INTERNATIONAL STANDARD

ISO 17621

First edition
2015-09-15

Workplace atmospheres — Short term detector tube measurement systems — Requirements and test methods

Air des lieux de travail — Systèmes de mesurage par tube détecteur à court terme — Exigences et méthodes d'essai

Reference number
ISO 17621:2015(E)

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 on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 146, *Air quality*, Subcommittee SC 2, *Workplaces atmospheres*.

Introduction

Many short-term detector tube measurement systems consist of a (length-of-stain) detector tube connected to an associated detector tube pump. When workplace air containing a particular chemical agent is drawn through the detector tube, a colour change takes place corresponding to the concentration.

Such short-term detector tube measurement systems have many applications. This International Standard refers to detector tubes used for workplace air monitoring. These detector tubes can be used for measurement tasks such as follows:

— determination of the presence or absence of an analyte;

— finding the approximate range of concentration;

— determination of the efficiency of control measurements;

— determination of emission sources and emission changes in time;

— determination of compliance with ceiling or short-term limit values, as long as the device covers the reference time period and the precision requirements for the measurement.

To cover the possible range of concentration that can be encountered in the workplace, a combination of two or more measurements using detector tubes with restricted but complementary and overlapping measuring ranges can also be used.

This International Standard will enable the manufacturers, test houses, certification bodies, and the users to adopt a consistent approach to the assessment of performance of short-term detector tube measurement systems.

Workplace atmospheres — Short term detector tube measurement systems — Requirements and test methods

1 Scope

This International Standard specifies requirements and test methods under prescribed laboratory conditions for length-of-stain detector tubes and their associated pump (detector tube measurement system) used for short-term measurements of the concentration of specified chemical agents in workplace air.

This International Standard is not applicable to measurements made to demonstrate compliance with long-term limit values to personal exposure with a reference period of more than 15 min.

2 Normative references

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

ISO 6141, *Gas analysis – Requirements for certificates for calibration gases and gas mixtures*

ISO 6142, *Gas analysis — Preparation of calibration gas mixtures — Gravimetric method*

ISO 6143, *Gas analysis — Comparison methods for determining and checking the composition of calibration gas mixtures*

ISO 6144, *Gas analysis — Preparation of calibration gas mixtures — Static volumetric method*

ISO 6145-1, *Gas analysis — Preparation of calibration gas mixtures using dynamic volumetric methods — Part 1: Methods of calibration*

ISO 6145-4, *Gas analysis — Preparation of calibration gas mixtures using dynamic volumetric methods — Part 4: Continuous syringe injection method*

ISO 6145-6, *Gas analysis — Preparation of calibration gas mixtures using dynamic volumetric methods — Part 6: Critical orifices*

ISO 6145-10, *Gas analysis — Preparation of calibration gas mixtures using dynamic volumetric methods — Part 10: Permeation method*

ISO 9169, *Air quality — Definition and determination of performance characteristics of an automatic measuring system*

IEC 60079-0, *Explosive atmospheres – Part 0: Equipment – General requirements*

3 Terms and definitions

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

3.1
(length-of-stain) detector tube
transparent tube containing chemical reagents in which a colour change is produced when an air sample is drawn through it

Note 1 to entry: The length of the stain produced, relative to a graduated scale, provides a measure of the concentration of a specific chemical agent in air.

Note 2 to entry: Some detector tubes are designed to work in two stages. In that case, a pre-tube and an analyser tube are used in series to produce one measurement.

[SOURCE: EN 1540:2011, 3.2.4, modified — "glass tube" replaced by "transparent tube" and Note 2 to entry added.]

3.2
short-term detector tube
detector tube category that provides a means of obtaining a rapid measurement of the concentration of a specified chemical agent in air

Note 1 to entry: The averaging period of the measurement can vary from a few seconds up to about 15 min depending on the measurement system and the target concentration of the analyte.

3.3
detector tube pump
device for pulling air through a detector tube

Note 1 to entry: Detector tube pumps can be manually or mechanically driven stroke pumps or piston pumps.

