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Cleanrooms and associated controlled environments —

Part 8:
Assessment of air cleanliness by chemical concentration (ACC)

Salles propres et environnements maîtrisés apparentés —

Partie 8: Évaluation de la propreté chimique de l'air

Reference number
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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 209, *Cleanrooms and associated controlled environments*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 243, *Cleanroom technology*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 14644-8:2013), of which it constitutes a minor revision. The changes are as follows:

- the term class (classification, classified) changed to grade or assessment where appropriate;
- 3.1.2, definition revised;
- Bibliography updated;
- minor editorial changes.

A list of all parts in the ISO 14644 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Cleanrooms and associated controlled environments provide for the control of airborne particulate contamination to levels of cleanliness appropriate for accomplishing process activities sensitive to a range of contaminants. Products and processes that benefit from the control of airborne contamination include those in such industries as aerospace, microelectronics, pharmaceuticals, medical devices, food, healthcare, optics, instrumentation, vacuum technology, coatings, photovoltaics, displays, LEDs, coatings, automotive and surface analysis.

In some of these industries, the product or process can be sensitive to, or can be destroyed by, chemical contamination resulting from chemicals that are present due to external, process or other generated sources.

Within this document, the presence of chemicals is expressed as air chemical contamination. Chemical contamination is a three-step event. The first step is *generation* due to external sources such as process leakage, construction material, personnel or material outgassing. The second step is *transport* as airborne chemical contamination. The third step is *sorption* on the sensitive surface, which can be quantified as a surface chemical contamination.

The generating materials and the surfaces where sorption takes place will have a large influence on the steps of generation and sorption in addition to the actual air contamination. Thus, for these two steps, not only the contaminants but also the involved bulk and surfaces need to be defined. In order to make a standard generally applicable to any type of cleanroom or associated controlled environment, air chemical cleanliness (ACC) has been chosen for the level assessment.

This document assigns ISO grading levels to be used to specify the level of ACC within a cleanroom and associated controlled environment, where the product or process is deemed to be at risk from air chemical contamination.

For level assessment purposes, this document provides guidance for a range of ACC levels and provides standard protocols for specifying such levels with regard to chemical compounds, methods of test and analysis, and time weighted factors.

Annexes A to D contain the following information:

- parameters for consideration: Annex A;
- typical contaminating chemicals and substances: Annex B;
- typical methods of measurement and analysis: Annex C;
- considerations of specific requirements for separative devices: Annex D.

This document is one of a series of standards concerned with cleanrooms and contamination control. Many factors besides ACC need to be considered in the design, specification, operation and control of cleanrooms and other controlled environments. These features are recognized in this document and covered in some detail in other parts of the International Standards prepared by ISO/TC 209, including the ISO 14698 series. In some circumstances, relevant regulatory agencies can impose supplementary policies or restrictions. In such situations, appropriate adaptations of this document can be required.

NOTE When assessment of ACC at critical control point(s) is used as an additional cleanliness attribute to classification of air cleanliness by airborne particle concentration in accordance with ISO 14644-1, then the space can be described as a *cleanroom* or *clean-zone*. If ACC is used alone, then the space must be described as a *controlled zone*.

Cleanrooms and associated controlled environments —

Part 8:
Assessment of air cleanliness by chemical concentration (ACC)

1 Scope

This document establishes typical assessment processes to determine grading levels of air chemical cleanliness (ACC) in cleanrooms and associated controlled environments, in terms of airborne concentrations of specific chemical substances (individual, group or category), and provides a protocol to include test methods, analysis and time-weighted factors for their determination. This document currently considers only concentrations of air chemical contaminants between 10^0 g/m^3 and 10^{-12} g/m^3 under cleanroom operational conditions.

This document is not relevant for application in those industries, processes or productions where the presence of airborne chemical substances is not considered a risk to the product or process.

It is not the intention of this document to describe the nature of air chemical contaminants.

This document does not give a classification of surface chemical contamination.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1 General

3.1.1
chemical contamination
non-particulate substances that can have a deleterious effect on the product, process or equipment

3.1.2
air cleanliness by chemical concentration
ACC
quantity of chemical detected in the air, expressed in terms of an ISO-ACC level N, which represents the maximum allowable concentration of a given chemical species or a group of chemical species, expressed in grams per cubic metre

Note 1 to entry: This definition does not include macromolecules of biological origin, which are judged to be particles.

3.1.3

air chemical contamination

any substance in the air that can, by its chemical nature, adversely affect the product, process or equipment

3.1.4

surface cleanliness by chemical concentration

SCC

condition of the surface cleanliness with respect to its chemical concentration

3.1.5

surface chemical contamination

any substance on the surface that can, by its chemical nature, adversely affect the product, process or equipment

3.1.6

contaminant category

common name for a group of compounds with a specific and similar deleterious effect when deposited on the surface of interest

3.1.7

outgassing

release of chemical substances in the gaseous or vapour state from a material

3.1.8

air cleanliness by chemical concentration level

grading number stating the maximum allowable concentration of a given chemical species or a group of chemical species in grams per cubic metre

Note 1 to entry: The range of concentrations are defined in Table 1 or determined by the formula for *N* in 4.2.

