**ECSS-Q-ST-70-01C Rev.1 DIR1**
18 November 2024


# Space product assurance

## Cleanliness and contamination control

This document is distributed to the ECSS community for Public Review.

Start of Public Review: 19 November 2024
**End of Public Review: 31 January 2025**

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This document is an ECSS Draft Standard. It is subject to change without any notice and may not be referred to as an ECSS Standard until published as such.

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## Foreword

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.

This Standard has been prepared by the ECSS-Q-ST-70-01C Rev.1 Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

## Disclaimer



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| Next steps | |
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| DIR + impl. DRRs | Draft with implemented DRRs |
| DIR + impl. DRRs | DRR Feedback |
| DIA | TA Vote for publication |
| DIA | Preparation of document for publication (including DOORS transfer for Standards) |
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| ECSS-Q-70-01B | Never issued |
| ECSS-Q-ST-70-01C<br>15 November 2008 | Second issue<br>The main differences between ECSS-Q-70-01A and this Standard are listed hereunder:<br>• Reorganization of the document to conform to the ECSS drafting rules (e.g. split of descriptive and normative text), and<br>• Creation of two DRDs |
| ECSS-Q-ST-70-01C Rev.1 DFR1 | Second issue, Revision 1 |

| | |
|---|---|
| 7 November 2024 | Changes with respect to ECSS-Q-ST-70-01C (15 November 2008 are the following and identified in the document with revision tracking:<br><br>Change log will be completed after the Public Review<br>**Main changes:**<br>• xxxx<br><br>**Detailed changes:**<br>Added requirements:<br>xxx<br><br>Modified requirements:<br>xxx<br><br>Deleted requirements:<br>xxx |

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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.

The reader of this standard is reminded that a "NOTE" statement does not modify the contractual obligations stated in the requirements. The "NOTE" statement is descriptive, which means that if removed, contractual obligations remain the same.

# 1 Scope

The purpose of this standard is to define:

- The selection of contamination sensitive and contamination critical items and critical items, the definition of cleanliness requirements to satisfy the mission performance requirements and control the levels to be met by personnel, items, facilities and operations of space projects.
- The management, including organization, reviews and audits, acceptance status and documentation control.

It covers design, development, production, testing, operation of space products, launch and mission.

In this standard are also guidelines given for identification of possible failures and malfunctions due to contamination and guidelines for achieving and maintaining the required cleanliness levels during ground activities, launch and mission.

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

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

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

This Standard does not address completely biocontamination aspects. However, references to relevant ECSS standards are provided.

This standard may be tailored for the specific characteristic and constrains of a space project in conformance with ECSS-S-ST-00.

# 2
# 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 revision 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 more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

| | |
|---|---|
| ECSS-S-ST-00-01 | ECSS system — Glossary of terms |
| ECSS-Q-ST-10-09 | Space product assurance – Nonconformance control system |
| ECSS-Q-ST-20 | Space product assurance — Quality assurance |
| ECSS-Q-ST-20-07 | Space product assurance — Quality assurance for test centres |
| ECSS-Q-ST-70 | Space product assurance — Materials, mechanical parts and processes |
| ECSS-Q-ST-70-02 | Space product assurance — Thermal vacuum outgassing test for the screening of space materials |
| ECSS-Q-ST-70-29 | Space product assurance — Determination of offgassing products from materials and assembled articles to used in manned space vehicle crew compartment |
| ECSS-Q-ST-70-50 | Space product assurance — Particle contamination monitoring for spacecraft systems and cleanrooms |
| ECSS-Q-TM-70-52 | Space product assurance — Kinetic outgassing of materials for space |
| ECSS-Q-ST-70-53 | Space product assurance — Material and hardware compatibility test for sterilization processes |
| ECSS-Q-ST-70-55 | Space product assurance — Microbial examination of flight hardware and cleanrooms |
| ECSS-Q-ST-70-58 | Space product assurance — Bioburden control of cleanrooms |
| ISO 14644 (latest edition) | Cleanrooms and associated controlled environments |
| IEST-STD-CC1246E | Product cleanliness levels and contamination control program |

# 3
# Terms, definitions and abbreviated terms

## 3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-ST-00-01 and ECSS-Q-ST-70 apply.

## 3.2 Terms specific to the present standard

### 3.2.1 airborne particle

particle suspended in air

### 3.2.2 airborne particle cleanliness class

level of cleanliness specified by the maximum allowable number of particles per cubic metre of air

### 3.2.3 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 can be done in a controlled atmosphere.

### 3.2.4 biocontamination

contamination of materials, devices, individuals, surfaces, liquids, gases or air with viable particles

### 3.2.5 blank test

verification run of an empty thermal vacuum test facility to confirm proper functionality, and to demonstrate its cleanliness status

### 3.2.6 cleaning

actions to reduce the contamination level

### 3.2.7 cleanliness (contamination) control

any organized action to control the level of contamination

### 3.2.8 cleanliness level

quantitative level of contamination

### 3.2.9 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

### 3.2.10 cleanroom

room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation and retention of particles inside the room, and in which other relevant parameters, e.g. temperature, humidity and pressure, are controlled as necessary

[ISO 14644-6]

### 3.2.11 clean zone

dedicated space in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation and retention of particles inside the room, and in which other relevant parameters, e.g. temperature, humidity and pressure, are controlled as necessary

[ISO 14644-6]

NOTE This zone can be open or enclosed and can or cannot be located within a cleanroom.

### 3.2.12 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

### 3.2.13 contaminate, to

act of introducing any contaminant

### 3.2.14 contamination budget

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

### 3.2.15 contamination potential

potential amount of contaminant in the source which can produce contamination

### 3.2.16 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

### 3.2.17 fibre

particle with a length to diameter ratio of 10 or more

### 3.2.18 FTIR spectrometer

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

### 3.2.19 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 μm thermally generated DOP or specified alternative aerosol

### 3.2.20 induced contaminant environment

environment created by the presence of contaminating items

### 3.2.21 molecular contamination

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

### 3.2.22 monitoring

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

### 3.2.23 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

### 3.2.24 obscuration factor (OF)

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

### 3.2.25 offgassing

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

### 3.2.26 outgassed quantity

total quantity of outgassed species expressed as a mass (e.g. gram or percent of the initial specimen) or as pressure × volume (e.g. hPa × $m^3$)

### 3.2.27 outgassing

evolution of gaseous species from a material, usually in vacuum

NOTE Outgassing also occurs in a higher-pressure environment.

### 3.2.28 particle

unit of matter with observable length, width and thickness

### 3.2.29 particle fallout

accumulated deposit of particulate matter on a surface by fallout

### 3.2.30 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.

### 3.2.31 particulate

of or relating to minute, separate particles

### 3.2.32 particulate contamination (PAC)

airborne or surface contamination relating to particles

### 3.2.33 plume

exhaust (molecules or particles) of thrusters and engines

### 3.2.34 pre-test

dedicated, project-specific thermal vacuum test run comprising the entire test setup, minus the test article

### 3.2.35 purging

supply of clean gas to protect the critical hardware from contamination

### 3.2.36 quartz crystal microbalance (QCM)

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

### 3.2.37 ram direction

in the direction of velocity vector

### 3.2.38 contamination sensitive item

item whose contamination may affect its performance or life time

### 3.2.39 contamination critical item

item that can contaminate a sensitive item by redistribution its particulate and molecular contamination

### 3.2.40 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 µm to 0,2 µm

### 3.2.41 vacuum cycle

entire sequence of a thermal vacuum test run , encompassing the complete process from the initial pump-down of the facility to the final venting to ambient conditions

NOTE Ambient conditions are typically defined by the specifications of the surrounding cleanroom or controlled zone.

### 3.2.42 venting

conveying unwanted gaseous products through an aperture

### 3.2.43 visibly clean

absence of surface contamination when examined when examined utilizing a specific light source (including UV), light intensity, angle of incidence and viewing distance using normal or magnified vision

NOTE Inspection methods described in detail in ECSS-Q-ST-70-50, equivalence can also be found in IEST 1246E.

### 3.2.44 visual inspection

act of examining an object under defined illumination and viewing conditions with normal or magnified vision

### 3.2.45 wake direction

direction opposite to the velocity vector

### 3.2.46 witness sample

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

## 3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

| Abbreviation | Meaning |
|---|---|
| **ACS** | American Chemical Society |
| **AIT** | assembly, integration and testing |
| **AIV** | assembly, integration and verification |
| **AO** | atomic oxygen |
| **BOL** | beginning of life |
| **CC** | contamination control |
| **C&CCP** | cleanliness and contamination control plan |

| | |
|---|---|
| **CRS** | cleanliness requirement specification |
| **CVCM** | collected volatile condensable material |
| **DIW** | deionised water |
| **DML** | declared materials list |
| **DOP** | dioctylphthalate |
| **ECLS** | environmental control and life support |
| **EGSE** | electrical ground support equipment |
| **EMC** | electromagnetic compatibility |
| **EOL** | end of life |
| **EVA** | extra vehicular activity |
| **FTIR** | Fourier transform infrared |
| **GSE** | ground support equipment |
| **HEPA** | high-efficiency particulate air filter |
| **ICC** | internal contamination control |
| **IPA** | isopropyl alcohol |
| **IR** | infrared |
| **LEO** | low Earth orbit |
| **MAIT** | manufacturing assembly integration and testing |
| **MGSE** | mechanical ground support equipment |
| **MLI** | multi layer insulation |
| **MOC** | molecular contamination |
| **MRR** | manufacturing readiness review |
| **NVR** | non-volatile residue |
| **OF** | obscuration factor |
| **PAC** | particulate contamination |
| **PDR** | product definition review |
| **PFO** | particle fallout |
| **PMP** | parts, materials and processes |
| **ppm** | parts per million ($10^{-6}$) |
| **QCM** | quartz crystal microbalance |
| **RH** | relative humidity |
| **RT** | room temperature |
| **RML** | recovered mass loss |
| **SRR** | system requirement review |
| **TB** | thermal balance |
| **TML** | total mass loss |

| | |
|---|---|
| **TRR** | test readiness review |
| **TV** | thermal vacuum |
| **UV** | ultra-violet |
| **ULPA** | ultra-low-particle air filter |
| **VBQC** | vacuum balance quartz crystal |
| **VCM** | volatile condensable material |

## 3.4 Nomenclature

The following nomenclature applies throughout this document:

a. The word “shall” is used in this Standard to express requirements. All the requirements are expressed with the word “shall”.

b. The word “should” is used in this Standard to express recommendations. All the recommendations are expressed with the word “should”.

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

c. The words “may” and “need not” are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word “may”. All the negative permissions are expressed with the words “need not”.

d. The word “can” is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS “may” and “can” have completely different meanings: “may” is normative (permission), and “can” is descriptive.

e. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

# 4
# Principles

The cleanliness and contamination control process is applied all along the project life cycle, from the definition of the C&CCP programme during the early phases (see clause 5.1) until its implementation during phases B, C, D, E and F (see clause 5.2) through the systematic verification of the cleanliness requirements baseline including: predictions through contamination modelling and the establishment of agreed procedures (see clause 5.3 and 5.4) for: environments control (see clause 5.3) packaging, containerization, transportation and storage of the space system.

NOTE Figure D-1 of Annex D gives an overview of an example of a cleanliness and contamination process.

# 5 Requirements

## 5.1 Cleanliness and contamination control programme

### 5.1.1 General

ECSS-Q-ST-70-01_0500001

a. The supplier shall define and implement a cleanliness and contamination control programme for each level of configuration.

NOTE 1 Surveys can also be made to determine the contamination control requirements, based on mission objectives and scenarios.

NOTE 2 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.

NOTE 3 In general, the organization of regular workshops dedicated to cleanliness and contamination control for a specific programme is a good practice.

ECSS-Q-ST-70-01_0500002

b. The supplier shall establish measures for the coordination and resolution of cleanliness and contamination control issues among the parties involved in the project.

c. The supplier shall appoint a C&CC responsible.

d. The C&CC responsible shall define contamination sensitivity of the programme for each level of configuration.

NOTE Contamination sensitivity is driven by the design, program phases depending on mission, and involved technologies.

### 5.1.2 Documentation

#### 5.1.2.1 Contamination requirements specification (CRS)

ECSS-Q-ST-70-01_0500003

a. The supplier shall define and document the cleanliness levels applicable to the contamination critical and contamination sensitive items, and any

other needs and provisions for contamination control, in a cleanliness requirement specification (CRS), in conformance with the DRD in Annex A.

NOTE "Cleanliness levels" are intended as:

- The maximum level of contamination for acceptable mission performances until EOL, and
- The maximum level of contamination applicable at the delivery of hardware from lower-tier suppliers.

ECSS-Q-ST-70-01_0500004

b. The CRS shall be defined as early as possible in the programme to ensure to ensure proper consideration during the design phase.

NOTE Cleanliness is of fundamental importance for the space system's performance.

ECSS-Q-ST-70-01_0500258

c. The CRS shall be reviewed and approved by users and engineers from all applicable and impacted disciplines.

NOTE 1 Users can be, for example, experimenters or scientists.

NOTE 2 Engineers can be, for example, payload, instrument, optics, mechanisms, thermal, structural.

ECSS-Q-ST-70-01_0500006

d. <<deleted>>

e. The CRS shall be provided by the SRR as part of the review data package.

f. The C&CC responsible shall ensure compliance to both the ground and flight functional requirements and constraints of the project for each level of configuration.

NOTE Typical good practices e.g. Preparing a C&CC coordination plan, organising and supporting co-engineering activities starting before SRR, establishing and maintaining cleanliness and contamination control boards starting no later than PDR.