Note 2 to entry: Other types of detector tube pumps which are not dealt with in this International Standard are electrically driven continuous pumps, which can emulate stroke pumps.

3.4
detector tube measurement system
complete measurement system consisting of a detector tube and a detector tube pump

3.5
chemical agent
chemical element or compound on its own or admixed as it occurs in the natural state or as produced, used, or released, including release as waste, by any work activity, whether or not produced intentionally and whether or not placed on the market

[SOURCE: EN 1540:2011, 2.1.2]

3.6
(detector tube) measuring range
scale of concentration which is marked on the detector tube

Note 1 to entry: By increasing or decreasing the number of sampling strokes, the measuring range can be shifted lower or higher.

3.7
specified (detector tube) measuring range
concentration range for which the measurement uncertainty of the detector tube is below a given value

3.8
interferent
constituent of the (air) sample having an adverse effect on the accuracy of the measurement

[SOURCE: EN 1540:2011, 4.5]

3.9
test gas
gas of sufficient stability and homogeneity whose composition is properly established for use to verify the response of a measuring instrument or to validate a measurement method

3.10
expanded uncertainty
quantity defining an interval about a result of a measurement, expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

[SOURCE: EN 1540:2011, 5.2.6]

3.11
reference period
specified period of time for which the occupational exposure limit value of a chemical or biological agent applies

Note 1 to entry: The reference period is usually 8 h for long term measurements and 15 min for short-term measurements.

[SOURCE: EN 1540:2011, 2.4.7]

4 Requirements

4.1 General

A functional detector tube measurement system consists of a detector tube and a detector tube pump. All components of the detector tube measurement system should be calibrated by the same manufacturer.

Materials used for the construction of the detector tube pump should be such that it remains functional for a period of at least three years when used in accordance with the manufacturer's instructions.

It is the user's primary responsibility to choose appropriate procedures or devices that meet the requirements of this International Standard. One way of doing this is to obtain information or confirmation from the manufacturer.

It is the manufacturer's primary responsibility to ensure that detector tubes meet the performance requirements under the test conditions specified in 5.6.

For workplace air measurements, additional requirements are to be met. For example, see EN 482.[4]

For the specified measuring range, the expanded uncertainty for a detector tube measurement system shall be ≤50 % (see EN 482[4]).

4.2 Detector tubes

4.2.1 Specified measuring range

The manufacturer shall provide the specified measuring range in which the detector tube complies with the requirement for the expanded uncertainty given in 4.1.

4.2.2 Scale

The scale shall have a minimum of three calibration marks perpendicular to the axis of the detector tube and shall be marked with concentration values or equivalent. Detector tube scales shall be graduated either in volume per unit volume or mass per unit volume or shall be accompanied by a calibration graph in the same units. The calibration marks shall have a minimum width of 0,3 mm. The starting line at the beginning of the indicating layer shall be clearly marked. The minimum length of a calibration mark shall be 3 mm and the size of the printed text shall be at least 1,5 mm.

The number of pump strokes or the sample volume required for a particular scale shall be marked on the detector tube.

4.2.3 Evaluation of the stain

The stain shall remain constant and clearly visible for at least 2 min after the end of measurement.

The maximum variation of stain length around the circumference of the tube at the interface between the stained and unstained indicating layer shall not exceed 20 % of the stain length when measured at its maximum length.

NOTE If the end point of the stain fades progressively, the manufacturer's instructions can be consulted for determining reading.

4.2.4 Shelf life

The shelf life of the detector tube, when stored in accordance with the manufacturer's instructions, shall be clearly indicated on the tube packet.

4.2.5 Mechanical strength

Subsequent to the tests carried out in accordance with 6.1.3, the detector tubes shall maintain their integrity.

4.2.6 Transportation temperature stability

After storage of the detector tubes at (0 ± 2) °C for 24 h and subsequently at (60 ± 2) °C for 24 h, the detector tubes shall meet the requirements of 4.1 and 4.2.4 after stabilizing to ambient temperature. The manufacturer may specify a maximum temperature range for any kind of transportation. In this case, a test shall be carried out at the temperature specified.