Note 2 to entry: Testing and monitoring in accordance with this document is limited to the range from 0 (the grade with the lowest cleanliness) to –12 (the cleanest level).

Note 3 to entry: The ACC grading number is only valid in connection with the ACC descriptor that specifies to which chemical species or group of chemical species it is related.

Note 4 to entry: The negative sign of the air chemical cleanliness levels (–1 to –12) is an integral part of the ACC level number *N* and shall always be used.

Note 5 to entry: Intermediate ISO grade numbers may be specified, with 0,1 being the smallest practical increment.

3.2 Contaminant categories

3.2.1

acid

substance whose chemical reaction characteristic is to establish new bonds by the acceptance of electron pairs

3.2.2

base

substance whose chemical reaction characteristic is to establish new bonds by the donation of electron pairs

3.2.3

biotoxic

contaminant substance that is obnoxious to the development and preservation of the life of organisms, microorganisms, tissues or individual cells

3.2.4
condensable
substance capable of depositing on a surface by condensation under cleanroom operating conditions

3.2.5
corrosive
substance that causes destructive chemical change of a surface

3.2.6
dopant
substance that, after sorption and/or diffusion, is incorporated in the bulk of a product and is capable of changing the properties of materials, even in trace amounts

3.2.7
organic
species based on carbon-containing compounds

Note 1 to entry: Inorganic carbon-containing compounds are excluded.

3.2.8
oxidant
substance that, upon deposition onto a surface or product of interest, results in the formation of an oxide or participates in a redox reaction

4 Testing and monitoring using grading levels

4.1 General

Testing or monitoring shall be specified by use of a descriptor as described in 4.2. This descriptor is designated “ISO-ACC” and indicates the maximum total chemical concentration for a contaminant category, an individual substance or a group of substances.

4.2 ISO-ACC descriptor format

An ACC grading number is only valid in connection with the ACC descriptor that specifies the chemical substance or group of substances for which this level number is valid. The ISO-ACC descriptor is expressed in the format:

ISO-ACC Level N (X)

where

X is a chemical substance or a group of chemical substances which includes, but is not limited to:

- acid (ac);
- base (ba);
- biotoxic (bt);
- condensable (cd);
- corrosive (cr);
- dopant (dp);
- organic, total (or);
- oxidant (ox); or
- a group of substances or an individual substance;

N is the ISO-ACC level, which is the logarithmic index of concentration, c_x, expressed in grams per cubic metre, and falls within a limiting range of 0 to −12. Intermediate concentrations may be specified, with 0,1 being the smallest practical increment of N;

$N = \log_{10}[c_x]$.

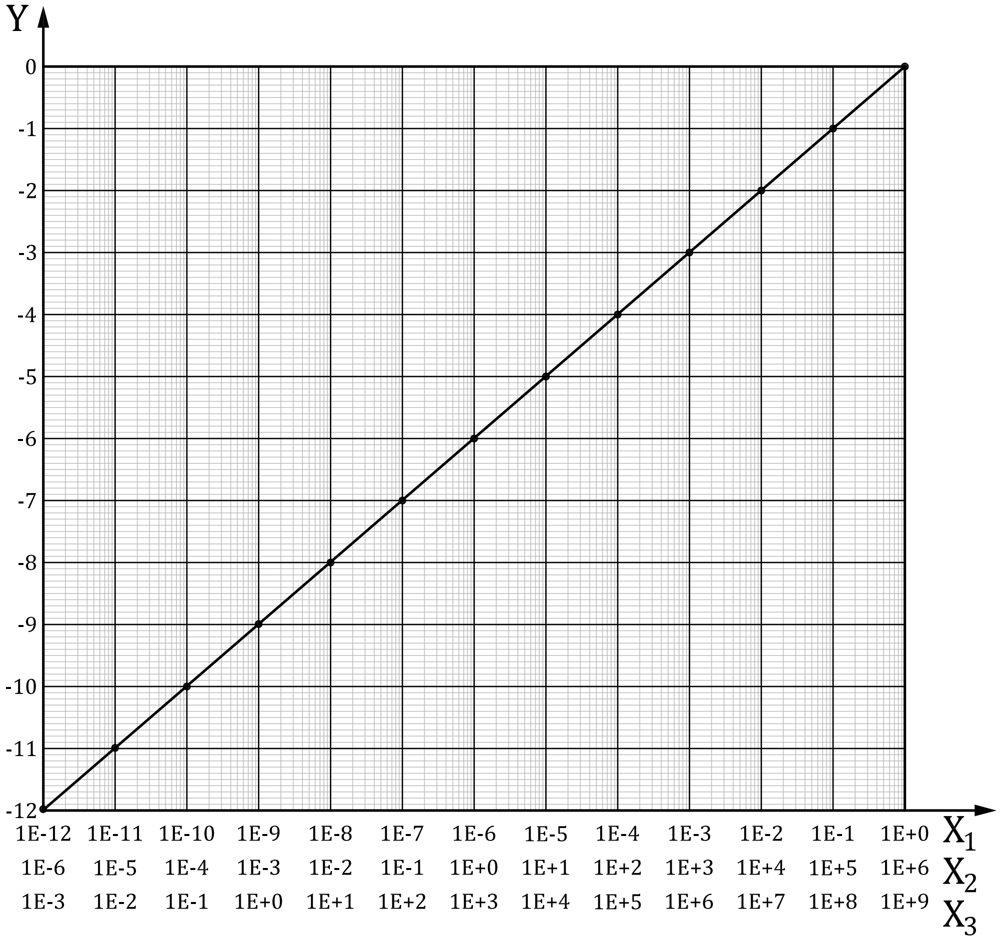
EXAMPLE 1 With an N-Methyl Pyrrolidone (NMP) sample, the measured value of air contamination was 8E-7 g/m^3; $N = -6{,}097$. This is within the level limit of 1E-6 g/m^3 for grade −6. The designation would be: "ISO-ACC Level −6 (NMP)".

