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**Cleanrooms and associated controlled environments —**

**Part 8:  
Classification of airborne molecular  
contamination**

*Salles propres et environnements maîtrisés apparentés —*

*Partie 8: Classification de la contamination moléculaire aéroportée*



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## 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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 14644-8 was prepared by Technical Committee ISO/TC 209, *Cleanrooms and associated controlled environments*.

ISO 14644 consists of the following parts, under the general title *Cleanrooms and associated controlled environments*:

- *Part 1: Classification of air cleanliness*
- *Part 2: Specifications for testing and monitoring to prove continued compliance with ISO 14644-1*
- *Part 3: Test methods*
- *Part 4: Design, construction and start-up*
- *Part 5: Operations*
- *Part 6: Vocabulary*
- *Part 7: Separative enclosures (clean air hoods, gloveboxes, isolators, mini-environments)*
- *Part 8: Classification of airborne molecular contamination*

## Introduction

Cleanrooms and associated controlled environments provide for the control of airborne particulate contamination to levels appropriate for accomplishing contamination-sensitive activities. Products and processes that benefit from the control of airborne contamination include those in such industries as aerospace, microelectronics, pharmaceuticals, medical devices, food and healthcare.

In some of these industries, the product or process can be sensitive to, or can be destroyed by, molecular contamination resulting from airborne molecules that are present due to external, process, or otherwise generated sources.

Within this part of ISO 14644, the presence of airborne molecules is expressed as airborne molecular contamination (AMC). Molecular contamination is a three-step event. The first step is *generation* due to external sources, process leakage or construction or human material outgassing. The second step is *transport* as AMC. The third step is *sorption* on the sensitive surface, which can be quantified as a surface molecular contamination (SMC).

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 AMC. Thus, for these two steps, not only the AMC 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, AMC has been chosen for the classification.

This part of ISO 14644 assigns ISO classification levels to be used to specify the limits of AMC concentrations within a cleanroom and associated controlled environment, where the product or process is deemed to be at risk from such contamination.

For classification purposes, this part of ISO 14644 is limited to a designated range of AMC concentrations and provides standard protocols for specifying such concentrations with regard to chemical compounds, methods of test and analysis, and time weighted factors.

Informative annexes are contained in this part of ISO 14644 covering

- 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 enclosures: Annex D.

This part of ISO 14644 is one of a series of standards concerned with cleanrooms and contamination control. Many factors besides AMC need to be considered in the design, specification, operation and control of cleanrooms and other controlled environments. These are covered in some detail in other parts of the International Standards prepared by ISO/TC 209. In particular, attention is drawn to ISO 14698 (all parts)<sup>[4]</sup>. In some circumstances, relevant regulatory agencies can impose supplementary policies or restrictions. In such situations, appropriate adaptations of this part of ISO 14644 may be required.



# Cleanrooms and associated controlled environments —

## Part 8:

## Classification of airborne molecular contamination

### 1 Scope

This part of ISO 14644 covers the classification of airborne molecular contamination (AMC) 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 within the specification for classification.

This part of ISO 14644 currently considers only concentrations of AMC between  $10^0$  and  $10^{-12}$  g/m<sup>3</sup> under cleanroom operational conditions.

This part of ISO 14644 is not relevant for application in those industries, processes or production, where the presence of airborne molecular substances is not considered a risk to the product or process.

It is not the intention of this part of ISO 14644 to describe the nature of airborne molecular contaminants.

This part of ISO 14644 does not give a classification of surface molecular contamination.

### 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14644-6, *Cleanrooms and associated controlled environments — Part 6: Vocabulary*

### 3 Terms and definitions

For the purposes of this part of ISO 14644, the terms and definitions given in ISO 14644-6 and the following apply.