#### 5.1.2.2 Cleanliness and contamination control plan (CCCP)

##### 5.1.2.2.1 General

ECSS-Q-ST-70-01_0500007

a. The supplier shall establish a Cleanliness and Contamination Control Plan (C&CCP) in conformance with the DRD outlined in Annex B (C&CCP DRD) and to be provided no later than the PDR.

#### 5.1.2.2.2 Contamination budget

ECSS-Q-ST-70-01_0500008

a. As part of the C&CCP (see Annex B), a contamination budget and allocations shall be established.

ECSS-Q-ST-70-01_0500009

b. The contamination budgets shall allocate the applicable cleanliness levels to the activities along the lifetime, at different MAIT, launch and mission phases.

NOTE As an example for reusable vehicles mission phases are on ground, launch, in-flight and atmospheric entry and re-entry to a planet, dwarf planet or a natural satellite.

#### 5.1.2.2.3 Contamination predictions

ECSS-Q-ST-70-01_0500010

a. As part of the C&CCP (see Annex B), prediction tables shall be established including MAIT, launch and all mission phases for the following:

1. Particulate contamination;
2. Molecular contamination.

ECSS-Q-ST-70-01_0500011

b. The contamination predictions shall demonstrate the accumulation of molecular and particulate contaminants expected at MAIT, launch and all mission phases.

ECSS-Q-ST-70-01_0500012

c. An analysis shall be performed to predict particulate and molecular deposition on sensitive items and documented in agreement with the customer:

1. In-flight molecular contamination (e.g. organic contaminants, water ice):
   (a) Kinetic parameters for in-flight molecular contamination modelling obtained as per ECSS-Q-TM-70-52.
2. Particulate and molecular contamination during launch from lift off until separation.
3. Particulate and molecular contamination during atmospheric entry, re-entry and landing.
4. Particulate and molecular contamination on sensitive items during mission phases such as on orbit servicing, in orbit manufacturing, docking.

NOTE 1 to item c: Examples of modelling techniques are given in Annex G.

NOTE 2 to item 1: Mathematical models and test methodology outlined in the ECSS-Q-TM-70-52 can be modified to increase accuracy by obtaining more parameters to increase the accuracy of the simulation.

NOTE 3 Heritage data may be used for predictions of particulate and molecular deposition on sensitive items.

d. Contamination corrective, mitigation (e.g. protective measures) and precaution actions to reduce contamination shall be investigated and implemented including their predicted efficiencies:

1. If contamination predictions or when available actual measurements, result in a higher than the specified level,

2. If models used for analysis in the early project phases are preliminary and considered high risk by the customer.

NOTE The cleanliness verification activities shall be specified in the CCCP. The C&CCP as per Annex B can be tailored for test facilities with a particular view to their cleanliness and contamination control policy.

#### 5.1.2.3 Cleanliness and contamination control verification report (C&CCV)

a. The supplier shall establish a Cleanliness and Contamination Control Verification Report (C&CCV) in conformance with the DRD outlined in Annex C (C&CCV DRD), to be provided no later than the PDR.

##### 5.1.2.3.2 Contamination verification and model validation

ECSS-Q-ST-70-01_0500015

a. The supplier shall verify the fulfilment of the applicable cleanliness levels.

NOTE 1 Cleanliness requirements are the maximum level of contamination for acceptable mission performances until EOL, and/or the maximum level of contamination applicable at the delivery of hardware.

NOTE 2 The demonstration as requirement 5.1.2.2.3b, with predictions updated using the actual measurements, is part of the verification.

b. The cleanliness verification of all activities specified in the CCCP shall be demonstrated in the C&CCV.

c. On-ground contamination predictions shall be continuously updated with actual data from ground activities, including contamination monitoring measurements, the actual duration of activities, and other relevant factors affecting the predictions (e.g., bakeout, hardware orientation, applied protections).

NOTE 1 The updated budgets can be documented in the Cleanliness and Contamination Control Verification Report as per 5.1.2.3.2, or in a separate document referenced by the Contamination Control Verification Report.

NOTE 2 Requirement 5.3.1.6a applies until the measurements from contamination monitoring are available.

d. Predictions for contamination sensitive and contamination critical items based on modelling analysis shall be verified and corrected against experimental data.

1. For in-flight molecular contamination via dedicated or as a part of planned testing activities during MAIT, or in-orbit measurements;

2. For particulate and molecular contamination during launch via dedicated tests, in situ data provided by the launch provider or heritage data.

#### 5.1.2.3.3 Cleanliness declaration of conformity

a. A cleanliness declaration of conformity shall be delivered for space hardware at DRB together with the C&CCV.

### 5.1.3 <<deleted>>

## 5.2 Phases

### 5.2.1 Design

#### 5.2.1.1 General design aspects

ECSS-Q-ST-70-01_0500019

a. The level of sensitivity to contamination shall be one of the drivers in the initial design.

ECSS-Q-ST-70-01_0500020

b. The design shall be cleanliness oriented.

NOTE 1 A way to implement a cleanliness-oriented design is given in Annex F.

NOTE 2 Such design can contribute to achieve the contamination levels defined by the CRS on ground as well during the launch and mission.

NOTE 3 A way to achieve the target contamination levels can be found in Annex E.

ECSS-Q-ST-70-01_0500021

c. When the design baseline is incompatible with cleanliness requirements, the design changes shall be identified, and corrective actions shall be taken in close cooperation with all levels involved.

#### 5.2.1.2 Materials selection

ECSS-Q-ST-70-01_0500022

a. When the offgassing effect of a material is a selection criterion, the supplier shall apply ECSS-Q-ST-70-29.

NOTE For modelling the molecular contamination during on-ground activities, when outgassing data are too conservative, offgassing data are advisable.

ECSS-Q-ST-70-01_0500023

b. For the particulate contamination monitoring, inspection and quantification the supplier shall apply ECSS-Q-ST-70-50.

ECSS-Q-ST-70-01_0500024

c. When the microbiological contamination effect is a selection criterion, the supplier shall apply ECSS-Q-ST-70-55.

ECSS-Q-ST-70-01_0500025

d. When sterilization and material compatibility are selection criteria, the supplier shall apply ECSS-Q-ST-70-53.

ECSS-Q-ST-70-01_0500026

e. The outgassing screening test of materials shall be performed in accordance with ECSS-Q-ST-70-02 including the following conditions:

1. outgassing data older than 10 years is not admissible for material selection;
2. screening outgassing tests is performed by a trusted test house.

NOTE 1 MODESA outgassing database can be referred to obtain updated list of the trusted test houses and reach the outgassing data.

NOTE 2 Trusted test houses are those that can provide a Certificate of Conformity in compliance with ECSS-Q-ST-70-02 standards.

ECSS-Q-ST-70-01_0500027

f. Outgassing requirements shall be based on the quantity of material concerned, and the specific environmental conditions.

NOTE Specific environmental conditions can be available volumes and temperatures.

g. The outgassing criteria for materials within the direct and indirect view of sensitive items shall conform to following tables based on defined temperatures:

1. at RT to Table 5-1;

2. at temperature below RT to Table 5-2.

NOTE 1 "Indirect view" in a vacuum environment refers not only to the immediate surroundings but also to the consideration of reflections from other volumes and surfaces.

NOTE 2 For contamination sensitive items more stringent requirements can be applied based on analysis and mission requirements.

h. The outgassing criteria for materials in the view of cryogenic surfaces shall conform to Table 5-3.

NOTE For materials in the view of cryogenic surfaces, more stringent requirements can be applied based on analysis and mission requirements.

ECSS-Q-ST-70-01_0500032

i. Volatile metals shall not be used.

NOTE 1 This is especially the case when the temperatures are above room temperatures.

NOTE 2 Some metals such as cadmium and zinc have high vapour pressures and deposit metallic films can occur on adjacent surfaces.

ECSS-Q-ST-70-01_0500254

**Table 5-1: Outgassing criteria for materials in the vicinity of sensitive items around RT**

| Mass of material concerned (g) | CVCM (%) | RML (%) |
|---|---|---|
| >100 | < 0,01 | < 1 |
| 10 - 100 | < 0,05 | < 1 |
| < 10 | < 0,1 | < 1 |

ECSS-Q-ST-70-01_0500255

**Table 5-2: Outgassing criteria for materials in the vicinity of sensitive items at temperature below RT**

| Mass of material concerned (g) | CVCM (%) | RML (%) |
|---|---|---|
| >100 | < 0,01 | < 0,1 |
| 10 - 100 | < 0,05 | < 1 |

| | | |
|---|---|---|
| < 10 | < 0,1 | < 1 |

ECSS-Q-ST-70-01_0500256

**Table 5-3: Outgassing criteria for materials in the vicinity of cryogenic surfaces**

| Mass of material concerned (g) | CVCM (%) | TML (%) |
|---|---|---|
| >100 | < 0,01 | < 0,1 |
| 10 - 100 | < 0,05 | < 1 |
| < 10 | < 0,1 | < 1 |

## 5.2.2 MAIT

### 5.2.2.1 Manufacturing

ECSS-Q-ST-70-01_0500033

a. Personnel involved in the manufacturing of sensitive items shall be trained with respect to the cleanliness control policy.

ECSS-Q-ST-70-01_0500034

b. All elements manufactured in non-controlled areas or under non-clean conditions shall be the object of a cleaning process until the cleanliness requirements are met, before they are packaged for delivery.

ECSS-Q-ST-70-01_0500035

c. Cleaning and packaging operations for all elements shall be processed according to procedures approved by the customer for the specific application/product.

ECSS-Q-ST-70-01_0500036

d. Elements that can be cleaned after manufacturing shall be cleaned till the cleanliness requirements are met.

ECSS-Q-ST-70-01_0500037

e. For elements that cannot be cleaned after manufacturing, then manufacturing and assembling areas shall meet the cleanliness level requirements specification.

ECSS-Q-ST-70-01_0500038

f. The cleanliness conformity of the facilities shall be verified during:

1. for manufacturing at MRR;

2. for integration at IRR;

3. for testing at TRR.

ECSS-Q-ST-70-01_0500039

g. An audit of the manufacturing facilities shall be performed according to ECSS-Q-ST-10 clause 5.2.3 criteria.

#### 5.2.2.2 Assembly and Integration

ECSS-Q-ST-70-01_0500041

a. Involved personnel shall be trained with respect to the cleanliness policy.

ECSS-Q-ST-70-01_0500042

b. Contamination critical and contamination sensitive elements shall only be exposed during a predefined MAIT activity.

NOTE Exposition of sensitive and critical elements during optical calibration or alignment cannot be avoided.

ECSS-Q-ST-70-01_0500043

c. When an exposure of contamination sensitive and critical elements cannot be avoided, the exposure time and conditions shall be recorded.

ECSS-Q-ST-70-01_0500044

d. A set of assembly tools and equipment for assembly and integration shall be used and maintained in clean conditions.

ECSS-Q-ST-70-01_0500045

e. Procedures for assembly and integration shall be established for contamination critical item assembly.

ECSS-Q-ST-70-01_0500046

f. For the selection of the cleanroom, the allocated contamination budget and the duration of the integration shall be known.

NOTE The correlation between the airborne contamination and the particle fallout for normal cleanrooms is basically known (see clause 5.3.1), and so a rough estimate can be made of the type of cleanroom required. A practical contamination level for the cleanroom can be measured with representative activities and a representative number of operators. The expected contamination levels depend on the type of protection applied to critical hardware (e.g. covers, shields and purging).

ECSS-Q-ST-70-01_0500047

g. The conformity of the facilities shall be verified during MRR or TRR.

ECSS-Q-ST-70-01_0500048

h. An audit of the integration facilities shall be performed according to ECSS-Q-ST-10 clause 5.2.3 criteria.

#### 5.2.2.3 Testing

ECSS-Q-ST-70-01_0500050

a. Involved personnel shall be trained with respect to the cleanliness policy.

ECSS-Q-ST-70-01_0500051

b. For test centres, ECSS-Q-ST-20-07 shall apply.

ECSS-Q-ST-70-01_0500052

c. The conformity of the facilities shall be verified during TRR.

### 5.2.3 pre-launch and launch

#### 5.2.3.1 General

ECSS-Q-ST-70-01_0500055

a. End to end launch campaign shall be designed and planned in accordance with the CRS, controlled by the C&CCP and verified in the C&CCV.

NOTE Launch campaign is intended to cover the activities from arrival to the launch site until the S/C separation including contributions from the separation.

b. A dedicated C&CCP shall be provided for the launch campaign by the launch provider.

c. Personnel involved in pre-launch activities shall be trained with respect to the cleanliness policy of

1. the launch provider;
2. spacecraft.

ECSS-Q-ST-70-01_0500056

d. The space system shall be shipped to the launch base under clean conditions as defined in the CRS, controlled by the C&CCP and verified in the C&CCV.

ECSS-Q-ST-70-01_0500057

e. The potential contamination during launch preparation shall be controlled.

NOTE This can be done through the C&CCP or through specific launch base procedures approved by the project.

ECSS-Q-ST-70-01_0500058

f. Contamination during launch shall be controlled through specific preventive actions and design provisions.

NOTE Preventive actions can consist of cleaning and purging of the fairing. Specific design provisions can consist of shields controlling the depressurization.

g. Contamination control activities for launch shall include

1. if available providing heritage data from previous launches;
2. cleanliness verification of fairing prior to encapsulation at the latest possible moment;
3. verification of all specific design provisions including but not limited to purging, shields, depressurization.