EXAMPLE 2 With an organic compound sample, the measured value was 6E-5 g/m^3 of total organic compounds (TOC). This is within the level limit of 1E-4 g/m^3 for grade −4. The designation would be: "ISO-ACC Level −4 (TOC)."

Table 1 and Figure 1 further illustrate the suggested ISO-ACC concentration levels as a function of contaminant concentration for the specified species.

Table 1 — ISO-ACC grades

ISO-ACC level	Concentration g/m^3	Concentration µg/m^3	Concentration ng/m^3
0	10^0	10^6 (1 000 000)	10^9 (1 000 000 000)
−1	10^{-1}	10^5 (100 000)	10^8 (100 000 000)
−2	10^{-2}	10^4 (10 000)	10^7 (10 000 000)
−3	10^{-3}	10^3 (1 000)	10^6 (1 000 000)
−4	10^{-4}	10^2 (100)	10^5 (100 000)
−5	10^{-5}	10^1 (10)	10^4 (10 000)
−6	10^{-6}	10^0 (1)	10^3 (1 000)
−7	10^{-7}	10^{-1} (0,1)	10^2 (100)
−8	10^{-8}	10^{-2} (0,01)	10^1 (10)
−9	10^{-9}	10^{-3} (0,001)	10^0 (1)
−10	10^{-10}	10^{-4} (0,000 1)	10^{-1} (0,1)
−11	10^{-11}	10^{-5} (0,000 01)	10^{-2} (0,01)
−12	10^{-12}	10^{-6} (0,000 001)	10^{-3} (0,001)



Key

X_1 airborne concentration (g/m^3)

X_2 airborne concentration (µg/m^3)

X_3 airborne concentration (ng/m^3)

Y ISO-ACC level

Figure 1 — ISO-ACC levels as a function of concentration

5 Demonstration of compliance with an ISO-ACC level

5.1 Principle

Compliance with an ISO-ACC level requirement specified by the customer is verified by performing specified testing procedures agreed between the customer and supplier and by providing specified documentation of the results and conditions of testing.

5.2 Testing

Example test methods are given in Annex C. The list of typical methods described is not exhaustive. Alternative methods of comparable accuracy may be specified by agreement.

NOTE 1 Analysis by different methods, even when correctly applied, can produce different results of equal validity.

Tests performed to demonstrate compliance shall be conducted using suitable test methods and calibrated instruments.

Sampling locations shall be determined by agreement between the customer and the supplier.

It is recommended that replicate sampling is carried out at the locations agreed.

NOTE 2 In analytical measurement, the contribution of particulate contamination cannot always be excluded.

NOTE 3 For trace analysis using grab sampling, the incorporation of a shipping blank sample, prepared and analysed in the same batch as the actual sample, is required to assess contamination from the overall process, excluding the air sampling.

The elapsed time period shall be agreed between the customer and supplier. See A.4.3.

5.3 Test report

The results from testing each cleanroom or associated controlled environment shall be recorded and submitted as a comprehensive report, along with a statement of compliance or non-compliance with the specified ISO-ACC level or levels.

The test report shall include the following:

a) name of the test operator, the name and address of the testing organization, and the date, time and duration of sampling;

b) number and year of publication of this document, i.e. ISO 14644-8:2022;

c) clear identification of the physical location of the cleanroom or controlled environment tested (including reference to adjacent areas if necessary) and specific designations for coordinates of all sampling locations;

d) specified designation criteria for the cleanroom or controlled environment, including the occupancy state, the ISO-ACC level or levels, the specified test method(s) and, where applicable, the substances, substance group or categories, the elapsed time period and the designated particulate type;

e) details of the test procedure used, with any available data describing the test circumstances or departures from the test method, and identification of the test instrument(s) and its current calibration certificate(s);

f) test results, including air chemical concentration(s) data, for all sampling locations.

Annex A
(informative)

Parameters for consideration

A.1 Principles

This annex is intended to give guidance to consideration of parameters affecting or contributing to ACC within a cleanroom or associated controlled environment. It is important to consider the development of such parameters at the initial stages of design and control requirements, along with any special considerations for operation of the facility.

