.

## G.5 Application and interrelationship

As it is of fundamental importance for the space system's performance, the CRS shall be defined as early as possible in the programme, in order to properly address the design for cleanliness.

This document should be prepared in collaboration with experimenters and engineers from the different disciplines.

In case the CRS cannot be produced at an early stage of the design, a cleanliness control policy document should be used.

This cleanliness control policy document shall give the correlation data between acceptable performance losses and the contamination levels from library search or from tests that shall be performed. The cleanliness control policy document becomes the CRS during the development of the design.

## G.6 CRS preliminary elements

### G.6.1 Title

This document shall be titled "Cleanliness requirement specification for [insert item name]"

### G.6.2 Title page

The title page shall identify the project document identification number and the title of the document.

### G.6.3 Approval page

The approval page shall identify the names, titles and affiliations of all parties who are to approve the CRS. Space shall be provided for the approval parties to affix and date their signatures.

The title and approval pages may be combined in a single page.

### G.6.4 Amendment control table

The amendment control table shall contain the

- change number,
- type of change,
- date of issue, and
- parts of CRS affected.

### **G.6.5 Contents list**

The contents list shall identify the title of every part, clause and major subclause, figure, table and annex contained in the document.

### **G.6.6 Introduction**

An introduction shall be included to provide specific information or commentary about the technical content of the CRS.

## **G.7 CRS contents**

### **G.7.1 Scope and applicability**

This clause shall be numbered 1 and shall describe the scope and applicability of the CRS. It shall include the identification of the hardware subject of the specification and the relevant programme phases involved

### **G.7.2 References**

This clause shall be numbered 2 and shall contain the following subclauses.

#### **G.7.2.1 Normative references**

This subclause shall be numbered 2.1 and shall contain the following statement:

“The following normative documents contain provisions which, through reference in this text, constitute provisions of this cleanliness requirement specification:

[insert document identifier] [insert document title]”

#### **G.7.2.2 Informative references**

This subclause shall be numbered 2.2 and shall contain the following statement:

“The following documents, although not a part of this cleanliness requirement specification, amplify or clarify its contents:

[insert document identifier] [insert document title]”

### **G.7.3 Terms, definitions and abbreviated terms**

This clause shall be numbered 3 and shall contain the following subclauses.

#### **G.7.3.1 Terms and definitions**

This subclause shall be numbered 3.1, and shall list any applicable project dictionary or glossary, and all unusual terms or terms with a meaning specific to this CRS, with the definition of each term.

#### **G.7.3.2 Abbreviated terms**

This subclause shall be numbered 3.2 and shall list all abbreviated terms used in the CRS, with the fully spelled-out meaning or phrase for each abbreviation.

### **G.7.4 Description of [insert item name]**

This clause shall be numbered with 4 and shall give a general overview of the item to which the CRS refers.

In particular, this clause shall identify sensitive items and contamination sources, in consideration of:

- possible impacts of contaminants on their physical or functional characteristics;
- possible effects of contamination on the performance
- their impact as potential sources of contamination.

This clause shall also state the pressures (or other molecular fluxes) that can be reached in connection with voltage breakdown, arcing, corona discharges, multiplication, opening time of shutters and ejection time of covers.

### **G.7.5 Environmental factors**

This clause shall be numbered 5 and shall be composed of the following subclauses.

#### **G.7.5.1 Ground environmental factors**

This subclause shall be numbered 5.1 and shall basically identify major on-ground activities and their impact on contamination. Usually, the preparation of a flowchart helps in the description. In this case, it shall be included in an appendix to the CRS.

#### **G.7.5.2 Flight environmental factors (natural and induced)**

This subclause shall be numbered 5.2 and shall describe the environmental factors that affect the contamination phenomena, such as solar radiation, electron, proton and AO fluxes, together with the planned mission profile/duration.