### 5.2.3.2 Specific design provisions

ECSS-Q-ST-70-01_0500059

a. Launcher parts shall be clean to comply with CRS, and in line with the C&CCV of the space system.

NOTE Launcher parts can be fairings and mechanical systems for double or multiple launches.

ECSS-Q-ST-70-01_0500060

b. The materials of the launch hardware in the direct and indirect view of the space system shall comply with CRS, and in line with the C&CCV of the space system itself.

ECSS-Q-ST-70-01_0500061

c. The building environment in which the spacecraft is put inside the fairing shall be compatible with the spacecraft characteristics.

NOTE 1 Specific spacecraft design provisions can be protection mechanisms used to limit the launch contaminants, especially the “unknown” figure of particle transfer during launch.

NOTE 2 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.

NOTE 3 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.

### 5.2.4 Mission

ECSS-Q-ST-70-01_0500062

a. Spacecraft contamination control during mission shall be done through preventive actions, specific design provisions and operations.

NOTE 1 Preventive actions include materials selection (see clause 5.5.3 in ECSS-Q-ST-70-02), bakeout (see clause 5.4.3.2) and purging (see clause 5.4.3.3).

NOTE 2 Specific design provisions include the implementation of heaters for decontamination of sensitive surfaces, of shutters and baffles.

NOTE 3 Operations include shielding during dumping, thrusters firing or venting, decontamination of sensitive surfaces through exposure to the Sun.

ECSS-Q-ST-70-01_0500063

b. Fluids that can emerge to the exterior by leakage or intentional use of valves shall be considered in the design and operational requirements of system and equipment hardware.

ECSS-Q-ST-70-01_0500064

c. A specific analysis shall be performed to ensure an optimum level of detection, location and isolation techniques.

NOTE These fluids are 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 as well as the propellant systems.

## 5.3 Environments

### 5.3.1 Cleanrooms

#### 5.3.1.1 Design of cleanroom: shell, entrances and anterooms

ECSS-Q-ST-70-01_0500065

a. Cleanroom shell, floors, walls and ceiling shall be low shedding and the finish readily cleanable.

ECSS-Q-ST-70-01_0500066

b. The covering floor shall consist of one piece or, if this is not feasible, shall have a minimum number of joints.

ECSS-Q-ST-70-01_0500067

c. The floor shall be resistant to withstand wear by personnel and operations within the room.

ECSS-Q-ST-70-01_0500068

d. The room shall be designed such that only one door or entrance can be opened at one time, except in case of emergency.

ECSS-Q-ST-70-01_0500069

e. Entrances shall provide an air lock to allow a maintained pressurisation of the area.

ECSS-Q-ST-70-01_0500070

f. Anterooms shall be equipped for the changing of clothes and the storage of clothing, personal belongings and cleaning equipment.

g. Cleanrooms shall comply with ISO 14644-4:2022 requirements.

#### 5.3.1.2 Air supply

ECSS-Q-ST-70-01_0500071

a. Air supply and filtration equipment shall have the capacity to filter all new and recirculated air entering the room to guarantee the defined ISO class.

ECSS-Q-ST-70-01_0500072

b. Air conditioning equipment for prefiltering (particular and molecular), cooling, heating, humidification and dehumidification of the cleanroom air supply shall be supplied to guarantee the environmental conditions.

NOTE See clauses 5.3.1.8, 5.3.1.9, 5.3.1.10 and 5.3.1.11.

ECSS-Q-ST-70-01_0500073

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 ± 20 % throughout the undisturbed room.

ECSS-Q-ST-70-01_0500074

d. Airflow patterns shall be uniform with minimum turbulence.

#### 5.3.1.3 Filters

ECSS-Q-ST-70-01_0500075

a. In laminar flow cleanrooms, (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.

ECSS-Q-ST-70-01_0500076

b. Monitoring shall be done and any work with highly sensitive equipment shall not be performed before the defined ISO class for the hardware has been reached. as specified in the C&CCP for the following situations:

1. after the installation of new filters,
2. after "at rest" period,
3. after stand by period.

NOTE Due to the transitory pressure gradients, contamination previously trapped by HEPA filters, together with a reduction in the operating life of the filters themselves can be released.

ECSS-Q-ST-70-01_0500077

c. The air flow inside cleanrooms and independent HEPA filtering systems shall be maintained during "at rest" periods, except for the maintenance operations.

NOTE 1 For example, during filters replacement.

NOTE 2 Independent HEPA filtering systems can be like those used for the laminar flow tents and benches.

NOTE 3 This is to avoid the risk of redistribution of particles at restart of the flow.

NOTE 4 Exception can be made for independent HEPA filtering systems that can work with a reduced air flow rate during stand-by periods.

ECSS-Q-ST-70-01_0500078

d. In cases where a uniform and controlled molecular environment is required, the filtering system shall be equipped with additional charcoal filters positioned before the HEPA filters.

ECSS-Q-ST-70-01_0500079

e. When charcoals filters are used, the initial charge shall be assessed on installation and analysed regularly.

NOTE It can be useful to evaluate the charge in contaminants of the filtering system which can release its charge in contaminants trapped. in

order to be able to monitor the evolution and when a failure occurs.

#### 5.3.1.4 Particle levels and cleanroom classification

ECSS-Q-ST-70-01_0500080

a. Any airborne controlled environment shall be classified according to the ISO 14644-1:2015.

NOTE 1 Suitability of the cleanroom class can only be assessed once the specified obscuration factors for critical surfaces are determined.

NOTE 2 Particles of 5 µm are more critical than smaller particles, as fallout is mainly influenced by particles of this size or larger.

NOTE 3 The 5 µm particle size is often used as a benchmark because particles larger than 5 µm are particularly detrimental to optical surfaces, while particles in the 10 µm to 40 µm range are generally more harmful to bearings and gears. However, more stringent criteria may be applied in certain situations to ensure even higher levels of cleanliness and protection for sensitive components.

**Table 5-4: ISO Classes of air cleanliness by particle concentration. (Table reproduced from ISO 14644-1:2015)**

| ISO Class number (*N*) | Maximum allowable concentrations (particles/m³) for particles equal to and greater than the considered sizes, shown below [a] | | | | | |
|---|---|---|---|---|---|---|
| | 0,1 µm | 0,2 µm | 0,3 µm | 0,5 µm | 1 µm | 5 µm |
| 1 | *10*[b] | d | d | d | d | e |
| 2 | 100 | *24*[b] | *10*[b] | d | d | e |
| 3 | 1 000 | 237 | 102 | *35*[b] | d | e |
| 4 | 10 000 | 2 370 | 1 020 | 352 | *83*[b] | e |
| 5 | 100 000 | 23 700 | 10 200 | 3 520 | 832 | d, e, f |
| 6 | 1 000 000 | 237 000 | 102 000 | 35 200 | 8 320 | 293 |
| 7 | c | c | c | 352 000 | 83 200 | 2 930 |
| 8 | c | c | c | 3 520 000 | 832 000 | 29 300 |
| 9g | c | c | c | 35 200 000 | 8 320 000 | 293 000 |

[a] All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 µm include all particles equal to and greater than this size.
[b] These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see ISO 14644:1 Annex D
[c] Concentration limits are not applicable in this region of the table due to very high particle concentration.
[d] Sampling and statistical limitations for particles in low concentrations make classification inappropriate.
[e] Sample collection limitations for both particles in low concentrations and sizes greater than 1 µm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.
[f] In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See ISO 14644:1 C.7.)
[g] This class is only applicable for the in-operation state.

#### 5.3.1.5 Monitoring of cleanroom air

ECSS-Q-ST-70-01_0500081

a. The cleanroom air shall be monitored with dust counters.

ECSS-Q-ST-70-01_0500082

b. Accuracy and repeatability of instrumentation shall be demonstrated.

ECSS-Q-ST-70-01_0500083

c. Particle counts shall be acquired continuously for the monitoring of the cleanroom itself.

ECSS-Q-ST-70-01_0500084

d. A minimum of two particles counters shall be installed, one close to the air inlet and one or more according to the surface extent of the cleanroom by using the following law:

$N = \log_{10}(S)$

where N is the number of particle counters and S is the surface of the cleanroom in $m^2$.

NOTE The purpose of the location close to the air inlet is to check the quality of the in-coming air.

ECSS-Q-ST-70-01_0500085

e. For any sensitive hardware, sampling frequency and locations shall be defined in the C&CCP.

ECSS-Q-ST-70-01_0500086

f. Monitoring techniques and routines shall be established to meet the requirements of a specific category of cleanroom or clean workstation.

ECSS-Q-ST-70-01_0500087

g. Sampling air volume for the cleanroom classification shall be established on the basis of the ISO 14644-1:2015, Annex B.

ECSS-Q-ST-70-01_0500088

h. Compliance with particles concentration limits shall be done with a frequency as specified per ISO 14644-2:2015, Clause 4.2.1.

ECSS-Q-ST-70-01_0500089

i. Determining the extent to which particles are deposited on surfaces shall be achieved.

NOTE This can be done through the exposure of test surfaces or samples to the environment and counting the settled particles by appropriate methods.

ECSS-Q-ST-70-01_0500090

j. Air monitoring of class ISO 8 or better shall be achieved by means of light scattering equipment.

ECSS-Q-ST-70-01_0500091

k. Tests shall be performed to determine if leaks exceed the specified limits, according to the filter characteristics:

1. in the filter media themselves,
2. in the bond between filter media and the interior of the filter frame,
3. between filter frame gasket and filter bank supporting frames,
4. between supporting frames and walls or ceilings.

ECSS-Q-ST-70-01_0500092

l. The cleanrooms shall have a monitoring function of the contamination levels and the environmental parameters.

ECSS-Q-ST-70-01_0500093

m. The cleanroom shall have an alarm function activated when warning levels are exceeded.

NOTE 1 Those warning levels are usually defined well below the out of specification limits in order to prevent their exceedance.

NOTE 2 Environmental parameters are temperature, relative humidity and differential pressure.

ECSS-Q-ST-70-01_0500094

n. Planned corrective actions shall be initiated to re-establish the nominal conditions in the shortest possible time and to prevent recurrence.

#### 5.3.1.6 Surface particulate levels

ECSS-Q-ST-70-01_0500095

a. Predictions shall assume particulate contamination deposition in cleanroom environments based on the correlation between airborne particles and PFO as established at rest values in Table 5-5, until actual PFO measurements are available.

NOTE 1 PFO calculation from Table 5-5 is not a conservative calculation and for this reason confirmation by PFO measurements as per this requirement is needed.

NOTE 2 The PFO calculation in Table 5-5 is based on the particle size distribution as defined for the cleanroom classes in the ISO 14644-1:2015 and does not consider bigger particles or fibres.

NOTE 3 At-rest values need to be adjusted with the predicted in-operation durations of the mission.

ECSS-Q-ST-70-01_0500096

b. The budget, during the different project phases, shall be consolidated with in-situ measurements.

c. PFO shall be monitored by witness plate exposure and measured according to ECSS-Q-ST-70-50.

d. PFO levels shall be measured during a cleanroom acceptance, or after rework.

e. Exposition duration shall be sufficient to ensure that the measured values are exceeding the method uncertainties.

f. Measured PFO rates of a cleanroom at-rest shall be compliant with Table 5-5.

g. Location and number of witness plates shall be selected in order to measure particles in significant points of the environment.

h. When MAIT activities are ongoing, local particulate contamination monitoring shall be implemented as per clause 1.1.1.1 and adapted to hardware configuration and sensitivity.

NOTE 1 Particulate deposit are strongly correlated to the level and type of activities in close vicinity, and therefore localized effects are expected

NOTE 2 The ISO class of the cleanroom is guaranteed through airborne particle measurements (see clause 5.3.1.5).

ECSS-Q-ST-70-01_0500257

**Table 5-5: Correlation airborne particles and PFO for cleanrooms**

| ISO class | PFO ($mm^2/m^2/24\ h$) |
|---|---|
| 5 | 2,0 |
| 6 | 10 |
| 7 | 52 |
| 8 | 275 |
| NOTE The data contained in this table are based on several measurements performed in different cleanrooms. They are represented by this approximate law: $PFO = 0{,}069\ 10^{(0{,}72M-2.16)}$ where M is the ISO class (e.g. ISO class 5) | |

### 5.3.1.7 Surface molecular levels

a. Predictions shall assume a molecular contamination deposition of $0{,}5 \times 10^{-7}$ g/cm² in cleanroom environments over a continuous one-week period, until actual MOC measurements are available.

NOTE Predictions can also be based on reliable historical molecular contamination deposition records and proven trends for a given environment.

ECSS-Q-ST-70-01_0500097

b. Molecular contamination in controlled environments shall not exceed $2 \times 10^{-7}$ g/cm² during a continuous period of one month, independently of the cleanroom classes.

NOTE 1 In case of contamination sensitive equipment, a lower level can be required, and more stringent requirements can be set in agreement with the customer based on the contamination budget including exposure time.

NOTE 2 Cleanliness verification frequency can be adjusted depending on the customer needs.

ECSS-Q-ST-70-01_0500098

c. Molecular contamination measurements shall be monitored, measured, and reported according to ECSS-Q-ST-70-05, using at least two sets of witness plates, each set comprising two plates, and minimum in two different locations.

NOTE The number of sets of witnesses can be increased depending on the size of the cleanroom.

ECSS-Q-ST-70-01_0500099

d. One of the two witness of each set, namely step witness plate, shall be analysed at least once per month.

NOTE Measurement frequency can be adjusted depending on the customer needs.