A.2 Concepts for establishing parameters

The following principles permit the establishment of the parameters which influence the ACC or which contribute to it and which should be taken into account.

a) First, establish if the product or process is affected by chemical contamination, as in many industries consideration of chemical contamination is not a governing factor.

b) Establish the contaminant categories that affect the product or process and if any particular substances or substance groups require special consideration.

c) Establish the maximum concentrations of contaminant categories and/or substances or substance groups permitted for the product or process and designate the associated ISO-ACC descriptor in accordance with 4.2.

d) Establish sources of chemical contamination and concentration levels that can occur from:

   1) outdoor air (providing fresh air to the facility);

   2) construction materials in the facility, especially those in contact with recirculating and make-up air streams;

   3) cross-contamination that can occur within the facility;

   4) operation and maintenance of the facility;

   5) personnel, cleanroom apparel and auxiliary materials;

   6) process media and tooling.

Further guidance on these occurrences is given in A.3 to A.8.

e) Establish the design requirements to avoid or reduce chemical contamination generated as per A.2 d) to achieve the ISO-ACC level for the product or process.

A.3 Outdoor air

A.3.1 Where outdoor air is provided as fresh air to the facility to which the product or process is exposed, the outdoor air quality and any seasonal variation should be established with regard to the concentration of compounds or substances affecting the product or process. In addition, the construction materials of heating, ventilation or air conditioning equipment, including cabling, should be taken into account.

A.3.2 The analysis of the concentration should be conducted over a period of time sufficient to evaluate its variability, along with consideration of any future developments that can affect the outdoor air quality.

A.3.3 In some cases, due to, for example, prevailing winds or proximity of contaminating sources, chemical contamination concentrations can be minimized by selective positioning of the fresh-air intake(s) to the facility.

A.3.4 Outdoor air contamination levels entering the incoming air to a building can include variable contamination levels from the same building exhaust, exhaust from neighbouring buildings, or other contamination sources including farms, sewer plants, dumps, highways, airports, train yards, local industry and other sources. These levels can vary dramatically with wind direction, wind velocity, time of day, precipitation, temperature, sunlight or other factors. Thus, it is important to use continuous monitoring where possible for the most important parameters, or to do periodic sampling on different dates and with sampling for many hours or days, so that a typical average or highest level can be assessed, rather than just a single data point.

Long-term average data are useful for predicting chemical filter lifetimes, and real-time data are valuable to assess the highest levels encountered in terms of whether they will affect the most sensitive products.

A.4 Construction materials

A.4.1 Construction materials serving the facility can be sources of chemical contamination because of outgassing.

Examples of suitable cleanroom construction materials are given in ISO 14644-4:2001, Annex E.

A.4.2 The degree of material outgassing can be dependent upon the temperature, relative humidity and pressure of the cleanroom or controlled environment, and these effects should be established specific to the design of the facility.

A.4.3 Outgassing from materials of construction can, in many cases, decay exponentially and asymptotically over a period of time. Thinner materials (e.g. coatings) and more volatile compounds (e.g. solvents) tend to decay more rapidly, but thicker materials (floor tiles, insulation, ULPA filter potting compounds) and higher boiling compounds (plasticisers, antioxidants, organophosphorus fire retardants, larger silicones) can decay much more slowly, and possibly outgas at significant levels for many years.

A.4.4 All materials forming the construction of a facility where air chemical contamination is of concern should be assessed with regard to their combined chemical characteristics and selected accordingly for their use. This analysis can be constructed as a table.

A.5 Cross-contamination

A.5.1 Chemical contamination can occur by migration between services, partial pressure change transfer systems and processes within the facility.

A.5.2 The degree of such contamination should be assessed and evaluated as part of the initial design concept.

A.5.3 In some cases, cross-contamination can be minimized or avoided by isolation, enclosure or barrier technology to contain the service or process or to provide protection to the product or process. Examples of such concepts are given in ISO 14644-4: 2001, Annex A and in ISO 14644-7.

A.5.4 A significant source of cross-contamination can include the facility's exhaust or external operations. Maintaining emissions, for example below regulatory limits, may not be adequate to protect incoming air, especially on calm days, for those processes that are sensitive to air chemical contamination at levels much lower than regulatory limits. Similarly, some compounds that are not regulated can still be very detrimental to sensitive processes.

A.6 Operation and maintenance

Chemical contamination sources from facility operation and maintenance can be prevented or minimized by scheduling disciplines, over and above those stated within ISO 14644-5, typically as follows:

- facemasks or ventilated or filtered helmets worn during working process;
- qualified chemical analysis of garments, gloves and packaging materials thereof;
- qualified chemical analysis of cleaning liquids and other cleaning materials;
- qualified chemical analysis of any product packaging materials, taking into consideration operations such as outgassing during heat-sealing of bags;
- operational disciplines to minimize chemical contamination from the use of any portable equipment or temporary materials;
- temporary isolation barriers for use during maintenance or repair of machinery or services;
- operative protocols instated to minimize chemical contamination.

For the areas most sensitive to air chemical contamination effects, positive pressurization or carefully controlled air flow is required. This includes ensuring all exhaust lines are under negative pressure relative to the room to prevent air chemical contamination from more contaminated areas – which can include plenums, trenches, vents, hollow walls, tunnels and conduit – from intruding into the critical areas.