#### **G.7.5.3 Temperatures of items sensitive to contamination**

This subclause shall be numbered 5.3 and shall provide figures for sensitive-item temperatures. The expected temperatures of these items can be important for condensation and the residence times of the contaminants.

### **G.7.6 Contaminants**

This clause shall be numbered 6 and shall include the following subclauses.

#### **G.7.6.1 Contamination sources**

This subclause shall be numbered 6.1 and shall identify possible contamination sources, such as materials outgassing, lubricants escaping from bearings, wear particles from moving parts, terrestrial contaminants such as dust, plume contaminants from thrusters and engines, leaks from fuel systems and from hermetically sealed components, dumps and EVA, co-passengers, fairing and equipment bay items of the launcher.

#### **G.7.6.2 Chemical nature or type of contaminants**

This subclause shall be numbered 6.2 and shall identify the chemical nature of the contaminants under subclause 6.1 and eventual vapour pressures or condensation conditions.

#### **G.7.6.3 Transport mechanisms**

This subclause shall be numbered 6.3 and shall identify the transport mechanisms of the potential contaminants from the sources under subclause 6.1 to the contamination sensitive items or areas e.g. direct flux, reflected flux, ambient scatter, self-scatter and creeping.

### **G.7.7 Contamination budget**

This clause shall be numbered 7 and shall provide the splitting of cleanliness requirements through the major integration and testing phases.

Acceptable contamination levels of MOC and PAC at delivery, for the items and areas under clause 4, and the expected contamination levels at BOL and EOL shall be identified.



## Annex H (normative)

# Cleanliness and contamination control plan — Document requirements definition (DRD)

## H.1 Introduction

As required by ECSS-Q-70-01, this document requirements definition (DRD) defines the methods to achieve the specified cleanliness and contamination levels.

## H.2 Scope and applicability

### H.2.1 Scope

This DRD establishes the data content requirements for the cleanliness and contamination control plan. This DRD does not define format, presentation or delivery requirements for the cleanliness and contamination control plan (C&CCP), which can vary depending on product level (i.e. equipment, subsystem, system), and specific contractual requirements.

### H.2.2 Applicability

This DRD is applicable to all projects using the ECSS standards.

## H.3 Terms, definitions and abbreviated terms

### H.3.1 Terms and definitions

For the purposes of this DRD, the definitions given in ECSS-P-001 and ECSS-Q-70-01 apply.

### H.3.2 Abbreviated terms

The following abbreviated terms are defined and used within this DRD.

<b>AIT</b>	assembly, integration and test
<b>AIV</b>	assembly, integration and verification
<b>BOL</b>	beginning-of-life
<b>C&amp;CCP</b>	cleanliness and contamination control plan
<b>CRS</b>	cleanliness requirement specification
<b>MOC</b>	molecular contamination

<b>PAC</b>	particulate contamination
<b>PMP</b>	parts, materials and processes

## H.4 Description and purpose

A cleanliness and contamination control plan shall be prepared in order to set out the ways in which the required cleanliness levels are achieved and maintained during the life of the programme, from design to launch, and which also defines cleanliness levels throughout the mission up to the end-of-life.

## H.5 Application and interrelationship

As it is of fundamental importance for the space system's performance, the C&CCP shall be established as early as possible in the programme, in order to properly address the design.

The C&CCP shall be prepared for all levels of configuration items defined in the project at the following levels:

- system
- subsystem
- equipment

The C&CCP is based on the requirements defined by the cleanliness requirements specification.

## H.6 C&CCP Preliminary elements

### H.6.1 Title

This document shall be titled "Cleanliness and contamination control plan for [insert item name]"

### H.6.2 Title Page

The title page shall identify the project document identification number and the title of the document.

### H.6.3 Approval page

The approval page shall identify the names, titles and affiliations of all parties who are to approve the C&CCP.

Space shall be provided for the approval parties to affix and date their signatures.

Title page and approval page may be combined in a single page.