4.2.7 Packing of the detector tubes

If the box contains more than one tube, it shall be re-closable.

If the manufacturer indicates that the tubes shall be protected from light, this shall be ensured by the box.

Subsequent to the tests carried out in accordance with 6.1.3, the box containing the detector tubes shall maintain its integrity.

4.2.8 Interferences

Information on the influence of typical interferents shall be provided by the manufacturer in the instructions for use (see 4.2.11).

4.2.9 Overloading

When the detector tube is tested at a concentration 10 times the upper limit of the scale, the detector tube shall clearly indicate overloading, lasting for at least 2 min.

4.2.10 Environmental influences

The manufacturer shall state the range of temperature and relative humidity for which the specified measuring range is valid. The temperature shall be in a range from at least 10 °C to 30 °C, and the relative humidity shall be in a range from at least 20 % to 80 %.

4.2.11 Instruction for use for detector tubes

The instruction for use supplied with each box of detector tubes shall contain at least the following information:

a) operating instructions;

b) directions for proper handling of a detector tube including opening and fitting it into the detector tube pump;

c) a statement that the detector tube pump shall be tested for leakage before each use;

d) general information on the reaction and colour change involved in the system and the levels at which other typical gases and vapours, including water, are likely to interfere to the extent of increasing the measurement uncertainty above the level specified in this International Standard

e) a statement that additional information on interferents can be provided on request, if possible;

f) if applicable, information about reagents and reactions that are hazardous;

g) where the contents of detector tubes present a disposal hazard, a warning to that effect shall be given together with advice that national regulations for disposal of hazardous waste should be followed;

h) a statement on the time required for the completion of one pump stroke;

i) information on the evaluation of the reading including calculation of results, e.g. equation, chart, or table used for correction of temperature, atmospheric pressure, and/or humidity, if any;

j) reference to the operating instructions of the detector tube pump;

k) specification of the detector tube pump brand or model;

l) information on storage and transport.

4.3 Detector tube pump

4.3.1 General

The requirements given in 4.3.2 to 4.3.6 shall be verified by the manufacturer.

4.3.2 Stroke volume

When tested in accordance with 6.2.1, the detector tube pump shall sample a volume of air within (100 ± 5) ml per stroke.

4.3.3 Leakage

The detector tube pump with a closed detector tube connection shall be tight, so that during the first minute of a pump stroke the leakage rate does not exceed 3 ml/min.

4.3.4 Mechanical strength

Subsequent to the test carried out in accordance with 6.2.3, the detector tube pump shall meet the requirements given in 4.3.2.

4.3.5 Mechanical durability

After execution of 1 000 strokes, the detector tube pump shall meet the requirement of 4.3.2 when fitted with the flow resistor given in 5.7.

4.3.6 Explosion hazard

If a detector tube pump is claimed by the manufacturer to be suitable for use in areas subject to explosion hazard, electrically driven detector tube pumps shall fulfil the requirements of IEC 60079-0.

4.3.7 Instructions for use for detector tube pumps

The instructions for use supplied with the detector tube pump shall contain at least the following information:

a) operating instructions;

b) instructions for testing for leakage before each use;

c) maintenance instructions;

d) reference to the operating instructions of the detector tube;

e) stroke volume;

f) indication for the end of one stroke;

g) specification of the detector tube pump brand or model.

5 Test conditions

5.1 General

Parts of the detector tube measurement system which have already been tested according to this International Standard are not required to be tested again.

5.2 Reagents

Test gas mixtures shall be prepared according to ISO 6141, ISO 6142, ISO 6143, ISO 6144, ISO 6145-1, ISO 6145-4, ISO 6145-6, ISO 6145-10, and ISO 9169. See also Reference [1].