#### 3.1 General

##### 3.1.1

##### **molecular contamination**

molecular (chemical, non-particulate) substances that can have a deleterious effect on the product, process or equipment

**3.1.2**

**airborne molecular contamination**

**AMC**

presence in the atmosphere of a cleanroom or controlled environment of molecular (chemical, non-particulate) substances in the gaseous or vapour state that may have a deleterious effect on the product, process or equipment in the cleanroom or controlled environment

NOTE This definition does not include macromolecules of biological origin that, which are judged to be particles.

**3.1.3**

**surface molecular contamination**

**SMC**

presence of molecular (chemical, non-particulate) substances in the sorbed state that may have a deleterious effect on the product, or surface of interest, in the cleanroom or controlled environment

**3.1.4**

**contaminant category**

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

**3.1.5**

**outgassing**

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

**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**

substance based on carbon and also containing hydrogen, with or without oxygen, nitrogen or other elements

**3.2.8****oxidant**

substance that, upon deposition onto a surface or product of interest, results in the formation of an oxide ( $O_2/O_3$ ) or participates in a redox reaction

**4 Classification****4.1 General**

Classification shall be specified by use of a classification descriptor as described in 4.2. This descriptor is designated "ISO-AMC" and specifies the maximum total airborne molecular concentration permitted for a contaminant category, an individual substances or a group of substances.

**4.2 ISO-AMC descriptor format**

The designation of AMC classification of a cleanroom or associated controlled environment shall be by means of an ISO-AMC descriptor(s) appropriate for the contaminant category(ies), substances or group(s) of substances under consideration.

The ISO-AMC descriptor is expressed in the format:

ISO-AMC Class  $N(X)$

where

$N$  is the ISO-AMC class, 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 the smallest permitted increment of  $N$ ;

$$N = \log_{10}[c_X];$$

and

$X$  is a contaminant category (interaction with product) 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 substances.

**EXAMPLE 1** To express an airborne concentration of ammonia of  $10^{-6}$  g/m<sup>3</sup>, the designation is "ISO-AMC Class -6 (NH<sub>3</sub>)".

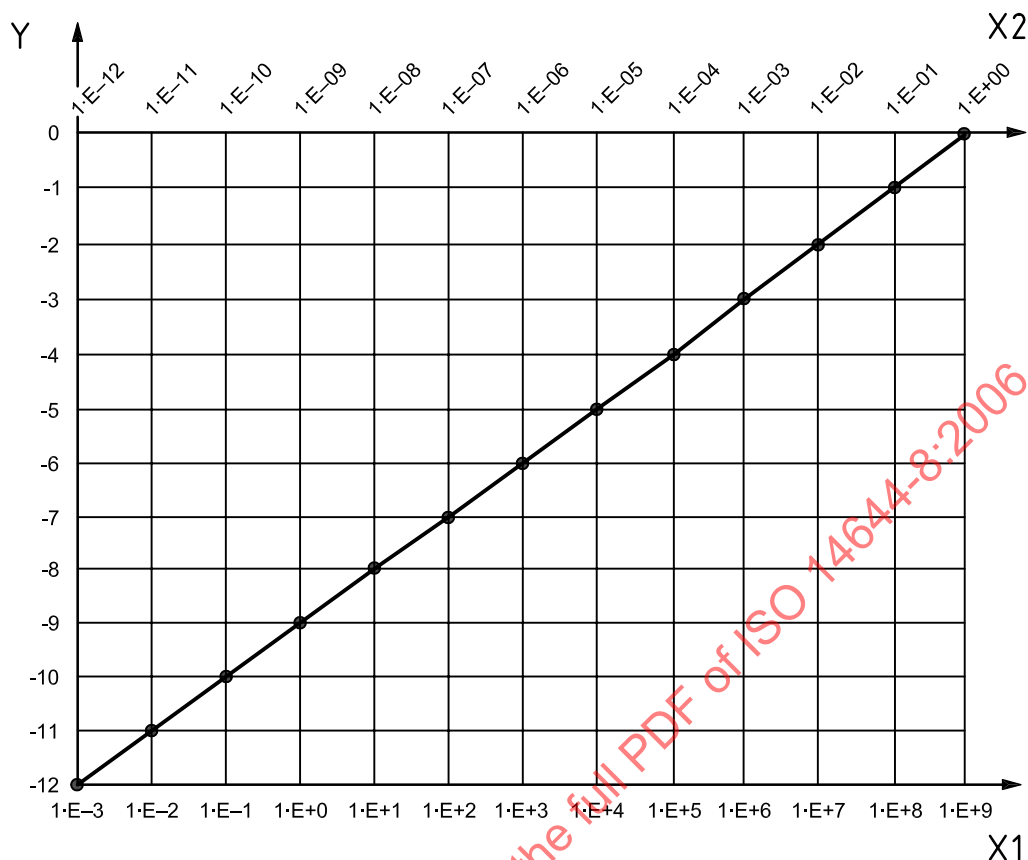
EXAMPLE 2 To express a total airborne concentration of organics, of  $10^{-4}$  g/m<sup>3</sup>, the designation is "ISO-AMC Class –4 (or)".