A.7 Personnel

Chemical contamination sources from personnel can be prevented or minimized by rules to control the following:

- use of cosmetics, deodorants, hand lotions, soaps perfumes and hair products;
- practice of smoking;
- use of medication;
- consumption of certain foods and drugs;
- entry and exit procedures;
- personal use of cleaning and disinfectant materials.

This list is not exhaustive.

NOTE The degree of control needed depends on the process concerned. Attention is drawn to the relevant clauses of ISO 14644-5.

A.8 Other sources

These can include:

- consumables;
- equipment;
- chemicals;
- reaction by-products, especially from etching or chemical vapour deposition (CVD);
- heaters, insulation, computers, displays, printers, electronics;
- leaks of chemicals, coolants, waste streams, sewer gases, antistatic treatments.

A.9 Air treatment processes for the abatement of air chemical contamination

Several processes are available in order to control or reduce the concentration of specific chemical contamination categories. These include:

- sorption on suitable materials (e.g. activated carbon, treated activated carbon, ion exchange resin, zeolites);
- photoelectron ionization and electrostatic ion removal;
- catalytic photo oxidation;
- wet scrubbers or sprays, air washes using water and/or chemicals.

Annex B
(informative)

Typical contaminants

The categorization of airborne chemical contaminants is a complex subject. Many compounds have chemical attributes that fit into multiple categories and therefore categorization of contaminants should be a function of the deleterious chemical reaction that the specific chemical compound of interest has on the final product that is manufactured in the cleanroom environment. Table B.1 gives typical examples of contaminating chemicals and categories that can be of concern to a product or process. Users are encouraged to categorize the chemicals or substances that are specific to their concern in application in a similar manner.

Table B.1 is given as guidance only and it is not intended to be exhaustive or comprehensive.

Table B.1 — Typical examples of contaminating chemicals and categories that can be of concern to a product or process

CAS No.	Substance	Rational formula	Contaminant category									
			ac	**ba**	**or**	**bt**	**cd**			**cr**	**dp**	**ox**
							H	**M**	**L**			
7664–41–7	Ammonia	NH_3		x		x		x		x		
141–43–5	2-Aminoethanol	$H_2NCH_2CH_2OH$		x	x				x	x		
78–91–1	2-Amino-propanol	$CH_3(NH_2)CHCH_2OH$		x	x			x				
7782–50–5	Chlorine	Cl_2				x				x		x
128–37–0	BHT:di(*t*-butyl)hydroxytoluene	$CH_3C_6H_2(t\text{-}C_4H_9)_2OH$			x	x		x				
85–68–7	Butyl benzylphthalate	$H_9C_4OCOC_6H_4COOCH_2C_6H_5$			x		x					
7637–07–2	Borontrifluoride	BF_3	x						x	x	x	
1303–86–2	Boron oxide	B_2O_3				x					x	
108–91–8	Cyclo hexylamine	$C_6H_{11}NH_2$		x	x			x				
—	Cyclopoly dimethyl-siloxanes	$(\text{-}Si(CH_3)_2O\text{-})_n$			x		x	x				
106–46–7	*p*-Dichloro benzene	ClC_6H_4Cl			x	x		x				

Key

ac acid

ba base

bt biotoxic

cd condensable

cr corrosive

dp dopant

or organic

ox oxidant

H highly condensable, boiling point > 200 °C

M moderately condensable, 200 °C ≥ T_b ≥ 100 °C

L weakly condensable, 100 °C > T_b (T_b is the boiling point)

Table B.1 *(continued)*

CAS No.	Substance	Rational formula	Contaminant category									
			ac	ba	or	bt	cd			cr	dp	ox
							H	M	L			
100–37–8	Diethyl aminoethanol	$(C_2H_5)_2NCH_2CH_2OH$		x	x			x				
117–84–0	Dioctylphthalate	$C_6H_4(C = OOC_8H_{17})_2$			x		x					
84–66–2	Diethylphthalate	$C_6H_4(C = OOC_2H_5)_2$			x		x					
84–74–2	Dibutylphthalate	$C_6H_4(C = OOC_4H_9)_2$			x		x					
117–81–7	Di(2-ethylhexyl)phthalate	$C_6H_4(C = OOCH_2CH\text{-}C_2H_5C_4H_9)_2$			x		x					
84–61–7	Dicyclohexylphthalate	$C_6H_4(C = OOC_6H_{11})_2$			x		x					
103–23–1	Di(2-ethylhexyl)adipate	$C_4H_8(C = OOCH_2CH\text{-}C_2H_5C_4H_9)_2$			x		x					
84–76–4	Dinonylphthalate	$C_6H_4(C = OOC_9H_{19})_2$			x		x					
84–77–5	Didecylphthalate	$C_6H_4(C = OOC_{10}H_{21})_2$			x		x					
541–02–6	Decamethylcyclopentasiloxane	$(\text{-}Si(CH_3)_2O\text{-})_5$			x		x					
540–97–6	Dodecamethylcyclohexasiloxane	$(\text{-}Si(CH_3)_2O\text{-})_6$			x		x					
104–76–7	2-Ethylhexanol	$CH_3(CH_2)_3C_2H_5CHCH_2OH$			x			x				
75–21–8	Ethylene oxide	C_2H_4O				x			x			
50–00–0	Formaldehyde	$HCHO$			x	x			x			
142–82–5	Heptane	C_7H_{16}			x				x			
66–25–1	Hexanal	$C_6H_{12}O$			x	x			x			
7647–01–0	Hydrochloric acid	HCl	x			x			x	x		
766–39–3	Hydrofluoric acid	HF	x			x			x	x		
10035–10–6	Hydrobromic acid	HBr	x			x			x	x		
7783–06–4	Hydrogen sulfide	H_2S	x			x			x	x		
999–97–3	Hexamethyldisilazane	$(CH_3)_3SiNHSi(CH_3)_3$		x	x			x				
541–05–9	Hexamethylcyclotrisiloxane	$(\text{-}Si(CH_3)_2O\text{-})_3$			x			x				
67–63–0	Isopropyl alcohol	$(CH_3)_2CHOH$			x	x			x			
10102–43–9	Nitrogen monoxide	NO	x			x			x	x		
10102–44–0	Nitrogen dioxide	NO_2	x			x			x	x		