ECSS-Q-ST-70-01_0500100

e. The second witness plate of each set, namely cumulative witness plate, shall be analyzed:

1. not longer than 6 months after the previous cumulative witness measurement, and
2. prior to cleanroom maintenance, cleaning and rework or other major activities performed in the cleanroom.

NOTE Measurement frequency can be adjusted depending on the customer needs.

ECSS-Q-ST-70-01_0500101

f. MOC measurement locations shall be selected to measure molecular contamination in significant points of the environment with at least one representative of the cleanroom at rest.

ECSS-Q-ST-70-01_0500260

g. For those hardware items where the accumulation from the air becomes a major issue, the use of charcoal filters within the ventilation system of the cleanroom as molecular contamination trap shall be considered.

NOTE Example of such a hardware are coated mirrors.

#### 5.3.1.8 Temperature control

ECSS-Q-ST-70-01_0500104

a. Cleanroom temperature shall be maintained and continuously monitored at nominally 22 °C ± 3 °C .

NOTE More stringent temperature variations conditions can be imposed in case of critical operations.

ECSS-Q-ST-70-01_0500105

b. The temperature distribution inside a cleanroom shall be controlled at representative locations for the hardware items.

NOTE 1 In order to ensure that a nominal temperature is achieved throughout the room. Automatic devices can be used for temperature monitoring.

NOTE 2 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.

#### 5.3.1.9 Pressure control

a. Segregation of the controlled environment shall be specified according to ISO 14644-4:2022 Section B.2.2 Segregation.

ECSS-Q-ST-70-01_0500106

b. In case a physical barrier segregation is specified the pressure differential between adjacent areas shall at least be 5 Pa, where

1. a positive pressure differential is maintained between the cleanroom and the personnel lock, and
2. the pressure decreases successively between the cleanroom, personnel lock and the surroundings.

c. The effectiveness of the utilised segregation concept shall be demonstrated as per utilised methodology defined in the ISO 14644-3:2019.

NOTE 1 The effectiveness of the physical barrier concept can be demonstrated by undertaking a containment leak test and experimental airflow visualization as described in ISO 14644-3:2019.

NOTE 2 Operational limitations that affect segregation can occur during certain activities, such as logistics in and out of the airlock. All impacted cleanroom users need to be informed in advance to implement appropriate contamination protection measures.

NOTE 3 The effectiveness can be reassessed with an agreement to the customer.

ECSS-Q-ST-70-01_0500109

d. Pressure in all areas shall be monitored continuously.

NOTE In order to take timely corrective actions in case of a pressure drop.

#### 5.3.1.10 Humidity control

ECSS-Q-ST-70-01_0500110

a. The relative humidity shall be maintained at (55 ± 10) % for general applications and shall be monitored continuously.

NOTE Relative humidity environments can be adjusted due to specific hardware constraints (see Annex J).

#### 5.3.1.11 Bioburden control

ECSS-Q-ST-70-01_0500111

a. ECSS-Q-ST-70-58 shall apply for the control of bioburden in cleanroom.

#### 5.3.1.12 Maintenance and cleaning

ECSS-Q-ST-70-01_0500112

a. All maintenance and cleaning activities shall be reported in a logbook.

ECSS-Q-ST-70-01_0500113

b. A maintenance and cleaning procedure or document shall be available, along with a planning.

ECSS-Q-ST-70-01_0500114

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 specified in ECSS-Q-ST-20.

ECSS-Q-ST-70-01_0500115

d. Inspections of the cleanroom shall be performed at specified frequency, depending on the ISO class.

NOTE Those inspections assess the quality of the clean facility and describe 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).

ECSS-Q-ST-70-01_0500116

e. The frequency of inspections and cleaning processes for a cleanroom shall be optimized.

NOTE The inspections and cleaning can themselves be the source of contamination.

ECSS-Q-ST-70-01_0500117

f. Data shall be recorded in a logbook.

ECSS-Q-ST-70-01_0500118

g. Regular cleaning shall be performed depending on the ISO class.

ECSS-Q-ST-70-01_0500119

h. Procedures shall cover the cleaning of the cleanroom including personnel air lock; equipment air lock, walls, floors, furniture, crane lifting devices and GSE.

ECSS-Q-ST-70-01_0500120

i. The cleanliness after the cleaning operations shall be verified by inspection by means of UV or high intensity white light.

ECSS-Q-ST-70-01_0500121

j. Any personnel involved in cleaning operations shall be trained and informed about the criticality of a cleaning operation within a cleanroom.

ECSS-Q-ST-70-01_0500122

k. Cleaning tools, solvents and gases that are used for cleaning purposes shall be chosen not to have a detrimental effect on the hardware within the cleanroom.

NOTE Cleanroom air of better than class ISO 8 is transported in a close loop. Since only a limited percentage of fresh air is fed to the loop, excessive use of solvents offgassing into the air, even if not flammable or toxic, can cause health problems.

ECSS-Q-ST-70-01_0500123

l. When the level of contamination exceeds the cleanliness requirements specification, corrective actions shall be taken.

NOTE The decision as to whether or not to clean depends on the integration flow of the unit within the cleanroom.

#### 5.3.1.13 Access control requirements

ECSS-Q-ST-70-01_0500124

a. An access control system shall be available independently for cleanrooms, storage area and equipment airlock.

ECSS-Q-ST-70-01_0500125

b. The access to the areas shall be controlled by a permanently operating access control or door lock system.

ECSS-Q-ST-70-01_0500126

c. Only authorized personnel shall have access to the cleanroom.

NOTE Access control areas have a security lock at the entrance.

ECSS-Q-ST-70-01_0500127

d. Visitors and personnel without a work order shall not be allowed to enter the cleanroom.

ECSS-Q-ST-70-01_0500128

e. Visitors working in the cleanroom, shall:

1. wear specified cleanroom clothing,
2. be identifiable,
3. be instructed about the behaviour in a cleanroom.

ECSS-Q-ST-70-01_0500129

f. Racks or cabinets for street clothing shall be separated from those used for cleanroom clothing.

ECSS-Q-ST-70-01_0500130

g. Barriers or similar means separating clean and not clean zones inside the airlock shall be placed.

NOTE Similar means can be tacky mats.

ECSS-Q-ST-70-01_0500131

h. Lint-free clothing shall be available and worn by all personnel within cleanroom area.

ECSS-Q-ST-70-01_0500132

i. Head covers or other garments shall be used as required to trap loose particles of hair, including but not only beard, moustache or skin flakes.

ECSS-Q-ST-70-01_0500133

j. Gloves, approved finger cots, tweezers or clean handling methods and equipment shall be used while working with or handling sensitive parts.

NOTE This is to avoid contamination of those parts by loose skin or natural skin oils.

ECSS-Q-ST-70-01_0500134

k. All equipment shall be cleaned by dusting, vacuum suction, washing, or other means suited to the equipment involved before being brought into the area.

ECSS-Q-ST-70-01_0500135

l. Exhaust systems for grinding, welding or soldering, machining or related operations shall be installed.

ECSS-Q-ST-70-01_0500136

m. Actions related to equipment items with cooling fans shall be identified and mitigated in order to avoid contamination of critical hardware.

NOTE Equipment items with cooling fans are potential contamination sources.

ECSS-Q-ST-70-01_0500137

n. Personnel shall be instructed about the behaviour in a cleanroom.

ECSS-Q-ST-70-01_0500138

o. Personnel movements to and from the cleanroom shall be kept to a minimum.

ECSS-Q-ST-70-01_0500139

p. Smoking, eating and drinking shall not be permitted in the cleanroom, including the entering areas and air locks.

ECSS-Q-ST-70-01_0500140

q. Local cleanroom instructions shall specify the amount of protective clothing to be worn and shall reduce to the minimum the contaminant transfer.

ECSS-Q-ST-70-01_0500141

r. If air showers are used, only suitably clothed personnel shall be allowed to enter.

ECSS-Q-ST-70-01_0500142

s. Paper, pencils or erasers shall be kept outside the clean facilities. Only special non-shedding papers and ball-points shall be used.

ECSS-Q-ST-70-01_0500143

t. Cosmetics and medicaments that can produce contamination shall not be used by any personnel.

NOTE In particular, eye make-up, rouge, face powder and hair spray.

ECSS-Q-ST-70-01_0500144

u. Fingernail polish shall not be permitted in the area.

ECSS-Q-ST-70-01_0500145

v. Before entering a cleanroom, hand lotions, creams or soap containing lanolin to tighten skin particles shall be used.

ECSS-Q-ST-70-01_0500146

w. Contact of hands with solvents shall be avoided.

NOTE Many solvents remove natural oils and cause excessive skin peeling or flaking.

### 5.3.2 Vacuum facilities

ECSS-Q-ST-70-01_0500147

a. Procedures shall be available for:

1. The cleaning of the test facilities.
2. The pump-down and recovery sequences with respect to contamination redistribution.
3. The regeneration of sorption pumps.
4. The cleaning of cold traps.

5. Verifying the cleanliness of the cold traps.
6. Contamination monitoring strategy:
   (a) QCM locations in the facility and operating procedures,
   (b) MOC witness locations in the facility and operating procedures,
   (c) PFO witness locations in the facility and operating procedures.

NOTE 1 to item 1: Handling of solvents and running a bakeout.

NOTE 2 to item 2: 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 ISO class 5).

NOTE 3 to item 3: Sorption pumps can be e.g. cryopumps, zeolites, or charcoal.

ECSS-Q-ST-70-01_0500148

b. During testing in a vacuum facility, the test item shall not exceed the contamination limits specified by the test facility.
   1. Threshold PFO values defined by the test facility in agreement with the customer.
   2. Threshold MOC values and measurement techniques defined by the test facility in agreement with the customer.

c. A minimum vacuum level of $1 \times 10^{-5}$ hPa shall be reached for TVAC testing.

ECSS-Q-ST-70-01_0500149

d. An approved declared material list (DML) of the hardware under test, including the test adapter and all connections shall be provided.

NOTE Including, for example mechanical and electrical connexions.

e. The cleanliness verification of the blank TVAC chamber shall be demonstrated.

NOTE 1 The cleanliness verification of the TVAC chamber can be demonstrated via prior tests performed when the duration and temperature range of the prior test conditions are in line with the test in question within an agreement to the customer.

NOTE 2 The cleanliness verification can be demonstrated with a blank test in agreement with the customer which should be at least 24 hours after reaching the required in vacuum temperature and pressure for the item under test.

ECSS-Q-ST-70-01_0500150

f. A pre-test shall be performed to prove the cleanliness of the facility with

1. a representative temperature and a duration of a single cycle of the TVAC test;

2. duration not less than 24 hours, after reaching the required in vacuum temperature and pressure for the item under test.

NOTE As an alternative to a pre-test, and with customer approval, proof of the facility's cleanliness can be demonstrated through other tests conducted immediately before the test of interest, provided they have similar temperature, duration, sequence, and contamination sensitivity requirements.

ECSS-Q-ST-70-01_0500152

g. During the pre-test, pump down and repressurization sequences shall be the same to the actual test.

NOTE In typical "clean" vacuum systems, a sensor (or a critical surface) is not contaminated by more than $1 \times 10^{-7}$ g/cm² during a pre-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, $0{,}3 \times 10^{-7}$ g/cm², 24 hours (or $0{,}5 \times 10^{-7}$ g/cm², week) for a pre-test is often specified.

ECSS-Q-ST-70-01_0500151

h. During the pre-test, test equipment, support equipment and cabling shall be included in the facility.

i. Thermal vacuum test facilities shall demonstrate meeting requirement for a total molecular contamination below $1{,}0 \times 10^{-7}$ g/cm² per vacuum cycle.

NOTE More stringent requirements can be defined on the specific project needs.

j. The temperature and location of the witness sample shall be representative for the most contamination sensitive hardware which will be in the vacuum chamber during the pre-test and actual TVAC testing.

k. Surface particle contamination deposition levels of TVAC cycles shall be

1. compatible with customer TVAC cycle budget allocations;

2. verified and demonstrated to be compatible against the PFO values specified in Table 5-5.

NOTE More stringent requirement might be specified due to mission/hardware constraints.

l. The locations and temperatures of QCMs during TVAC cycles shall be assessed if TVAC is used as the verification activity for the in-flight molecular contamination model.

### 5.3.3 Other facilities

ECSS-Q-ST-70-01_0500153

a. The CRS and the C&CCP shall address the cleanliness and contamination control policy for any other facility such as acoustic chamber, vibration facilities, anechoic chamber, and EMC chamber.

## 5.4 Activities

### 5.4.1 Cleaning of hardware

#### 5.4.1.1 General aspects

ECSS-Q-ST-70-01_0500154

a. Cleaning shall be performed in order to ensure that the required cleanliness levels, expected in the contamination budget, and the final product cleanliness level are achieved.

NOTE In order to meet the BOL requirements, a final cleaning of external surfaces can take place just before the entry of the space system into the fairing, or even just before closing the fairing.

ECSS-Q-ST-70-01_0500155

b. The choice of the cleaning method shall be determined by the following criteria:

1. The type of contaminants to be removed.
2. The physical or chemical nature of the item to be cleaned.
3. The actual on ground phase.

NOTE 1 Examples are provided in Annex K for removal of both particulate and molecular contamination.

NOTE 2 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).

NOTE 3 Any detrimental effect of cleaning is evaluated as well as the order of the defined cleaning methods.

NOTE 4 For those items that are too delicate to withstand cleaning, preventive contamination control is of the utmost importance.

ECSS-Q-ST-70-01_0500156

c. The cleaning procedures shall be mentioned in the process specification.