EXAMPLE 3 To express a total airborne concentration of condensables of  $5 \cdot 10^{-8}$  g/m<sup>3</sup>, the designation is "ISO-AMC Class –7,3 (cd)".

Table 1 and Figure 1 further illustrate the ISO-AMC classification as a function of contaminant concentration.

Table 1 — ISO-AMC classes

| ISO-AMC Class | Concentration<br>g/m <sup>3</sup> | Concentration<br>µg/m <sup>3</sup> | Concentration<br>ng/m <sup>3</sup> |
|---------------|-----------------------------------|------------------------------------|------------------------------------|
| 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

X1 concentration (ng/m<sup>3</sup>)

X2 concentration (g/m<sup>3</sup>)

Y ISO-AMC class

Figure 1 — ISO-AMC classes as a function of concentration

## 5 Demonstration of compliance

### 5.1 Principle

Compliance with classification (ISO-AMC class) requirements 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 supplier.

It is recommended to carry out replicate sampling at the locations agreed.

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

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-AMC class(es).

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 part of ISO 14644, i.e. ISO 14644-8:2006;
- 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-AMC class or classes, the specified test method(s) and, where applicable, the substances, substance group or category(ies), the elapsed time period and the designated particulate class;
- 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 airborne molecular 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 AMC 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 AMC or which contribute it and which should be taken into account.

- a) First, establish if the product or process is affected by molecular contamination, as in many industries consideration of molecular 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-AMC descriptor in accordance with 4.2.
- d) Establish sources of molecular 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 molecular contamination generated per A.2 d) to achieve the ISO-AMC class 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 prevailing winds, proximity of contaminating sources, etc., molecular contamination concentrations can be minimized by selective positioning of the fresh-air intake(s) to the facility.

## **A.4 Construction materials**

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

Examples of suitable cleanroom construction materials are given in Annex E of ISO 14644-4:2001<sup>[1]</sup>.

**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.

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

## **A.5 Cross contamination**

**A.5.1** Molecular contamination can occur by migration between services, partial pressure change transfer systems and/or 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 Annex A of ISO 14644-4:2001<sup>[1]</sup> and in ISO 14644-7<sup>[3]</sup>.

## **A.6 Operation and maintenance**

Molecular contamination sources from facility operation and maintenance can be prevented or minimized by scheduling disciplines, over and above those stated within ISO 14644-5<sup>[2]</sup>, typically as below:

- facemasks or ventilated/filtered helmets worn during working process;
- qualified chemical analysis of garments and packaging materials thereof;
- qualified chemical analysis of cleaning liquids and other cleaning materials;
- qualified chemical analysis of any product packaging materials;

- operational disciplines to minimize molecular 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 molecular contamination.

## A.7 Personnel

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

- use of cosmetics, perfumes and hair products;
- practice of smoking;
- use of medication;
- consumption of certain foods;
- 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 relevant clauses of ISO 14644-5<sup>[2]</sup>.

## A.8 Other sources

These may include

- consumables;
- equipment;
- chemicals.