Key

ac	acid
ba	base
bt	biotoxic
cd	condensable
cr	corrosive
dp	dopant
or	organic
ox	oxidant
H	highly condensable, boiling point > 200 °C
M	moderately condensable, 200 °C ≥ T_b ≥ 100 °C
L	weakly condensable, 100 °C > T_b (T_b is the boiling point)

Table B.1 *(continued)*

CAS No.	Substance	Rational formula	Contaminant category									
			ac	ba	or	bt	cd			cr	dp	ox
							H	M	L			
872–50–4	N-Methylpyrrolidone	$-(NCH_3)(C = O)(CH_2)_3-$		x	x			x				
644–31–5	Ozone	O_3				x				x		x
556–67–2	Octamethylcyclotetrasiloxane	$(-Si(CH_3)_2O-)_4$			x			x				
7803–51–2	Phosphine	PH_3				x			x		x	
7446–09–5	Sulfur dioxide	SO_2	x			x			x	x		
75–50–3	Trimethylamine	$(CH_3)_3N$		x	x					x		
121–44–8	Triethylamine	$(C_2H_5)_3N$		x	x				x	x		
45–40–0	Triethyl phosphate	$(C_2H_5O)_3P = O$			x		x				x	
6145–73–9	Tris(2-chloro-1-propyl) phosphate	$(CH_3ClCHCH_2O)_3P = O$			x			x		x	x	
13674–73–9	Tris(1-chloro-2-propyl) phosphate	$((CH_3)(ClCH_2)CH-O-)_3P = O$			x			x		x	x	
78–30–8	Tricresyl phosphate	$(CH_3C_6H_4O)_3P = O$			x		x				x	
126–73–8	Tri(n-butyl) phosphate	$(C_4H_9O)_3P = O$			x		x				x	
20405–30–5	Tris(2,2,2-trichloroethyl) phosphate	$(Cl_3CH_2)_3P = O$			x		x				x	
115–96–8	Tris(chloroethyl) phosphate	$(ClC_2H_4O)_3P = O$			x		x			x	x	
75–59–2	Tetramethylammonium hydroxide	$(CH_3)_4N+OH-$		x	x		x					
95–47–6	Xylene	$(CH_3)_2C_6H_4$			x	x		x				
57–13–6	Urea	$C = O(NH_2)_2$		x								
	Total phthalates	$R_1OCOC_6H_4COOR_2$			x		x					
	Total phosphates	$(RO)_3P = O$			x		x				x	
	Total siloxanes, linear plus cyclic				x		x	x	x			
	Total silicon compounds, organic + inorganic				x		x	x	x			
	Total sulfur		x		x	x	x	x	x	x		
	Total cyclosiloxanes	$(-Si(CH_3)_2O-)_n$			x		x					

Key

ac acid

ba base

bt biotoxic

cd condensable

cr corrosive

dp dopant

or organic

ox oxidant

H highly condensable, boiling point > 200 °C

M moderately condensable, 200 °C ≥ T_b ≥ 100 °C

L weakly condensable, 100 °C > T_b (T_b is the boiling point)

Table B.1 *(continued)*

CAS No.	Substance	Rational formula	Contaminant category									
			ac	**ba**	**or**	**bt**	**cd**			**cr**	**dp**	**ox**
							H	**M**	**L**			
	Total hydrocarbon derivatives	$C_mH_nO_pX_y$ (where X is any other element)			x		x	x	x			
	Total non-methane hydrocarbon derivatives	$C_mH_nO_pX_y$, minus CH_4 (where X is any other element)			x		x	x	x			
	Total unsaturated hydrocarbon derivatives	$C_mH_nO_pX_y$ (where X is any other element, with $n \leq 2m$ and $C = O$)			x		x	x	x			

Key

ac	acid
ba	base
bt	biotoxic
cd	condensable
cr	corrosive
dp	dopant
or	organic
ox	oxidant
H	highly condensable, boiling point > 200 °C
M	moderately condensable, 200 °C ≥ T_b ≥ 100 °C
L	weakly condensable, 100 °C > T_b (T_b is the boiling point)

Annex C

(informative)

Typical methods of measurement

C.1 Principle

C.1.1 This annex is intended to give guidance on the various methods of measurement and analysis of chemical contamination, in consideration of the compounds and the compounds' anticipated concentrations.