ECSS-Q-ST-70-01_0500157

d. The cleaning procedures shall be validated by tests on representative samples, or by experience from previous and similar projects, in which they were validated.

#### 5.4.1.2 Cleaning tools

##### 5.4.1.2.1 Cleaning aids

ECSS-Q-ST-70-01_0500158

a. Cleaning aids shall not increase the contaminant levels of the items to be cleaned.

ECSS-Q-ST-70-01_0500159

b. Aids, such as wipe tissues, papers, cloths, brushes and foams shall be non-flaking, lint free and dust free.

ECSS-Q-ST-70-01_0500160

c. Damage to surfaces as scratches shall be minimal.

ECSS-Q-ST-70-01_0500161

d. NVR of cleaning wipe materials shall be less than 0,01g/m$^2$ for wiping extremely clean surfaces when extracted with IPA.

NOTE Different examples of NVR for common tissues are given in 0.

ECSS-Q-ST-70-01_0500162

e. When wipe materials are selected for cleaning, measurements shall be taken to determine their contaminant content.

ECSS-Q-ST-70-01_0500261

f. All wipe materials should be precleaned to achieve the specified level of cleanliness.

NOTE Extraction by solvents is the way for precleaning the wipes materials.

#### 5.4.1.2.2 Cleaning fluids

ECSS-Q-ST-70-01_0500164

a. The cleaning solvent shall be selected based on its compatibility with the material or item to be cleaned and its efficiency in removing contaminants.

NOTE A compatibility table between materials and solvents is given in 0.

ECSS-Q-ST-70-01_0500165

b. Toxicity and flammability of solvents shall be evaluated to demonstrate fit for use for the intended environment (see MIL-HDBK-406).

ECSS-Q-ST-70-01_0500166

c. For precision cleaning, solvents of high purity shall be used.

d. Verified cleaning processes shall be applied to clean sensitive surfaces.

ECSS-Q-ST-70-01_0500167

e. The cleaning gas shall be:

1. verified clean or certified,
2. free of oil,
3. filtered to remove water contamination, molecular or particulate contamination in accordance with the mission needs.

f. The use of chemicals shall be in line with applicable local laws.

NOTE 1 EU REACH, UK REACH, Swiss Chemicals Ordinance (ChemO) regulation and others ban or restrict the use of certain substances.

NOTE 2 Basics of chemical regulatory framework and associated obsolescence risk management is described in detail in ECSS-Q-HB-70-23A, Annex D.

## 5.4.2 Cleanliness monitoring of space hardware

### 5.4.2.1 General

ECSS-Q-ST-70-01_0500168

a. Particulate and molecular contamination shall be monitored

1. during all the on-ground phases;
2. for specific missions during launch and in space.

### 5.4.2.2 Contamination monitoring in ambient environments

#### 5.4.2.2.1 Particulate contamination monitoring

ECSS-Q-ST-70-01_0500169

a. Particulate contamination shall be monitored through visual inspection and shall be quantified through optical monitoring of surfaces as per ECSS-Q-ST-70-50.

ECSS-Q-ST-70-01_0500170

b. Surfaces shall be examined using a suitable methodology and inspection sensitivity as outlined in ECSS-Q-ST-70-50:

1. visibly clean standard to be performed under oblique white light of more than 540 lx and from a distance of 150 cm to 300 cm using normal vision;
2. visibly clean sensitive to be performed under oblique white light of more than 540 lx and from a distance of 60 cm to 120 cm using normal vision;
3. visibly clean highly sensitive to be performed under oblique white light of more than 1080 lx and from a distance of 15 cm to 45 cm using normal or magnified vision.

NOTE 1 Different kinds of lights can be used: portable diving light or “white light” is often used for standard inspection. In addition, ultra-violet lamp or “black light” (365 nm) can be used for inspection of organic residues and dust particles as it increases their visibility.

NOTE 2 Typical methods are the measurement of transmission or reflection loss and nephelometry (i.e. scattering of light). These methods can be used for all types of contaminants, both organic and inorganic. Photographic determination of dust particles on surfaces is also possible, as is automatic counting.

NOTE 3 Extraction methods can be performed by:

- tape lift, using sticky tapes (according to ECSS-Q-ST-70-50);
- 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.

NOTE 4 Visible inspection cannot be used to quantify surface cleanliness levels, it is only a qualitative method as per ECSS-Q-ST-70-50.

ECSS-Q-ST-70-01_0500171

c. When using ultra-violet or “black light” (365 nm) lamps for inspection of organic residues, the induced thermal and health effects shall be assessed.

#### 5.4.2.2.2 Molecular contamination monitoring

ECSS-Q-ST-70-01_0500172

a. Molecular contamination shall be monitored as follows:

1. Visual inspection methodology used only for qualitative assessment;
2. quantitative methods used directly on the surface of interest, witness materials or indirectly after transfer of contaminants as per ECSS-Q-ST-70-50.

NOTE 1 to item 1: Surfaces can be examined by the same visual inspection methods as for particulate contamination., A contamination can be revealed by contrast.

NOTE 2 to item 2: Direct measurements can be made in situ using quartz crystal microbalances (QCM).

NOTE 3 to item 2: Further analyses can be performed to characterize molecular contamination (e.g. gas chromatography, mass spectrometry, ultra-violet degradation, SEM).

### 5.4.2.3 Contamination monitoring in vacuum facility

ECSS-Q-ST-70-01_0500173

a. Monitoring of molecular and particulate contaminants in vacuum facilities shall be achieved using:

1. for all contamination sensitive and contamination critical items the QCM together with the witness method, including auxiliary items, and
2. for all non-contamination sensitive and non-contamination critical items the QCM or the witness method or a combination of both.

ECSS-Q-ST-70-01_0500174

b. When using the witness method, the temperature and location of witnesses shall be representative of the item.

NOTE 1 Witnesses (for both molecular and particulate contamination) can be placed on or near suspect places for a specified time and then subjected to one of the standard analyses.

NOTE 2 A QCM can be used to detect contamination levels down to $1 \times 10^{-9}$ g/cm², and to measure condensation rates. Such QCMs can operate down to liquid nitrogen temperatures.

NOTE 3 A mass spectrometer is not sufficient to monitor the condensable contaminants but in combination with a QCM, it can help describing the different condensed species during a controlled re-evaporation from the QCM.

NOTE 4 A cryopanel can be used to collect all molecular contaminants for further analyses.

## 5.4.3 Bakeout and purging

### 5.4.3.1 <<deleted>>

a. <<deleted and moved to 5.1.2.3.2b>>

b. <<deleted, modified and moved to 5.1.2.3.3a>>

### 5.4.3.2 Bakeout

ECSS-Q-ST-70-01_0500185

a. The supplier shall perform vacuum bakeouts to reduce the non-water contaminants outgassed in vacuum and the surface contamination collected during ground life.

NOTE 1 Bakeouts started at the lowest possible product level allow to reach highest bakeout temperatures (i.e. avoiding the temperature constraints at higher assembly level) and hence a more efficient bakeout programme.

NOTE 2 Typical materials on which bakeout is applied are:

- Harness,
- MLI,
- Carbon and glass fibre components,
- Glued, coated or potted materials,
- Contamination critical items/ equipment / sub-system,
- Contamination sensitive items/ equipment / sub-system.

ECSS-Q-ST-70-01_0500186

b. The bakeout conditions (temperature, time, pressure) shall not have a detrimental effect on the functionality of the item / equipment / sub-system under bakeout.

c. The bakeout chamber shall incorporate (by design) at least one "cryo-panel" (Liquid Nitrogen cooled plate - "scavenger plate" or "cold trap") to collect and trap outgassed components evolved during the bake-out.

d. When determining the bakeout temperature, the following aspects shall be considered:

1. The maximum survivable temperature of the limiting material within the item, equipment, or subsystem shall be determined, ensuring no degradation occurs.

2. The maximum temperature experienced during the mission, whether in operational or non-operational mode, shall be identified.

3. The qualification temperature of the item, equipment, or subsystem shall not be exceeded, accounting for the temperature measurement uncertainties of the facility.

NOTE 1 It is more efficient to perform a bakeout at the lowest possible product level to allow reaching higher bakeout temperature to avoid temperature constraints at higher assembly level.

NOTE 2 Items with cavities and venting holes require an effective bakeout strategy due to potential inefficiencies during the process. Outgassed products may take a long time to fully vent and could potentially cross-contaminate sensitive surfaces within the cavity.

ECSS-Q-ST-70-01_0500187

e. The effectiveness of the bakeout shall be monitored by using a QCM considering:

1. the QCM is properly installed and operated;

2. the observed frequency change during the hardware test is large enough to avoid artefacts in the measurement while avoiding saturation of the sensor;

NOTE 1 to item 2: Depending on which type of the QCM is used, the dynamic range of a QCM can be anywhere from a few kHz to a few 100 kHz.

NOTE 2 to item 2: The actual observed frequency rate depends on the view factor (VF) of the QCM with the hardware. Ideally, the VF is such that the full range of the QCM is used. If the VF is too small, the observed frequency change may contain artefacts from the temperature dependence of the sensor crystals and/or electronics. These artefacts are typically of the order of a few Hz, so a sensor signal of 10s of a few Hz is necessary to avoid that the artefacts become dominant in the analysis. On the other

hand, if the VF is too large, the risk is that the sensor saturates within hours making analysis impossible.

NOTE 3 to item 2: A saturated QCM in-situ can be cleaned by thermal evaporation of the contaminants on the sensor crystal, by temporarily setting the sensor temperature to the maximum temperature before returning to the original (or new) set point.

3. The bakeout is performed when all parts have reached temperature within 0,5 °C of the steady state temperature;

4. temperature fluctuations and temperature r.m.s. variation cannot be more than ±1,0 °C in an hour and no more than ±2,0 °C in a day;

5. temperature drift cannot be more than a 1,0 °C change in the average temperature of consecutive 24-hour periods;

6. QCM temperature is constant;

7. sample temperature and facility pressure data is provided along with the QCM data.

NOTE 1 to item 2: Depending on which type of the QCM is used, the dynamic range of a QCM can be anywhere from a few kHz to a few 100 kHz.

NOTE 2 to item 2: The actual observed frequency rate depends on the view factor (VF) of the QCM with the hardware. Ideally, the VF is such that the full range of the QCM is used. If the VF is too small, the observed frequency change may contain artefacts from the temperature dependence of the sensor crystals and/or electronics. These artefacts are typically of the order of a few Hz, so a sensor signal of 10s of a few Hz is necessary to avoid that the artefacts become dominant in the analysis. On the other hand, if the VF is too large, the risk is that the sensor saturates within hours making analysis impossible.

NOTE 3 to item 2: A saturated QCM in-situ can be cleaned by thermal evaporation of the contaminants on the sensor crystal, by temporarily setting the sensor temperature to the maximum temperature before returning to the original (or new) set point.

NOTE 4 to item 6: In addition to the QCM, other complementary methods e.g. Residual Gas Analysis (RGA) can be used to monitor the chemical species in vacuum.

NOTE 5 to item 6: QCM sensor temperatures are typically maintained at temperatures in the

range from -50 °C to 0 °C. Since the deposition rate on the QCM depends on the QCM temperature, with low sensor temperatures showing a higher deposition rate than high sensor temperatures, QCM sensor temperature can be used to modify the QCM signal during the bake-out.

f. If the steady state temperature as specified in 5.4.3.2e.3 changes during the bakeout the following shall be performed:

1. a re-evaporation of the QCM, and
2. restarting of the timer on the 48 hours of data requirement for the analysis.

ECSS-Q-ST-70-01_0500188

g. Independently of the chosen method, success criteria shall be established and approved before starting the bakeout.

ECSS-Q-ST-70-01_0500193

h. Independently of any stopping and verification criteria, the minimum bakeout duration shall be 72 hours.

ECSS-Q-ST-70-01_0500189

i. A bakeout "stopping criterion" of a 1% per hour deviation from linearity shall be used based on QCM monitoring, with a minimum bakeout duration of 72 hours.

NOTE 1 This "stopping" criterion is a method to assess whether continuing the bakeout is worthwhile. For example, this criterion can be based on the change in the mass rate, specifically the second derivative of the QCM frequency.

NOTE 2 the deviation from linearity of the parameter can be optimized based on the contamination sensitivity of the item.

NOTE 3 If a facility that has a demonstrated QCM view factor is used for the bakeout stopping criterion can be based on deposition rate e.g. grams/hour.

ECSS-Q-ST-70-01_0500192

j. The background of the baking facility shall be determined before starting the bakeout.

ECSS-Q-ST-70-01_0500194

k. Baking time shall start when the material/item under baking has reached the predefined bakeout temperature.

l. When selecting the bake out temperature the following aspects shall be considered:

1. maximum survivable temperature, without degradation, of the limiting material within the item / equipment / sub-system;
2. maximum temperature during mission, whether in the operational or non-operational mode;
3. qualification temperature of the item, equipment or sub-system does not be exceeded, also considering the temperature measurement uncertainties, of the facility.

NOTE The bakeout conditions for temperature, time, are pressure, are selected such that there is no detrimental effect on the functionality of the material and/or item being baked out. As a general principle, the maximum temperature possible (subject to the limits above) is used for bakeout to increase the effectiveness.

#### 5.4.3.3 Purging

ECSS-Q-ST-70-01_0500195

a. The purging shall be performed inside a cavity to maintain a constant exchange of the gas present in the cavity.

NOTE 1 This exchange depends on the entry flow rate of the gas and the total surface leaks.

NOTE 2 The aim of the purging is not only to protect the critical hardware such as optics from contamination by injecting a non-ionized high-purity dry gas inside a cavity but also a way for decontamination (e.g. removal of water for dimensional stability of composite).