5.3 Apparatus

5.3.1 Usual laboratory apparatus and chemical reagents of analytical grade.

5.3.2 Dynamic or static systems for preparation of test gas mixtures, for example an exposure chamber constructed of inert materials such as glass or PTFE, through which the generated test gas mixture is passed.

5.3.3 Equipment for measuring, controlling and varying systematically the rate of air flow through the generating system and the composition, temperature, and relative humidity of the test gas mixture (see Reference [1]).

5.4 Independent method

An independent validated method shall be used to verify the composition of the test gas mixture used. The composition of the test gas mixture and the related uncertainty shall be given in the test report.

5.5 Generation of test gas mixtures

Prepare test gas mixtures for at least three concentrations, for example at approximately 20 %, 50 %, and 80 % of the specified measuring range, and at the values of temperature, relative humidity, etc. specified in the appropriate test methods in Clause 6. Determine the mean concentration of the test gas mixture within the exposure chamber experimentally using the results of the independent method (see 5.4). A correction should be applied for any known bias in the independent method.

Compare the determined mean concentration with the value calculated from the test gas generation parameters. If the experimentally determined value is within ±10 % of the calculated value of the concentration of the delivered test gas mixture, take the calculated value as the true value of the delivered concentration. If this requirement is not met, then adjustments shall be made or an alternative generation method shall be used or the independent method shall be verified.

If it is not possible to calculate a mass concentration of the test gas, the value determined by the independent method shall be used as the true value.

5.6 Test conditions for detector tubes

For the purpose of type testing, the test shall be carried out on 10 detector tubes and one detector tube pump. A recommended sequence of tests is given in Annex A.

Unless otherwise stated, the test procedures are run at the following environmental conditions:

— temperature (20 ± 2) °C;

— relative humidity (50 ± 5) %;

— atmospheric pressure (1013 ± 30) hPa.

At an atmospheric pressure outside of the stated range, the measured concentration values shall be corrected to an atmospheric pressure of 1 013 hPa.

5.7 Test conditions for detector tube pumps

Unless otherwise stated, the test shall be carried out for the purpose of type testing on one detector tube pump.

The tests according to 6.2.1 to 6.2.4 are carried out with a flow resistor, typical for detector tubes, with a pressure drop of either

a) (140 ± 10) hPa, flow rate 500 ml/min, or

b) (430 ± 30) hPa, flow rate 100 ml/min

when connected to the detector tube pump.

6 Test methods

6.1 Detector tubes

6.1.1 Visual checks

6.1.1.1 Instructions for use

Check the information given in 4.2.8 and 4.2.11 for completeness and correctness.

6.1.1.2 Measuring range

Determine whether the measuring ranges stated in the instruction for use and on the detector tube are consistent. The instruction for use should clearly state when the measuring range can be extended by having its volume and hence concentration range altered.

6.1.1.3 Scale

Measure and check the requirements given in 4.2.2 visually.

6.1.1.4 Packing of the detector tubes

Check the requirements given in 4.2.7 visually.

6.1.1.5 Interferences

Check the requirement given in 4.2.8 visually.

6.1.2 Test procedures

6.1.2.1 General

The test instruments used are listed in Annex B. For the required number of detector tubes, see Table A.1.

6.1.2.2 Test gas concentrations of the specified measuring range

Prepare test gas mixtures for at least three concentrations, for example at approximately 20 %, 50 %, and 80 % of the specified measuring range, under the following environmental conditions:

— temperature (20 ± 2) °C;

— atmospheric pressure (1013 ± 30) hPa;

— relative humidity (50 ± 5) %.

NOTE Some gases can react with water. For such gases the tests can be carried out under dry air conditions, i.e. less than 10 % relative humidity.

For each test gas concentration, expose a detector tube and take a sample according to the manufacturer's instructions for use. Record the measured concentration at the scale of the detector tube. Carry out this procedure 10 times in total.