C.1.2 The instruments referred to in this annex are not intended to form an exhaustive or comprehensive list, but merely represent examples in relation to the parameters of current technology as listed in Table C.1.

C.2 Method concepts

C.2.1 Methods can be broadly divided into two categories:

- methods of direct analysis, including online or continuous monitors;
- methods where the sample collection is separate or even remote from the analysis of the sample.

C.2.2 Direct analysing instruments provide the possibility of relatively instantaneous measurement. Sample collection instruments, by necessity, provide a value integrated over the sample collection time period.

C.2.3 Sample-collection instruments can be further subdivided into passive sampling or active sampling, which utilizes a form of pump.

C.2.4 Passive diffusive samplers (DIFF) employ a specially prepared surface that selectively collects one or more gas component(s). This method requires extended sampling time periods for low concentration levels of ACC.

C.2.5 Active sampling collects contamination by drawing a determined volume of air through an adsorptive medium. This technique allows sampling of low concentration levels of chemical contamination within a reduced time period. Active sampling instruments can involve complex apparatus, and considerations have to be made for uptake efficiencies and handling.

C.2.6 Typical collection methods may be as follows:

- Sorbent tube (SOR), employing a steel or glass tube filled with a suitable adsorbent, such as Tenax[1], activated charcoal or silica gel.
- Coated filter, impregnated with a suitable chemical reagent that specifically adsorbs the contaminant.
- Impinger (IMP), comprising a single or series of gas-washing bottles filled with deionized water or suitable liquid reagent.

---

[1] Tenax is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of this product.

- Sample bag (SB), for use at high concentrations of air chemical contamination that can be directly sampled by analysis equipment. The SB does not normally employ adsorptive media. For bag sampling, the following factors shall be considered for accurate analysis: stability of sample in sample bag due to factors including diffusion of analytes into or out of the bag; adsorption onto the bag; reactions between analytes; and carryover from previous samples. This method is not as useful for very high boiling point compounds that adsorb onto the polymer bags.
- Canister (CAN) or cylinder sampling, using either evacuated canister that has a valve that is opened at location to be sampled, thus requiring no pump, or a cylinder that is purged using valves at both ends for many volumes, before sealing at one atmosphere, or higher pressures if available from compressed air lines. The surfaces of the sampling vessels shall be appropriately passivated to avoid loss of analytes during the typical delay time between sampling and analysis, at the concentrations of interest.

C.3 Selection of typical sampling devices and analysis methods

C.3.1 Typical sampling methods

These can include, but are not limited to:

- passive diffusive sampler (DIFF);
- filter collector (FC);
- impinger (IMP) set in series filled with suitable solvent, ultrapure water or other trapping fluids that can also contain reagents;
- sample bag (SB), canister or container (CAN) for direct sampling of air;
- sorbent tube (SOR);
- witness wafer (WW) or plate used as sample collector;
- droplet scanning extraction (DSE);
- diffusion tube (DT).

C.3.2 Typical analysis methods

C.3.2.1 Off-line analysis methods

These can include, but are not limited to:

- atomic absorption spectroscopy (AA-S);
- atomic absorption spectroscopy – graphite furnace (AA-GF);
- atomic emission spectroscopy (AES) or, more broadly, optical emission spectrometry (OES);
- vapour phase decomposition – TXRF;
- vapour phase decomposition – ICP-MS;
- drop scan extraction – ICP-MS;
- mass gain detection (MGD) with resonators, including quartz crystal microbalances (QCM), surface acoustic wave (SAW) and similar devices;
- chemiluminescence (CL);
- capillary zone electrophoresis (CZE);

- gas chromatography – flame ionization detector (GC-FID);
- gas chromatography – mass spectroscopy (GC-MS);
- ion chromatography (IC);
- inductively coupled plasma – mass spectroscopy (ICP-MS);
- infrared spectroscopy (IR);
- mass spectroscopy (MS);
- ultraviolet spectroscopy (UVS);
- Fourier transform infrared spectroscopy (FTIR);
- total reflection X-ray fluorescence spectroscopy (TXRF);
- vapour phase decomposition – total reflection X-ray fluorescence (VPD-TXRF);
- time of flight – secondary ion mass spectrometry (TOF-SIMS);
- atmospheric pressure ionization – mass spectroscopy (API-MS).

C.3.2.2 Online monitors

These can include, but are not limited to:

- colorimetric detection on chemically impregnated paper reel-type analyser (CPR);
- ion mobility spectroscopy (IMS);
- mass gain detector (MGD) (of condensed organic build-up) using different types of piezoelectric resonators;
- portable gas chromatograph equipment (PGC);
- sensors of electrochemical cell type (ECS);
- ion chromatography monitoring system (ICS);
- chemiluminescence monitoring system (CLS);
- fluoride ion monitor (FIM);
- surface acoustic wave (SAW);
- quartz crystal microbalance (QCM);
- cavity ringdown spectroscopy (CRDS).