NOTE 3 The purging can be implemented at instrument or spacecraft 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, transport and pre-launch phases up to the final close of the fairing. (In case of an aborted launch, purging can be not re-installed).

b. The analytical method used to verify the purge system cleanliness shall be agreed with the customer depending on one or more of the items below:
   1. chemical species of interest;
   2. water content;
   3. number of locations to be verified;
   4. number of gas outlets;
   5. limit(s) of detection of the measurement(s).

c. The cleanliness of each pipe shall be verified when multiple purge system pipes are used throughout the system lifetime.

d. The purity of the gas at each outlet of the purge system shall be verified using an analytical technique agreed with the customer.

NOTE 1 For example, purging the gas through a sorption tube followed by thermal desorption GC-MS is an established technique for verifying VOC.

NOTE 2 In practice, multiple purge system pipes are used throughout the lifetime of the project. Thus, it is a good practice to verify the cleanliness of each pipe individually.

NOTE 3 In this context "each outlet" is not limited to the final interfaces between the purge system and the spacecraft. Rather, outlets preceding the final interface are also described by this term. For example, connection between the gas source and the purge cart is also considered an outlet.

ECSS-Q-ST-70-01_0500197

e. Filtering systems (both for MOC and PAC) compatible with the relevant cleanliness requirements shall be provided before the gas comes into contact with the hardware.

ECSS-Q-ST-70-01_0500198

f. The purging strategy of the mission shall be described and delivered as a part of the CRS (see Annex A DRD).

### 5.4.4 Packaging, containerization, transportation, storage

ECSS-Q-ST-70-01_0500199

a. Provisions shall be taken for packaging, containerization, transportation and storage.

NOTE In order to maintain the cleanliness levels achieved at any point from initial precision cleaning to delivery to the launch site.

ECSS-Q-ST-70-01_0500200

b. Cleanliness protection shall be provided prior to leaving the controlled areas, or whenever a storage period is planned.

ECSS-Q-ST-70-01_0500202

c. Transport and storage containers shall be made of non-particle shedding materials.

ECSS-Q-ST-70-01_0500203

d. Transport and storage containers shall be made of low particle shedding materials that do not evolve contaminants.

ECSS-Q-ST-70-01_0500204

e. Containers carrying sensitive items shall be pressurized with gaseous nitrogen.

NOTE Optical units and payloads are examples of sensitive units

ECSS-Q-ST-70-01_0500205

f. Containers carrying sensitive items shall also have as rigorous cleaning schedule as the parts themselves.

ECSS-Q-ST-70-01_0500206

g. It shall be ensured that containers used for transportation of clean parts do not transfer contamination from surface to surface within the cleanroom itself.

NOTE Witness plates can be placed inside containers.

ECSS-Q-ST-70-01_0500207

h. When sensitive items are packaged, containers for long-term storage or transportation, shall include provision for internal flushing with dry high-purity nitrogen and over-pressurization of 100 hPa minimum, except if units are put in sealed bags.

ECSS-Q-ST-70-01_0500208

i. For long term storage of sensitive items, containers shall be equipped with an inlet valve and an outlet valve clearly identified.

ECSS-Q-ST-70-01_0500209

j. The design of the container shall facilitate easy cleaning and inspection of its surfaces, avoiding any kind of dirt traps.

ECSS-Q-ST-70-01_0500210

k. Small clean parts shall be double bagged in airtight envelopes during storage or transportation outside controlled clean areas.

ECSS-Q-ST-70-01_0500211

l. Bags for contamination_sensitive items shall be flushed with dry nitrogen or dry clean air and then sealed.

ECSS-Q-ST-70-01_0500212

m. Only approved materials that were procured as cleaned films shall be used.

ECSS-Q-ST-70-01_0500213

n. Static sensitive items shall use metallized films.

ECSS-Q-ST-70-01_0500214

o. Outer bags shall not enter controlled clean areas.

ECSS-Q-ST-70-01_0500215

p. When used, desiccants shall be in bags that are clean and do not produce particulate contamination.

ECSS-Q-ST-70-01_0500216

q. Desiccants and humidity indicators shall be placed in the external envelope.

ECSS-Q-ST-70-01_0500217

r. Procedures shall be provided for packaging, containerization, transportation and storage.

# Annex A (normative) Cleanliness requirement specification (CRS) - DRD

## A.1 DRD identification

### A.1.1 Requirement identification and source document

The CRS is called by the ECSS-Q-ST-70-01, requirement 5.1.2.1a.

### A.1.2 Purpose and objective

The purpose of the cleanliness requirement specification (CRS) is to establish cleanliness and contamination levels to be achieved at different MAIT, launch and mission stages.

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

The CRS defines and identifies the spacecraft items and the environmental areas that are sensitive to contamination; and describes the effects of contaminants on their performance.

Specifying the spacecraft performance requirements to be met is the responsibility of the customer. The spacecraft performances specification is a major input parameter to define the acceptable contamination levels.

The CRS provides the acceptable contamination levels for all on ground and in-flight phases to guarantee that the mentioned spacecraft performances are met.

On ground surface cleanliness levels are also univocally defined.

NOTE By using ISO 14644 or IEST-STD-CC1246E.

## A.2 Expected response

### A.2.1 Scope and content

#### <1> Introduction

ECSS-Q-ST-70-01_0500218

a. The CRS shall give a general overview of the item to which the CRS refers, describing sensitive items and contamination sources, in consideration of:

   1. possible impacts of contaminants on their physical or functional characteristics;

2. possible effects of contamination on the performance;

3. their impact as potential sources of contamination.

ECSS-Q-ST-70-01_0500219

b. The CRS shall specify the pressures (or other molecular fluxes) that can be reached in connection with voltage breakdown, arcing, corona discharges, multipaction, opening time of shutters and ejection time of covers.

### <2> Environmental factors

ECSS-Q-ST-70-01_0500220

a. The CRS shall basically specify major on-ground activities to be analysed for their impact on contamination and the relevant on-ground contamination environment.

NOTE Usually, the preparation of a flowchart, that can be added as appendix to the CRS, helps in the description (see Annex D).

ECSS-Q-ST-70-01_0500221

b. The CRS shall specify the flight environmental factors (natural and induced) that affect the contamination phenomena, such as solar radiation, electron, proton and AO fluxes, together with the planned mission profile/duration.

ECSS-Q-ST-70-01_0500222

c. The CRS shall specify sensitive item temperatures to be used for the analyses during ground and in-flight operations.

NOTE The expected temperatures and temperature profiles of these items can be important for condensation and the residence times of the contaminants.

### <3> Contaminants

ECSS-Q-ST-70-01_0500223

a. The CRS shall describe all possible contamination sources to be analysed and the maximum acceptable emissions.

NOTE For example: 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.

ECSS-Q-ST-70-01_0500224

b. The CRS shall specify the chemical nature of the contaminants listed under <3>a. with their vapour pressures or relevant condensation conditions.

ECSS-Q-ST-70-01_0500225

c. The CRS shall specify the transport mechanisms of the potential contaminants from the sources under <3>a. to the contamination sensitive items or areas to be considered in the contamination analysis.

NOTE For example: direct flux, reflected flux, ambient scatter, self-scatter and creeping.

ECSS-Q-ST-70-01_0500226

d. The CRS shall specify the contamination environment to be applied for design.

NOTE For example, molecular column density, maximum molecular deposition on the sensitive items.

e. The CRS shall specify the maximum allowable contamination levels for all contamination-sensitive items, where the limits are determined through analysis, based on the acceptable performance losses expected by the mission's EOL.

NOTE Laboratory test data could be necessary for adequate analyses.

### <4> Contamination budget

ECSS-Q-ST-70-01_0500227

a. The CRS shall specify all cleanliness requirements allocated to the major integration and testing phases.

ECSS-Q-ST-70-01_0500228

b. The CRS shall specify acceptable contamination levels of MOC and PAC for all on ground and in-flight phases.

## A.2.2 Special remarks

None.

# Annex B (normative) Cleanliness and contamination control plan (C&CCP) - DRD

## B.1 DRD identification

### B.1.1 Requirement identification and source document

The C&CCP is called by the ECSS-Q-ST-70-01, requirement 5.1.2.2.1a.

### B.1.2 Purpose and objective

The purpose of the Cleanliness and contamination control plan (C&CCP) is to establish 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.

A cleanliness and contamination control plan is 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 end-of-life.

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

The C&CCP is 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 (CRS).

The supplier is responsible for this document.

The C&CCP is prepared in collaboration with experimenters and engineers.

## B.2 Expected response

### B.2.1 Scope and content

#### <1> Introduction

ECSS-Q-ST-70-01_0500229

a. The C&CCP shall contain description of the purpose, objective, content and the reason prompting its preparation.

#### <2> Applicable and reference documents

ECSS-Q-ST-70-01_0500230

a. The C&CCP shall list the applicable and reference documents to support the generation of the document.

#### <3> Terms, definitions and abbreviated terms

ECSS-Q-ST-70-01_0500231

a. The C&CCP shall include any additional terms, definitions or abbreviated terms used.

#### <4> Description of [item name]

ECSS-Q-ST-70-01_0500232

a. The C&CCP shall give a general overview of the item it pertains to.

ECSS-Q-ST-70-01_0500233

b. The C&CCP shall describe sensitive items and contamination critical items and contamination sources, listing those surfaces/items to be strictly controlled or protected from the cleanliness point of view due to:
   1. The possible impacts of contaminants on their physical or functional characteristics.
   2. Their impact as potential sources of contamination.

#### <5> Cleanliness requirements

##### <5.1> Requirements in CRS

ECSS-Q-ST-70-01_0500234

a. The C&CCP shall contain a summary of cleanliness requirements, relevant for the system or hardware and eventual sub-assemblies, as given in CRS or dedicated analysis.

NOTE Example of such requirements are MOC, PAC, and during the different phases on ground and in-flight.

### <5.2> Contamination budgets

ECSS-Q-ST-70-01_0500235

a. The C&CCP shall contain the allocation of contamination levels through the splitting of cleanliness requirements during the major integration and testing phases.

NOTE In case the outgassing contribution to the performance loss is large with respect to other contributions (mainly for sensitive instruments with tight requirements), more detailed modelling are performed.

### <5.3> Selection of materials and processes

ECSS-Q-ST-70-01_0500236

a. The C&CCP shall define the requirements that have design impacts like PMP selection criteria (see ECSS-Q-ST-70), venting, purging and thrusters' locations, in accordance with the mission cleanliness and outgassing requirements and the outcome of the clauses 5.1 and 5.2.

### <5.4> Mitigation and corrective actions

ECSS-Q-ST-70-01_0500237

a. The C&CCP shall describe the measures for the coordination and resolution of cleanliness and contamination control issues among the parties involved in the project.

ECSS-Q-ST-70-01_0500238

b. The C&CCP shall describe the corrective actions in terms of design, shielding, purging, bakeout in case the predictions are outside acceptance limits and in cases where corrective actions are necessary because of deviation from the original cleanliness policy.

NOTE In general, the organization of regular workshops dedicated to cleanliness and contamination control for a specific programme is a good practice.

## <6> Environments and facilities

ECSS-Q-ST-70-01_0500239

a. The C&CCP shall contain a brief description of MAIT areas, their classification, facility location and tools for contamination control.

ECSS-Q-ST-70-01_0500240

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

ECSS-Q-ST-70-01_0500241

c. The C&CCP shall contain a list (or brief description) of internal procedures for personnel training and rules to operate under contamination control conditions.

## <7> MAIT activities

### <7.1> Contamination prediction

ECSS-Q-ST-70-01_0500242

a. The C&CCP shall detail the splitting of cleanliness prediction during MAIT phases, according to planned duration, environment class, type of operation, and dedicated provisions adopted.

ECSS-Q-ST-70-01_0500243

b. The C&CCP shall list all phases where contamination can be expected and where the levels can exceed the allocated levels.

### <7.2> Contamination control

ECSS-Q-ST-70-01_0500244

a. The C&CCP shall describe selected methods, procedures and instruments to control contamination levels during MAIT activities on systems or equipment and relevant documentation; in particular:
   1. Contamination monitoring methods and tools.
   2. Inspection procedures and tools.
   3. Verification of tools or hardware.
   4. Dedicated cautions for critical AIV operations.

### <7.3> Cleaning and decontamination methods and tools

ECSS-Q-ST-70-01_0500245

a. The C&CCP shall define the cleaning and decontamination methods, procedures and tools, also making reference to their applicability and eventual process parameters.

NOTE List of items and process parameters (e.g. for a bakeout: temperature, pressure and minimum durations, stop criteria are part of the information of this clause.

### <7.4> Packaging, storage and transportation

ECSS-Q-ST-70-01_0500246

a. The C&CCP shall describe the provisions for the transportation of contamination sensitive, contamination critical items, including items defined in the critical item list.

ECSS-Q-ST-70-01_0500247

b. The C&CCP shall include:
   1. A description of containers and packaging tools to be used during hardware transportation.
   2. The way they are stored.
   3. The way they are handled.
   4. The way they are monitored and cleaned.
   5. The way their cleanliness is verified.
   6. The way their cleanliness is maintained.

### <7.5> Contamination control flow

ECSS-Q-ST-70-01_0500248

a. The C&CCP shall define:
   1. the sampling plan for PAC and MOC,
   2. cleaning operations (when planned), and
   3. inspection points.

ECSS-Q-ST-70-01_0500249

b. A cleanliness control flow chart shall be established, showing the stages at which specific cleanliness controls are undertaken, reported in an annex to the C&CCP.