## A.9 Air treatment processes for the abatement of the AMCs

Some processes are available in order to control or reduce the concentration of specific AMC categories. These include

- sorption on suitable materials (activated carbon, treated activated carbon, ion exchange resin, zeolites, etc.);
- photoelectron ionization and electrostatic ion removal;
- catalytic photooxidation.

## **Annex B** (informative)

### **Typical contaminants**

#### **B.1 Principle**

The categorization of airborne molecular 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 likewise categorize the chemicals or substances that are specific to their concern in application.

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

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**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 <sup>a</sup> |    |    |    |    |   |   |    |    |    |
|------------|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|----|----|----|----|---|---|----|----|----|
|            |                                        |                                                                                                                                               | ac                                | ba | or | bt | cd |   |   | cr | dp | ox |
|            |                                        |                                                                                                                                               |                                   |    |    |    | H  | M | L |    |    |    |
| 7664-41-7  | Ammonia                                | NH <sub>3</sub>                                                                                                                               |                                   | x  |    | x  |    |   | x | x  |    |    |
| 141-43-5   | 2-Aminoethylalcohol                    | CH <sub>3</sub> NH <sub>2</sub> CH <sub>2</sub> OH                                                                                            |                                   | x  | x  |    |    |   | x |    |    |    |
| 35320-23-1 | 2-Aminopropanol                        | CH <sub>3</sub> NH <sub>2</sub> C <sub>2</sub> H <sub>4</sub> OH                                                                              |                                   | x  | x  |    |    |   | x |    |    |    |
| 128-37-0   | BHT:di( <i>t</i> -butyl)hydroxytoluene | H <sub>3</sub> CC <sub>6</sub> H <sub>3</sub> ( <i>t</i> -C <sub>4</sub> H <sub>9</sub> ) <sub>2</sub> OH                                     |                                   |    | x  | x  |    | x |   |    |    |    |
| 85-68-7    | Butylbenzyl phthalate                  | H <sub>9</sub> C <sub>4</sub> OCOC <sub>6</sub> H <sub>4</sub> COOCH <sub>2</sub> C <sub>6</sub> H <sub>5</sub>                               |                                   |    | x  |    | x  |   |   |    |    |    |
| 7637-07-2  | Boron trifluoride                      | BF <sub>3</sub>                                                                                                                               | x                                 |    |    |    |    | x |   |    | x  |    |
| 1303-86-2  | Boron oxide                            | B <sub>2</sub> O <sub>3</sub>                                                                                                                 |                                   |    |    | x  |    |   |   |    | x  |    |
| 108-91-8   | Cyclohexylamine                        | C <sub>6</sub> H <sub>11</sub> NH <sub>2</sub>                                                                                                |                                   | x  | x  |    |    | x |   |    |    |    |
| —          | Cyclopolydimethylsiloxanes             | (-Si(CH <sub>3</sub> ) <sub>2</sub> O-) <sub>n</sub>                                                                                          |                                   |    | x  |    | x  |   |   |    |    |    |
| 106-46-7   | <i>p</i> -Dichlorobenzene              | ClC <sub>6</sub> H <sub>4</sub> Cl                                                                                                            |                                   |    | x  | x  |    | x |   |    |    |    |
| 100-37-8   | Diethylaminoethanol                    | (C <sub>2</sub> H <sub>5</sub> ) <sub>2</sub> NC <sub>2</sub> H <sub>5</sub> OH                                                               |                                   | x  | x  |    |    |   | x |    |    |    |
| 117-84-0   | Dioctyl phthalate                      | C <sub>6</sub> H <sub>4</sub> (C=OOC <sub>8</sub> H <sub>15</sub> ) <sub>2</sub>                                                              |                                   |    | x  |    | x  |   |   |    |    |    |