The user should note the detection limits and remain within them.

Table C.1 illustrates a selection matrix for examples of these measurement methods.

NOTE The applicable analysis method for a given contaminant concentration is dependent on sampling rate and duration.

Table C.1 — Selection matrix illustrating examples of measurement methods in relation to expected air chemical concentrations

ISO-ACC Level N 10^n g/m^3	**Contaminant category**						
	Acid	**Base**	**Organics**	**Biotoxics**	**Condensables**	**Corrosives**	**Dopants**
0	IMP, IC, UVS, DIFF, ECS	IMP, IC, UVS, DIFF, ECS	DIFF, SOR, SB, GC-FID, GC-MS, IR	IMP, IC, UVS, SB, DIFF, SOR, GC-FID, GC-MS, IR, CPR, ECS	SOR, GC-FID, GC-MS, IR	IMP, IC, UVS, DIFF, SOR, GC-FID, GC-MS, IR, ECS	SOR, GC-FID, GC-MS, IR, IMP, IC, ICP-MS, GF-AAS, UVS
−1							
−2							
−3							
−4	IMP, IC, UVS, CLS, IR, CPR, DIFF	IMP, IC, UVS, CLS, IR, CPR, DIFF		IMP, IC, UVS, CLS, IR, CPR, DIFF		IMP, IC, UVS, CLS, IR, CPR, DIFF	
−5							
−6	IMP, IC, UVS, IR, CLS, CPR, DIFF	IMP, IC, UVS, IR, CLS, CPR, DIFF	SOR, GC-FID, GC-MS, IMS	IMP, IC, UVS, IR, CLS, CPR, DIFF, SOR, GC-MS, ICP-MS	SOR, GC-FID, GC-MS, MGD	IMP, IC, UVS, IR, CLS, CPR, DIFF, SOR, GC-FID, GC-MS	IC, SOR, GC-MS, IMP, ICP, MS
−7							
−8	IMP, IC	IMP, IC, IMS		IMP, IC, SOR, GC-MS, ICP-MS		IMP, IC, SOR, GC-MS	
−9	IMP, IC, CZE, IMS		SOR, GC-MS	IMP, IC, CZE, IMS, SOR, GC-MS, ICP-MS	SOR, GC-MS	IMP, IC, CZE, IMS, SOR, GC-MS	
−10	IMP, CZE	IMP, IC, CZE		IMP, CZE, SOR, GC-MS, ICP-MS,		IMP, CZE, SOR, GC-MS	
−11							
−12							
NOTE Methods corresponding to these abbreviated terms are listed in C.3.							

Annex D
(informative)

Consideration of specific requirements for separative devices

D.1 Principle

D.1.1 This annex is intended to give guidance for separative devices that, by their nature and application, embody special design features that require consideration when establishing level requirements for air chemical contamination. Details of the various types and applications of such devices are given in ISO 14644-7.

D.1.2 Consideration should be given to the possibility of contamination from a separative device itself.

In some cases, where no direct measurement of the ACC is possible (e.g. in a volume too small), measurements of the SCC are the only possible way of characterizing the degree of cleanliness.

NOTE The relation between SCC (expressed in concentration/unit of area) and ACC (expressed in concentration/unit of volume of air) is generally not known. In cases where the relationship between the measured SCC and the ACC has been determined experimentally (or by another way) and is known, SCC results can be used to calculate units of ACC to establish the levels for testing and monitoring.

D.2 Specific considerations

D.2.1 The design of the barrier technology employed can restrict choices in the method of sampling and measuring ACC. The optimum testing method should be established and agreed between customer and supplier, and provisions made as necessary concerning the design of the device for any fittings or fixings required for testing purposes.

D.2.2 The materials used in the construction of the device should be considered in conjunction with Annex A of this document. Many such devices employ flexible screens or barriers in conjunction with flexible gloves, bags or manipulative devices. These materials and their potential sources of chemical contamination should be considered.

D.2.3 Any retrofitted materials or extensions to the device and their potential sources of chemical contamination should be considered.

D.2.4 Where the product is of particular concern, it may be decided to verify the performance of the device by a process of measurement and analysis of the surface chemical cleanliness of the product (see D.1.2).

Where verification is performed by evaluating SCC, the time period in which the product remains in the device can be a major influencing factor and should be considered.

D.2.5 Pumped sampling of small enclosure using a feed gas to make up for the gas sampled can significantly dilute the air chemical contaminant's concentration at the start of sampling, especially if the sampling volume is much larger than the enclosure. This can lead to artificially low values for the concentration calculated based on sampling volume versus the actual concentration prior to sampling.

D.2.6 While the ACC tests in this document are for cleanroom air, similar principles can be applied to other devices, enclosures and potentially environments purged with gases, including clean dry air, nitrogen, inert gases or gas mixtures. Similar concepts can also be applied to pressurized sampling locations, but these are not covered in this document.

D.2.7 Specific industries can have specific recommended test methods or specifications, or guidelines for control of air chemical contamination. See the Bibliography.

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