6.1.2.3 Evaluation of the stain

In each series of measurements in 6.1.2.2, observe the coloured zones of the tubes for about 2 min. If any of the detector tubes used for the measurement according to 6.1.2.2 shows a slant of the colour zone, the biggest and the smallest length of the colour zone is measured in millimetres and the slant determined as a percentage using Formulae (1) and (2):

$$S = \frac{l_{max} - l_{min}}{l_{ave}} \times 100 \quad (1)$$

$$l_{ave} = \frac{l_{max} + l_{min}}{2} \quad (2)$$

where

S is the slant of the colour zone, given in per cent (%);

l_{max} is the biggest length of the colour zone, given in millimetres (mm);

l_{min} is the smallest length of the colour zone, given in millimetres (mm);

l_{ave} is the average length of the colour zone, given in millimetres (mm)

6.1.2.4 Environmental influences

The reading and the measurement deviation are tested according to 6.1.2.2 and 6.1.2.3 with 10 detector tubes at each of the following environmental conditions:

a) temperature (10 ± 2) °C;

atmospheric pressure (1013 ± 30) hPa;

relative humidity (20 ± 5) %.

b) temperature (30 ± 2) °C;

atmospheric pressure (1013 ± 30) hPa;

relative humidity (20 ± 5) %.

c) temperature (30 ± 2) °C;

atmospheric pressure (1013 ± 30) hPa;

relative humidity (80 ± 5) %.

Test at a concentration of (80 ± 10) % of the specified measuring range. For detector tubes with several specified measuring ranges, the test is performed for each range.

If the manufacturer states temperature and/or humidity, atmospheric pressure corrections in the instructions for use, the reading value should be corrected accordingly.

As the impact of the environmental influences only depends on the detector tube type, only a single evaluation needs to be carried out for each detector tube type determined by the test house.

6.1.2.5 Transportation temperature stability

Store the detector tubes at (0 ± 2)°C and then at (60 ± 2)°C for about 24 h at each temperature. After adjusting to room temperature, test 10 detector tubes according to 6.1.2.2 and 6.1.2.3 for reading and measurement deviation. Carry out the tests at a concentration of (50 ± 10) % of the specified measuring range. For detector tubes with several measuring ranges, the testing is performed for the lowest one. If the manufacturer has specified a maximum temperature for transportation, the test shall be carried out at the specified maximum temperature.

6.1.2.6 Overloading

Test three detector tubes at concentration 10 times the upper limit of the specified measuring range.

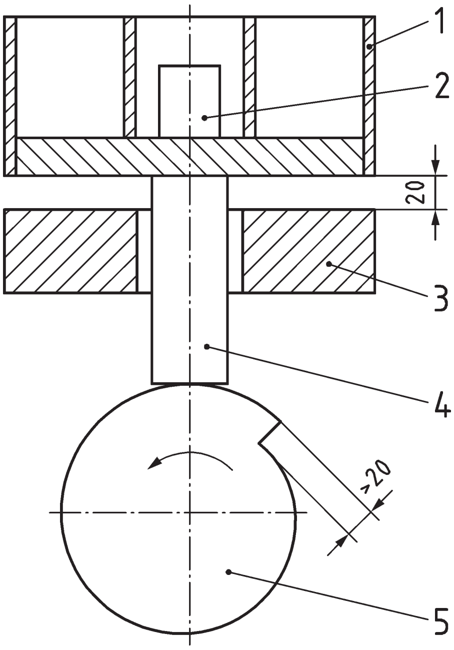
For detector tubes with more than one scale, perform the test by using the scale with the highest scale end value at the corresponding stroke number.

6.1.3 Mechanical strength

6.1.3.1 Equipment

For the shock treatment, a test set-up or equivalent shock testing machine as shown schematically in Figure 1 shall be used.

Dimensions in millimetres



Key

1 steel case

2 detector tube pump or detector tube

3 steel plate

4 vertically moving piston

5 rotating cam

Figure 1 — Example for a test set up for shock treatment

The apparatus consists of a steel case (1) which is fixed on a vertically moving piston (4), capable of being lifted up 20 mm by a rotating cam (5) and dropping down onto a steel plate (3) under its own mass as the cam rotates. See also ISO 13137.[2]

6.1.3.2 Procedure

Insert the detector tubes, still in the unopened detector tube package as they are delivered, into the test equipment horizontally and vertically and fix tightly.