| 84-66-2    | Diethyl phthalate                      | C <sub>6</sub> H <sub>4</sub> (C=OOC <sub>2</sub> H <sub>5</sub> ) <sub>2</sub>                                                               |                                   |    | x  |    | x  |   |   |    |    |    |
| 84-74-2    | Dibutyl phthalate                      | C <sub>6</sub> H <sub>4</sub> (C=OOC <sub>4</sub> H <sub>9</sub> ) <sub>2</sub>                                                               |                                   |    | x  |    | x  |   |   |    |    |    |
| 117-81-7   | Di(2-ethylhexyl) phthalate             | C <sub>6</sub> H <sub>4</sub> (C=OOC <sub>2</sub> H <sub>5</sub> CHC <sub>2</sub> H <sub>5</sub> C <sub>4</sub> H <sub>9</sub> ) <sub>2</sub> |                                   |    | x  |    | x  |   |   |    |    |    |
| 84-61-7    | Dicyclohexyl phthalate                 | C <sub>6</sub> H <sub>4</sub> (C=OOC <sub>6</sub> H <sub>11</sub> ) <sub>2</sub>                                                              |                                   |    | x  |    | x  |   |   |    |    |    |
| 103-23-1   | Di(2-ethylhexyl) adipate               | C <sub>4</sub> H <sub>8</sub> (C=OOC <sub>2</sub> H <sub>5</sub> CHC <sub>2</sub> H <sub>5</sub> C <sub>4</sub> H <sub>9</sub> ) <sub>2</sub> |                                   |    | x  |    | x  |   |   |    |    |    |
| 84-76-4    | Dinonyl phthalate                      | C <sub>6</sub> H <sub>4</sub> (C=OOC <sub>9</sub> H <sub>19</sub> ) <sub>2</sub>                                                              |                                   |    | x  |    | x  |   |   |    |    |    |
| 84-77-5    | Didecyl phthalate                      | C <sub>6</sub> H <sub>4</sub> (C=OOC <sub>10</sub> H <sub>21</sub> ) <sub>2</sub>                                                             |                                   |    | x  |    | x  |   |   |    |    |    |
| 541-02-6   | Decamethylcyclopentasiloxane           | (-Si(CH <sub>3</sub> ) <sub>2</sub> O-) <sub>5</sub>                                                                                          |                                   |    | x  |    | x  |   |   |    |    |    |
| 540-97-6   | Dodecamethylcyclohexasiloxane          | (-Si(CH <sub>3</sub> ) <sub>2</sub> O-) <sub>6</sub>                                                                                          |                                   |    | x  |    | x  |   |   |    |    |    |
| 141-43-5   | Ethanolamine                           | H <sub>2</sub> NCH <sub>2</sub> CH <sub>2</sub> OH                                                                                            |                                   | x  | x  |    |    |   | x |    |    |    |
| 104-76-7   | 2-Ethylhexanol                         | CH <sub>3</sub> (CH <sub>2</sub> ) <sub>3</sub> C <sub>2</sub> H <sub>5</sub> CHCH <sub>2</sub> OH                                            |                                   |    | x  |    |    | x |   |    |    |    |
| 50-00-0    | Formaldehyde                           | HCHO                                                                                                                                          |                                   |    | x  | x  |    |   | x |    |    |    |
| 142-82-5   | Heptane                                | C <sub>7</sub> H <sub>16</sub>                                                                                                                |                                   |    | x  |    |    |   | x |    |    |    |
| 66-25-1    | Hexanal                                | HC <sub>6</sub> H <sub>12</sub> 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  |    |    |
| 7783-06-4  | Hydrogen sulfide                       | H <sub>2</sub> S                                                                                                                              | x                                 |    |    | x  |    |   | x | x  |    |    |
| 999-97-3   | Hexamethyldisilazane                   | (CH <sub>3</sub> ) <sub>3</sub> SiNHSi(CH <sub>3</sub> ) <sub>3</sub>                                                                         |                                   |    | x  |    |    | x |   |    |    |    |
| 541-05-9   | Hexamethylcyclotrisiloxane             | (-Si(CH <sub>3</sub> ) <sub>2</sub> O-) <sub>3</sub>                                                                                          |                                   |    | x  |    |    | x |   |    |    |    |
| 67-63-0    | Isopropyl alcohol                      | (CH <sub>3</sub> ) <sub>2</sub> CHOH                                                                                                          |                                   |    | x  | x  |    |   | x |    |    |    |