### <7.6> Responsibilities

ECSS-Q-ST-70-01_0500250

a. Responsibility and authority shall be assigned for the implementation of the cleanliness and contamination control tasks.

ECSS-Q-ST-70-01_0500251

b. The C&CCP shall describe responsibilities for:
   1. Hardware inspections
   2. Cleanrooms and facilities
   3. Contamination monitoring (hardware).

**<8> Forms**

ECSS-Q-ST-70-01_0500252

a. The C&CCP shall define the forms that are used to document the cleanliness and contamination control activities defined by the C&CCP.

ECSS-Q-ST-70-01_0500253

b. As minimum, the following forms shall be defined:
   1. PAC and MOC measurement report.
   2. Cleanliness declaration of conformity (see ECSS-Q-ST-20).

### B.2.2 Special remarks

None.

# Annex C(normative) Cleanliness and contamination control verification report (C&CCV report) - DRD

## C.1 DRD identification

### C.1.1 Requirement identification and source documentation

The C&CCV is called by the ECSS-Q-ST-70-01, requirement 5.1.2.3a.

### C.1.2 Purpose and objectives

The purpose of this document is to outline the reporting requirements for the cleanliness status of contamination-sensitive instruments. It specifies how the current cleanliness levels are evaluated against the predefined requirements and allocations for all mission phases, as stipulated in the Contamination Control and Cleanliness Plan (CCCP) as defined in Annex B.

This document provides the outcomes derived from cleanliness measurements and ensures that the relevant requirements are met. It includes references to supporting technical documentation, such as witness measurements, verification techniques, cover efficiency, purge efficiency, and simulations (e.g., outgassing, venting, plume, particulate distribution, and other applicable models), as well as the associated analyses. These documents are available for review in conjunction with this report.

As a controlled, evolving document, it will be updated as necessary to reflect any changes. The document will also contain a comprehensive list of Requests for Actions (RFAs), including cleaning processes, Requests for Deviations (RFDs), and Requests for Waivers (RFWs), that may impact the cleanliness and contamination control of sensitive instruments and critical surfaces.

## C.2 Expected response.

### <1> Introduction

a. The C&CCV shall contain description of the purpose, objective, content and the reason prompting its preparation.

### <2> Applicable and reference documents

a. The C&CCV shall list the applicable and reference documents to support the generation of the document.

## <3> Terms, definitions and abbreviated terms

a. The C&CCV shall include any additional terms, definitions or abbreviated terms used.

## <4> Description of contamination sensitive items

a. The C&CCV shall provide a table of:

1. contamination sensitive items and contamination critical items as defined in Annex B;
2. impacted performance for the contamination sensitive items;
3. the implemented contamination verification techniques including but not only for the allocated budgets, but also for major MAIT activities, transportation, storage, launch campaign, launch, in-flight and in-orbit;
4. contamination mitigation measures;
5. contamination preventive measures;
6. contamination corrective measures.

b. The C&CCV shall provide a list and status of all RFAs, RFDs and RFWs impacting the analysis of all the contamination critical and contamination sensitive items.

## <5> Verification Matrix

a. The C&CCV shall provide:

1. a verification and a validation matrix and reference to supporting documents for all items in the C.2<4>;
2. a verification matrix for all requirements in Annex A and Annex B for all contamination sensitive items;
3. a verification matrix for all cleanliness and contamination control impacted items defined in Critical Item List (CIL);
4. The efficiency of contamination corrective, mitigation (e.g. protective measures) and precaution actions to reduce contamination shall be verified by test with the methodology to be agreed with the customer;
5. All mathematical models and simulations shall be verified against experimental data to ensure its accuracy and validity.

## <6> Results

a. The C&CCV shall provide a table comparing the maximum allowable contamination levels for each contamination sensitive item with the contamination levels verified by measurement for on-ground phases and by modelling for the in-orbit phases.

## <7> Synthesis

a. The C&CCV shall certify the compliancy of the contamination levels regarding the contamination requirements for each sensitive items.

b. The C&CCV shall provide the acceptability status of the contamination levels documented in the Table requested by requirement <6>a. regarding the impacted system performances.

# Annex D(informative) Cleanliness and contamination control process overview

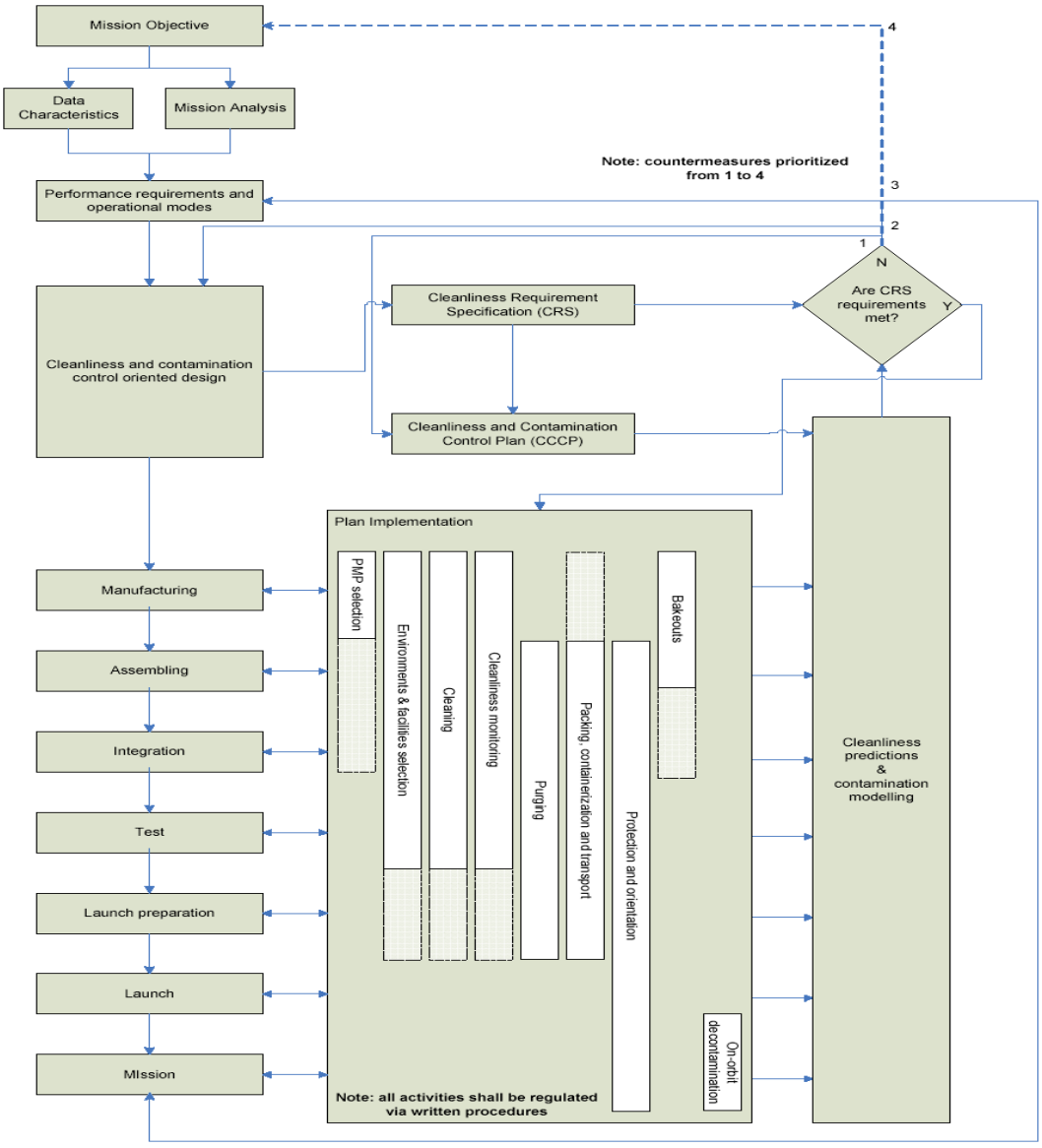


**Figure D-1: Cleanliness and contamination control process overview**

# Annex E (informative) Guidelines for general cleanliness and contamination control

## E.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.

NOTE This kind of information can be available in the mass production areas of electronics and precision mechanical devices.

## E.2 Contamination attributes

### E.2.1 Typical contaminants and their sources

#### E.2.1.1. On ground

##### E.2.1.1.1 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 all on ground phases of the space system, especially during testing activities.

NOTE Test facilities can be inside cleanrooms, but are basically not clean and can loosen particles and cause their redistribution

For example:

- **Human sources**
  - Hair cosmetics, dead human skin cells.
  - Fibres and lint from clothing, dust carried in on hair and clothes.
- **MAIT**
  - Chips and burrs from machined surfaces, solder and weld spatters.
  - Particles produced by wear or shedding, corrosion products, flakes from coatings and air filters.
  - Particles released from anechoic walls during the test.
  - Redistribution of particles during pumping down and repressurization of vacuum chambers, vibration test, transportation…
- **Other sources**
  - Bacteria, fungi, viruses and secondary products

#### E.2.1.1.2 Molecular contaminants

A considerable quantity of molecular contaminants are produced during all on ground phases of the space system, especially during testing activities.

NOTE Test facilities even if inside cleanrooms can be source of molecular contaminants the tested items.

Molecular contaminants can be found in different chemical phases, such as:

- Gases and vapours
  - 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 packaging materials and test facilities (e.g. vacuum pump oils)
  - Vapours from substances used in cleanrooms (e.g. plasticizers and cleaning fluids)
  - Secondary products coming from micro-organisms.
- Liquids
  - Residues from cleaning agents
  - Residues from adhesive masking tapes
  - Machine oils
  - Coolants

- Lubricants
- Solder fluxes
- Cosmetics
- Grease from human skin
- Secondary products coming from micro-organisms.

- Other contaminants
  - salt
  - acid
  - alkaline
  - corrosion products
  - oxidation products
  - finger prints
  - stains.

### E.2.1.2. On launch

#### E.2.1.2.1 Particulate contamination

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.

#### E.2.1.2.2 Molecular contamination

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

### E.2.1.3. During mission

#### E.2.1.3.1 Overview

Even with a good contamination and cleanliness control policy, contamination during mission can not be completely avoided. Indeed, 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.

Natural environments and induced environment are normally taken into consideration.

#### E.2.1.3.2 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 clauses are described in detail in ECSS-E-ST-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. Photon induced deposition.

   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 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 H2O. 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 SiOx.

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.

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.

#### E.2.1.3.3 Induced environment

The space system environment can be seen as being created by the space system itself or by its operation.

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. 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.

c. 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.

d. 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.

e. 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

## E.2.2 Transport mechanisms

### E.2.2.1. Overview

Most of the effects of contamination occur in space, especially when solar radiation is involved.

### E.2.2.2. Contaminants transport on ground

#### E.2.2.2.1 Overview

Surfaces can become contaminated by particles during all on ground phases (e.g. MAIT, pre-launch, and transportation).

#### E.2.2.2.2 Particle transport

For particles transport, the main mechanisms are fallout and air transport, especially caused by air turbulences (e.g. human activities and pumping down and air inlet in vacuum facilities) and vibrations (e.g. vibration test and acoustic test).

#### E.2.2.2.3 Molecular contaminants transport

For molecular contaminants transport, the main mechanisms are due to diffusion of airborne contaminants and creeping of liquids.

During vacuum tests, the mechanisms are basically the same as in space (see next clause).

### E.2.2.3. Contaminants transport in space

#### E.2.2.3.1 Particle transport

Only the surfaces in direct view of other surfaces can be contaminated by particles originating from the other surface. Return of released particles to the space system, for example return of charged particles to a charged spacecraft (depending on their mass), can occur but such mechanisms are not often modelled..

#### E.2.2.3.2 Molecular contaminants transport

- 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 are generally applied.

- Direct flux

  Contaminants in space move in straight lines from the space system into deep space and can sometimes contaminate items located in the direct view.

  In order to mitigate this effect, design provision are generally a solution.

- Indirect flux

  Contaminants from space systems can impinge on a surface and after reflection (specular) or re-evaporation (diffusive) these contaminants can affect other 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 can be deployed or ejected when the outgassing has dropped to a certain level or after a pre-determined time after the launch.

### E.2.3 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, $\alpha/\varepsilon$) 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 + $O_2$).
- HF for a motor.
- Disturbance of gas flux and combustion within thrusters.
- Disturbance and propagation within RF wave guides.
- For the space environment around the space system, the “column density”, local gas pressures and gas composition can be limiting factors for some experiments.

# Annex F (informative) Cleanliness-oriented design

The lowest contamination levels can be achieved by applying the following rules:

a. Locate contamination sensitive items far away from the contaminant sources.

b. 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.

    1. Locate the vent holes of the space system and the instruments away from the sensitive items (= backdoor venting).

    2. Manufacture the hardware in such a way that venting (of, for example, thermal blankets) is directed towards the backdoor.

    3. Design baffles or shields for the sensitive items or even for the contaminant sources.

    4. 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)

    5. Design deployable covers for very sensitive instruments, that are operated only in space.

    6. 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.

    7. Selection of materials, processes, mechanisms and components with low particulate and molecular, and bio- contamination potential. In this respect low outgassing materials should be chosen, and zinc and cadmium (or cadmium plating) should not be used because of the relatively high vapour pressures of these materials.

    8. If the contamination potential of selected materials is still too high, bakeout of the hardware should be considered before assembly or even during tests.