### H.6.4 Amendment control table

The amendment control table shall contain the

- change number,
- type of change,
- date of issue, and
- parts of C&CCP affected.

### H.6.5 Contents list

The contents list shall identify the title of every part, clause and major subclause, figure, table and annex contained in the document.

### H.6.6 Introduction

An introduction shall be included to provide specific information or commentary about the technical content of the C&CCP.

## H.7 C&CCP contents

### H.7.1 Scope and applicability

This clause shall be numbered 1 and shall describe the scope and applicability of the C&CCP. It shall include the identification of the hardware (system, subsystem and equipment) to be monitored and controlled through the C&CCP and the relevant programme phases involved

### H.7.2 References

This clause shall be numbered 2 and shall contain the following subclauses.

#### H.7.2.1 Normative references

This subclause shall be numbered 2.1 and shall contain the following statement:

“The following normative documents contain provisions which, through reference in this text, constitute provisions of this cleanliness and contamination control plan:

[insert document identifier] [insert document title]”

#### H.7.2.2 Informative references

This subclause shall be numbered 2.2 and shall contain the following statement:

“The following documents, although not a part of this cleanliness and contamination control plan, amplify or clarify its contents:

[insert document identifier] [insert document title]”

### H.7.3 Terms, definitions and abbreviated terms

This clause shall be numbered 3 and shall contain the following subclauses.

#### H.7.3.1 Terms and definitions

This subclause shall be numbered 3.1, and shall list any applicable project dictionary or glossary, and all unusual terms or terms with a meaning specific to this C&CCP, with the definition of each term.

#### H.7.3.2 Abbreviated terms

This subclause shall be numbered 3.2 and shall list all abbreviated terms used in the C&CCP, with the full spelled-out meaning or phrase for each abbreviation.

### H.7.4 Description of [insert item name]

This clause shall be numbered with 4 and shall give a general overview of the item to which the C&CCP is refers.

In particular, this clause shall identify sensitive items and contamination sources, listing those surfaces/items to be strictly controlled or protected from the cleanliness point of view due to:

- the possible impacts of contaminants on their physical or functional characteristics;
- their impact as potential sources of contamination.

### H.7.5 Cleanliness requirements

This clause shall be numbered 5 and shall contain the following subclauses.

#### H.7.5.1 Higher level requirements

This subclause shall be numbered 5.1 and shall contain a summary of cleanliness requirements (e.g. MOC, PAC, level at delivery and at BOL), relevant for the

system or hardware and eventual sub-assemblies, as derived from CRS or dedicated analysis.

#### **H.7.5.2 Prediction of contamination levels**

This subclause shall be numbered 5.2 and shall contain the prediction of contamination levels and eventually a modellization in case the outgassing contribution is large with respect to other contributions (mainly for sensitive instruments with tight requirements).

#### **H.7.5.3 Selection of materials and processes**

This subclause shall be numbered 5.3 and shall define the requirements that have design impacts, like: PMP selection criteria (e.g. as per ECSS-Q-70), venting, purging and thruster locations, in accordance with the mission requirements (cleanliness/outgassing), and with the outcome of the subclauses 5.1 and 5.2 defined above.

#### **H.7.5.4 Corrective actions**

This subclause shall be numbered 5.4 and shall describe the corrective actions in terms of design, shielding, purging, baking in case the predictions are outside acceptance limits and in cases where corrective actions are necessary because of deviation from the original cleanliness policy.

#### **H.7.6 Environment and facilities**

This clause shall be numbered 6 and shall contain a brief description of manufacturing and AIT areas, their classification, facility location and tools for contamination control.

References for internal procedures dedicated to area or facilities verification, control and maintenance shall be included.

This clause shall also contain a list (or brief description) of internal procedures for personnel training and rules to operate under contamination control conditions.

#### **H.7.7 MAIT activities**

This clause shall be numbered 7 and shall contain the following subclauses.