Table B.1 (continued)

| CAS No.    | Substance                                 | Rational formula                                                                                                       | Contaminant category <sup>a</sup> |    |    |    |    |   |   |    |    |    |
|------------|-------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-----------------------------------|----|----|----|----|---|---|----|----|----|
|            |                                           |                                                                                                                        | ac                                | ba | or | bt | cd |   |   | cr | dp | ox |
|            |                                           |                                                                                                                        |                                   |    |    |    | H  | M | L |    |    |    |
| 141-43-5   | Monoethanolamine                          | $\text{H}_2\text{NC}_2\text{H}_5\text{OH}$                                                                             |                                   | x  | x  |    |    |   | x |    |    |    |
| 10102-43-9 | Nitrogen monoxide                         | NO                                                                                                                     | x                                 |    |    | x  |    |   | x | x  |    |    |
| 10102-44-0 | Nitrogen dioxide                          | $\text{NO}_2$                                                                                                          | x                                 |    |    | x  |    |   | x | x  |    |    |
| 872-50-4   | N-Methylpyrrolidone                       | $-\text{CHNCH}_3\text{CHCH}_2\text{CO}-$                                                                               |                                   | x  | x  |    |    | x |   |    |    |    |
| 644-31-5   | Ozone                                     | $\text{O}_3$                                                                                                           |                                   |    |    | x  |    |   |   | x  |    | x  |
| 556-67-2   | Octamethylcyclotetrasiloxane              | $(-\text{Si}(\text{CH}_3)_2\text{O}-)_4$                                                                               |                                   |    | x  |    |    | x |   |    |    |    |
| 7803-51-2  | Phosphine                                 | $\text{PH}_3$                                                                                                          |                                   |    |    | x  |    |   | x |    | x  |    |
| 7446-09-5  | Sulfur dioxide                            | $\text{SO}_2$                                                                                                          |                                   |    |    | x  |    |   | x |    |    |    |
| 121-44-8   | Triethylamine                             | $(\text{C}_2\text{H}_5)_3\text{N}$                                                                                     |                                   | x  | x  |    |    |   | x |    |    |    |
| 45-40-0    | Triethyl phosphate                        | $(\text{C}_2\text{H}_5\text{O})_3\text{P}=\text{O}$                                                                    |                                   |    | x  |    | x  |   |   |    | x  |    |
| 6145-73-9  | Tris(2-chloro-1-propyl) phosphate         | $(\text{CH}_3\text{ClCHCH}_2\text{O})_3\text{P}=\text{O}$                                                              |                                   |    | x  |    |    | x |   | x  |    |    |
| 13674-73-9 | Tris(1-chloro-2-propyl) phosphate         | $((\text{CH}_3)(\text{ClCH}_2)\text{CH-O})_3\text{P}=\text{O}$                                                         |                                   |    | x  |    |    | x |   | x  |    |    |
| 78-30-8    | Tricresyl phosphate                       | $(\text{CH}_3\text{C}_6\text{H}_4\text{O})_3\text{P}=\text{O}$                                                         |                                   |    | x  |    | x  |   |   |    | x  |    |
| 126-73-8   | Tri(n-butyl) phosphate                    | $(\text{C}_4\text{H}_9\text{O})_3\text{P}=\text{O}$                                                                    |                                   |    | x  |    | x  |   |   |    | x  |    |
| 306-52-5   | Trichloroethyl phosphate                  | $(\text{ClC}_2\text{H}_4\text{O})_3\text{P}=\text{O}$                                                                  |                                   |    | x  |    | x  |   |   |    | x  |    |
| 75-59-2    | Tetramethylammonium hydroxide             | $(\text{CH}_3)_4\text{N}^+\text{OH}^-$                                                                                 |                                   | x  | x  |    | x  |   |   |    |    |    |
| 95-47-6    | Xylene                                    | $(\text{CH}_3)_2\text{C}_6\text{H}_4$                                                                                  |                                   |    | x  | x  |    | x |   |    |    |    |
|            | Total phthalates                          | $\text{R}_1\text{OCOC}_6\text{H}_4\text{COOR}_2$                                                                       |                                   |    | x  |    | x  |   |   |    |    |    |
|            | Total phosphates                          | $(\text{RO})_3\text{P}=\text{O}$                                                                                       |                                   |    | x  |    | x  |   |   |    | x  |    |
|            | Total cyclosiloxanes                      | $(-\text{Si}(\text{CH}_3)_2\text{O}-)_n$                                                                               |                                   |    | x  |    | x  |   |   |    |    |    |
|            | Total hydrocarbon derivatives             | $\text{C}_m\text{H}_n\text{O}_p\text{X}_y$ (where X is any other element)                                              |                                   |    | x  |    | x  | x | x |    |    |    |
|            | Total non-methane hydrocarbon derivatives | $\text{C}_m\text{H}_n\text{O}_p\text{X}_y$ , minus $\text{CH}_4$ (where X is any other element)                        |                                   |    | x  |    | x  | x | x |    |    |    |
|            | Total unsaturated hydrocarbon derivatives | $\text{C}_m\text{H}_n\text{O}_p\text{X}_y$ (where X is any other element, with $n \leq 2m$ and $\text{C} = \text{O}$ ) |                                   |    | x  |    | x  | x | x |    |    |    |