    9. The design, manufacturing order and assembly should 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).

    10. Where sensitive items are expected, the design of the instruments or space system should be such that purging is feasible in the periods

of assembly, integration, tests and launch preparations or even up to launch.

11. Based upon these effects, the venting holes and other contaminant sources should be located in the wake side of the space system.

c. 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.

d. Cleaning aptitude of materials and mechanical parts, e.g. in case hardware cannot be cleaned after manufacturing temporary protection devices are needed.

e. Measurement of contamination, e.g. adaptations for contamination sensors.

f. Verification of the compatibility of the surface treatment with the cleanliness level.

g. Ground support equipment, packaging, containerization, transportation and storage.

h. Any other design provisions according to the specificity of the mission (e.g. planetary missions).

# Annex G (informative) Modelling guidelines

## G.1 Introduction

Molecular and particulate contamination characterizations are essential for the modelling of contamination in the environment surrounding a space system. Regardless of the specific model used, the following key points are essential to ensure the model's reliability and accuracy:

a. Model Definition: The type and level of the model must be defined according to the project's aims.

b. Consistency and Simplicity: Model components must be consistent with the system, and the model should be as simple as possible while still meeting objectives.

c. Parameterization: Parameters and measurements must be linked to measurable features of the system for accurate predictions.

d. Mathematical Definition: The model must be fully defined mathematically, including equations, parameters, and units.

e. Analytical Methods: Well-understood analytical and numerical methods must be used for analysis.

f. Software Validation: Software and algorithms must be thoroughly tested, and results must be validated before use.

g. Data Processing: Well-justified methods must be applied to process data and make comparisons.

h. Model Verification: The model must be verified against experimental data to ensure accuracy.

i. Clarity in Presentation: Results must be presented clearly, avoiding unnecessary complexity.

j. Conclusions: Conclusions must align with the model's scope, and any speculation must be clearly indicated.

## G.2 Molecular Contamination

For molecular contamination, knowledge of outgassing molecule transport in vacuum is essential. The following points highlight the key considerations:

a. Outgassing Parameters: Understanding outgassing fluxes over time, surface temperatures, geometric view factors, and residence times (as a function of surface temperature) is critical for modelling contaminants on surfaces.

b. Outgassing Data: Modelling methodologies are generally based on outgassing data obtained during kinetic tests (as per ECSS-Q-TM-70-52),

1. For worst-case modelling, Micro-VCM data (as per ECSS-Q-ST-70-02) may be used.

(a) The first assumption is that all contaminants released during the 24-hour Micro-VCM test at 125°C are released during the actual mission lifetime.

(b) The second assumption is that contaminants impinging on a surface will stick, using the geometric view factor (VF).

(c) The third assumption is that contaminants, depending on surface temperature, are permanently deposited (as per ECSS-Q-ST-70-01, Tables 5-1 to 5-3).

c. Plume Contamination: For plume modelling, knowledge of plume shape, effluence composition, temperature, speed, direction, and discharge frequency are necessary.

d. Contamination sensitive Instruments: For sensitive instruments like optical devices, modelling can estimate the superficial density of contaminants condensed on surfaces over time. Complementary experimental tests are recommended to evaluate the transmittance losses induced by molecular contaminants.

## G.3 Particulate Contamination

For particulate contamination, the following key points must be addressed:

a. Particulate Sources: Identifying potential sources of particulate contamination, such as exhaust gases, mechanical abrasion, or debris, is crucial for effective modelling.

b. Modelling of Particulates: The size, shape, distribution and material composition of particulates must be incorporated into the model to understand how they will interact with sensitive surfaces.

c. Deposition Behaviour: The model should account for particulate behaviour in different environmental conditions (e.g., vacuum, microgravity), as these factors influence deposition rates and patterns.

d. Contamination Sensitive Areas: For sensitive equipment, such as sensors, optical instruments, radiators particulate contamination models must estimate deposition rates and their impact on performance.

e. Mitigation Measures: The modelling process should include assessments of potential mitigation strategies, such as shielding or air filtration systems, and their effectiveness in reducing particulate contamination.

## G.4 Model Foundation

The model shall be based on the actual design or system configuration to ensure that all contamination sensitive and contamination critical areas relevant to the

study are accurately represented. Simplifications may be applied, provided they do not compromise the integrity of the results.

## G.5 Input Parameters and Environmental Factors

The input parameters must be derived from reliable, measured data or validated sources. Parameters shall reflect real-world measurements or best estimates, and the environmental factors (e.g., temperature, pressure) must be based on the latest available data, accounting for operational ranges and potential lifecycle changes.

## G.6 Validation and Documentation

The model shall undergo a final review and validation before execution, ensuring that all assumptions and parameters are agreed upon by stakeholders. All model setups, input data, and results shall be documented comprehensively, ensuring transparency and compliance with relevant standards.

This annex provides a structured approach to contamination modelling for space systems, ensuring thorough analysis, verification, and documentation throughout the process.

# Annex H(informative)
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# Annex I (informative) Particulate levels on surfaces

## I.1 Standard method 1: Particle distribution

This can be done as per IEST-STD-CC1246E and ISO 14644-9:2022.

These documents give the size-number distribution function for particles on surfaces.

Levels are measured by counting the number and sizes of the particles on a known surface area.

## I.2 Standard method 2: Obscuration factor

### I.2.1 Overview

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 are expressed in parts per million ($mm^2/m^2$) and acceptable values are roughly between 10 $mm^2/m^2$ and 10 000 $mm^2/m^2$.

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

### I.2.2 Correlation for particles on surfaces

A correlation for particles on surface between levels of IEST STD 1246E and the obscuration factor is given in Table I-1.

NOTE This correlation is theoretically based on ideal distribution of IEST- STD-CC1246E (i.e. the slope factor of 0,926) and considering only particles between 1 μm and 10 μm.

**Table I-1: Correlation between ideal class of IEST-STD-CC1246E and obscuration factor**

| IEST-STD-CC1246E PCL | ECSS-Q-ST-70-01C OF ($mm^2/m^2$) |
|---|---|
| 100 | 2 |
| 200 | 27 |
| 300 | 163 |
| 400 | 632 |
| 500 | 1891 |
| 600 | 4766 |
| 700 | 10636 |
| 750 | 15328 |
| 800 | 21650 |
| 900 | 41012 |
| 1000 | 73316 |

# Annex J (informative) Effects of humidity on materials and components

**Table J-1: Effect of humidity on materials and components**

| % 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<br>Some plastics swell |
| 80 - 100 | Rapid corrosion<br>Reduced electrical resistivity |
| NOTE For some materials, humidity has an effect on the material dimensional stability | |

# Annex K (informative) Cleaning methods

## K.1 Removal of particulate contamination

### K.1.1 Overview

The removal of particulate contamination can be performed with, but not limited to, the methods described in K.1.2 to K.1.4

### K.1.2 Vacuum cleaning and wiping

- 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 should be recovered with a vacuum cleaner at the end.

- An effective form of wiping can be used of tissues dipped in methanol.

### K.1.3 Gas jet cleaning

- 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.
- Cleaning with dry ice (e.g. CO2 jet spray) can be very effective.

### K.1.4 Tapes and films trapping

- Larger particles can be removed by means of polyimide adhesive tape, eventually rolled around a metal or other appropriate tool (e.g. swabs).
- 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).

## K.2 Removal of molecular contamination

### K.2.1 Overview

The removal of molecular contamination can be performed with, but not limited to, the methods described in K.2.2 to K.2.8.

### K.2.2 Mechanical cleaning

- 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 or paper is used in conjunction with organic solvents.
- Other mechanical cleaning are grinding, brushing and blasting.

### K.2.3 Solvent and detergent cleaning

- Solvent cleaning: examples are washing, dipping, spraying, vapour cleaning and ultrasonic cleaning.
- Detergent cleaning or soap cleaning: 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 or electrochemical cleaning with, for example, acids, alkalines and salts for smoothing metal surfaces

### K.2.4 Films trapping

- Use of shrinkable polymer film, peeled after drying, can also be very effective for the removal of molecules (not for optical surfaces).

### K.2.5 Gas jet cleaning

- Cleaning with dry ice (CO2 jet spray): this is very effective for the removal of molecular layers.

### K.2.6 Plasma cleaning

- Cleaning with ionized inert low pressure gas: This is very effective for the removal of polymerized products.

### K.2.7 Bakeout

- Volatilizing under vacuum is especially successful for cleaning assembled units, or when solvent cleaning is too delicate an operation.

### K.2.8 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.

# Annex L (informative) Bakeout Analysis Methodology

## L.1 Introduction

The criteria at which a bake-out is considered sufficient are that the first and second derivative of the outgassing curves must be below certain values. These values are set in such a way as to be reasonably difficult to reach but are somewhat arbitrary in that they are facility specific. The purpose of this note is to describe a more general criterion based on a robust analysis method.

## L.2 Methodology

The outgassing from a material can usually be described with first order desorption kinetics. During isothermal bake-out, the outgassing characteristic is then given by a sum of exponential decay functions:

$f(t) = \sum_i a_i \cdot \left(1 - e^{-t/\tau_i}\right)$. (1)

where $f(t)$ is the outgassing characteristic that is being monitored, e.g. the frequency of a QCM kept at a certain temperature. ai gives the contribution of species i to the total outgassing characteristic, t is time and τ i the residence time of outgassing species i. A single material can have many outgassing species, although at any given time only a few may be dominant. However, since flight hardware generally contains many different types of outgassing materials, the number of outgassing species can be very large at any given point in time.

A QCM cannot discriminate the different outgassing species and treats the outgassing from the hardware as a black box instead. However, Eq. (1) is still a useful way to describe the outgassing in a phenomenological way, as its mathematical properties match the physical properties of the outgassing process. That is, it is a continuously increasing function with a continuously decreasing rate and decreasing higher order derivatives.

From Eq. (1) it follows that the outgassing rate $f'$ is given by

$f'(t) = \sum_i \frac{a_i}{\tau_i} \cdot e^{-t/\tau_i}$. (2)

and the change of the rate is given by

$f''(t) = -\sum_i \frac{a_i}{{\tau_i}^2} \cdot e^{-t/\tau_i}$. (3)

In practice, the outgassing characteristic of flight hardware eventually appears linear in time, i.e. the rate becomes near constant. The linear and non-linear part of the outgassing characteristic can be separated using a Taylor expansion of the outgassing rate $f'$:

$f'(t + \Delta t) = f'(t) + f'(t) \cdot \Delta t + \cdots$. (4)

The higher order terms can be safely ignored since we are interested in the bake-out time at which the deviation from linearity becomes small. Inserting Eq. (2) and Eq. (3) into Eq. (4) we get:

$$f'(t+\Delta t) = \sum_i \frac{a_i}{\tau_i} \cdot e^{-t/\tau_i} - \Delta t \cdot \sum_i \frac{a_i}{\tau_i^2} \cdot e^{-t/\tau_i}. \quad (5)$$

We can define the total deviation from linearity $\zeta$ as:

$$\zeta = \left|\frac{f''(t)}{f'(t)}\right| \cdot \Delta t. \quad (6)$$

or the deviation from linearity per unit of time $\zeta'$ (hereafter referred to as simply the deviation from linearity):

$$\zeta' = \left|\frac{f''(t)}{f'(t)}\right| = \frac{\sum_i \frac{a_i}{\tau_i^2} \cdot e^{-t/\tau_i}}{\sum_i \frac{a_i}{\tau_i} e^{-t/\tau_i}}. \quad (7)$$

The inverse of $\zeta'$ is also a useful quantity which we define as the apparent residence time $\tau_{app}$ according to

$$\tau_{app} = \frac{1}{\zeta'} = \left|\frac{f'(t)}{f''(t)}\right|. \quad (8)$$

The apparent residence $\tau_{app}$ can be considered as a weighted average residence time of all species outgassing after a time t.

The deviation from linearity or the apparent residence time are convenient quantities on which to base the stopping criterion for bake-outs. Regardless of the actual distribution of the outgassing species and their individual temperature dependence, at any given bake-out temperature the most volatile species will always outgas first until their contribution becomes negligible compared to species with higher residence times. As follows from Eq. (1), for a single species i with residence time $\tau_i$, the reservoir of species i after t = $\tau_i$ is just 37 % of the initial amount present. At t = $3 \cdot \tau_i$ this has decreased to just 5 % of the original, and less than 1% after t = $5 \cdot \tau_i$. Thus, over time, the contribution of the most volatile species (smallest $\tau_i$) decreases. As a result, the apparent residence time will increase and the deviation from linearity decreases. The time at which a deviation from linearity of less than x %/hour (or $\tau_{app}$ > 100/x hours) is reached does depend on the distribution of outgassing species after a certain bake-out time. It does not depend on the total amount of outgassing mass from the hardware nor on the heating rate of the facility, since the analysis is valid only for the isothermal part of the bake-out. Setting a stopping criterion below a deviation from linearity of x %/hour thus ensures that a "best effort" has been reached.

The value at which the stopping criterion is set can be decided on a case-by-case basis, depending on the expected efficiency of the bake-out temperature w.r.t. the nominal flight temperature, with a maximum value of 1 %/hour. The actual time

at which the stopping criterion $\zeta'$ < x %/h ($\tau_{app}$ > 100/x h) is reached will vary depending on the outgassing characteristics of the species involved, but usually this time is somewhere between 0.5×(100/x) hours up to 3×(100/x) hours. The practical implementation of the method requires Eq. (1) to be curve-fitted to the QCM data of the isothermal bake-out phase to avoid interference from e.g. temperature fluctuations. The deviation from linearity and/or the apparent residence time can then be calculated from the first and second derivative of the fit function.

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