##### **H.7.7.1 Contamination allocation**

This subclause shall be numbered 7.1 and shall detail the splitting of cleanliness requirements during manufacturing and AIT (MAIT) phases, according to planned duration, environment class, type of operation, and dedicated provisions adopted.

In addition, this subclause shall list all phases where contamination can be expected and where the levels can exceed the allocated levels.

##### **H.7.7.2 Contamination control definition**

This subclause shall be numbered 7.2 and shall describe methods, procedures and instruments adopted to control contamination levels during manufacturing and AIT activities on systems or equipment and relevant documentation; in particular:

- contamination monitoring methods and tools;
- inspection procedures and tools;
- verification of tools or hardware;
- dedicated cautions for critical AIV operations.

### **H.7.7.3 Cleaning and decontamination methods and tools**

This subclause shall be numbered 7.3 and shall define the cleaning and decontamination methods, procedures and tools, also making reference to their applicability and eventual process parameters (i.e. temperature, pressure and time for parts bakeout).

### **H.7.7.4 Packing, storage and transportation**

This subclause shall be numbered 7.4 and shall describe the provisions for the transportation of critical items. Descriptions of containers and packaging tools to be used during hardware transportation, and the way in which they have to be stored, handled, monitored and cleaned shall to be included.

### **H.7.7.5 Contamination control flow**

This subclause shall be numbered 7.5 and shall define:

- the sampling plan for PAC and MOC,
- cleaning operations (when planned), and
- inspection points.

The outputs of this definition should be described in the form of a flowchart, reported in an appendix to the C&CCP.

### **H.7.7.6 Responsibilities**

This subclause shall be numbered 7.6 and shall identify responsibilities for:

- hardware inspections,
- cleanrooms and facilities, and
- contamination monitoring (hardware).

### **H.7.8 Forms**

This clause shall be numbered 8 and shall define the forms that are used to document the cleanliness and contamination control activities defined by the C&CCP.

As minimum, the following forms shall be defined:

- PAC and MOC measurement report;
- Cleanliness certificate of conformance.

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## Bibliography

ASTM-E1216-87(1992)	Standard Practice for Sampling for Surface Particulate Contamination by Tape Lift
ASTM-E1235M-95	Standard Test Method for Gravimetric Determination of Nonvolatile Residue (NVR) in Environmentally Controlled Areas for Spacecraft
ASTM-E1559-93	Standard Test Method for Contamination Outgassing Characteristics of Spacecraft Materials
ECSS-E-10-04	System engineering — Space environment
ESA-QME-WI-F-03	Standard test method for VBQC outgassing kinetics
ISO 15388	Contamination and Cleanliness Control
NASA SP-5076	Contamination control handbook
MIL-STD-1246C	Product cleanliness levels and contamination control program
MIL-HDBK-406	Contamination control technology cleaning materials for precision precleaning and use in cleanrooms and clean work

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## ECSS Document Improvement Proposal

<b>1. Document I.D.</b> ECSS-Q-70-01A	<b>2. Document date</b> 11 December 2002	<b>3. Document title</b> Cleanliness and contamination control
<b>4. Recommended improvement</b> (identify clauses, subclauses and include modified text or graphic, attach pages as necessary)		
<b>5. Reason for recommendation</b>		
<b>6. Originator of recommendation</b>		
Name:	Organization:	
Address:	Phone: Fax: e-mail:	<b>7. Date of submission:</b>
<b>8. Send to ECSS Secretariat</b>		
Name: W. Kriedte ESA-TOS/QR	Address: ESTEC, P.O. Box 299 2200 AG Noordwijk The Netherlands	Phone: +31-71-565-3952 Fax: +31-71-565-6839 e-mail: Werner.Kriedte@esa.int

**Note:** The originator of the submission should complete items 4, 5, 6 and 7.

An electronic version of this form is available in the ECSS website at: <http://www.ecss.nl/>  
At the website, select "Standards" - "ECSS forms" - "ECSS Document Improvement Proposal"

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