<sup>a</sup> ac : acid; ba : base; bt : biotoxic; cd : condensable; cr : corrosive; dp : dopant; or : organic; ox : oxidant.

H : Highly condensable, boiling point  $> 200\text{ }^\circ\text{C}$ ;

M; Moderately condensable,  $200\text{ }^\circ\text{C} \geq T_b \geq 100\text{ }^\circ\text{C}$ ;

L : weakly condensable,  $100\text{ }^\circ\text{C} > T_b$  ( $T_b$  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 molecular 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;
- methods where the sample collection is separate and even remote from the analysis of the sample.

**C.2.2** Direct analysing instruments provide the possibility of relative 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 AMCs.

**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 AMCs within a reduced time period. Active sampling instruments may involve complex apparatus and considerations have to be made for uptake efficiencies and handling.

**C.2.6** Typical collection methods may be

- sorbent tube (SOR), employing a steel or glass tube filled with a suitable adsorbent, e.g. Tenax<sup>1)</sup>, activated charcoal, silica gel, etc.;
- 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 de-ionized water or suitable liquid reagent;
- sample bag (SB), for use at high concentrations of AMCs that can be directly sampled by analysis equipment. The SB does not normally employ adsorptive media.

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1) Tenax is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 14644 and does not constitute an endorsement by ISO of this product.

### C.3 Selection of typical sampling devices and analysis methods

#### C.3.1 Typical sampling methods

These may include, but are not limited to

- passive diffusive sampler (DIFF);
- filter collector (FC);
- impinger set in series filled with suitable solvent (IMP);
- sample bag, canister/container, for direct collection of cleanroom air (SB);
- sorbent tube (SOR);
- witness wafer or plate used as sample collector (WW);
- droplet scanning extraction (DSE);
- diffusion tube (DT).

#### C.3.2 Typical analysis methods

##### C.3.2.1 Off-line analysis methods

These may include, but are not limited to

- atomic absorption spectroscopy (AA-S);
- atomic absorption spectroscopy – graphite furnace (AA-GF);
- atomic emission spectroscopy (AES);
- 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);
- infra-red spectroscopy (IR);
- mass spectroscopy (MS);
- ultra-violet spectroscopy (UVS);
- Fourier Transform infra-red spectroscopy (FTIR);
- total reflection X-ray fluorescence spectroscopy (TXRF);