For each of the two tests, a total of 2 000 shock treatment strokes are generated. The frequency is chosen, in a way that the detector tube packages come to a stand-still between two strokes, e.g. 2 000 shock treatment strokes in 15 min. After visual examination of filling layers and holding elements (see 6.1.1.4), test 10 detector tubes per test according to 6.1.2.2 for reading and measurement deviation. Carry out the tests at a concentration between 20 % and 30 % of the specified measuring range. For detector tubes with different measuring ranges, the testing is performed for the lowest one.

6.2 Detector tube pumps

6.2.1 Stroke volume

Test with a volume measuring device with a range of at least 90 ml to 110 ml and a resolution of at most ±1 ml. The detector tube pump is connected to the measuring device via a flow resistor. The stroke volume is measured at the end of a pump stroke as indicated in the instructions for use, a second value is measured 30 s later. Both values shall meet the requirement given in 4.3.2. Test five detector tube pumps, each six times.

6.2.2 Leakage

Test with a volume measuring device according to 6.2.1. The detector tube pump is connected to the measuring device via a cut-off valve. A pump stroke is started with closed cut-off valve. After one minute, the cut-off valve is opened. Volume is measured at the visible end of the pump stroke. The mean value of six repeated measurements shall not differ by more than 3 ml from the mean stroke volume determined in 6.2.1.

6.2.3 Mechanical strength

Test with equipment according to 6.1.3.1 using in total 4 000 shock treatment strokes in 40 min. Then the detector tube pump is tested according to 6.2.1.

6.2.4 Mechanical durability

Connect the detector tube pump and flow resistor (see 5.7) to each other followed by 1 000 pump strokes according to the instructions for use. Then test the detector tube pump according to 6.2.1.

NOTE Batteries used in electrically driven detector tube pumps can be recharged or replaced during the test.

6.2.5 Explosion hazard (electrically driven detector tube pumps only)

Verify by means of a test certificate.

6.2.6 Instructions for use

Check the information supplied for completeness and correctness.

7 Uncertainty of measurement

7.1 Potential sources of uncertainty

The uncertainty of measurement for detector tube measurement systems used for the direct detection and direct concentration measurement of gases and vapours is calculated as far as practically feasible in terms of error source by estimating individual random and non-random uncertainty components.

Table 1 lists potentially significant sources of uncertainty for the detector tube measurements with the indication of whether they are random or non-random and whether they need or need not be considered.

NOTE Several features of uncertainty not listed in Table 1, for example, mechanical strength, mechanical durability, shelf life, and overloading, are considered pass/fail, with failure rate controlled ideally at less than 5 %.

Table 1 — Sources of uncertainty for detector tube measurements

Parameter (symbol used for associated uncertainty component)		Uncertainty	
		Random	**Non-random**
Combined stain component (i.e. concentration as read[a])	Detector tube intra-batch uncertainty component (u_S)	Yes	—
	Detector tube intra-batch uncertainty component (u_B)	—	Yes
Pump stroke volume (u_P)		—	Yes
Pump leakage		Not applicable	
Effect of temperature (u_T)		—	Yes
Effect of relative humidity (u_H)		—	Yes
Test gas concentration used for evaluation (u_{EC})		—	Yes
Stain-length reading		Not explicitly considered	
Analytical phenomena		Not explicitly considered	
Atmospheric pressure		Not applicable, as generally negligible	
Diffusive leakage into detector tube		Not applicable, as generally negligible	
Non-constant sampling flow		Not applicable, as generally negligible	

[a] Includes random sources: reading, analytical precision, and sampling volume precision

7.2 Estimation of the uncertainty components

7.2.1 Combined stain component

7.2.1.1 General

Although each parameter listed in Table 1 is considered as a rough estimate only, analysis of the overall effect of each on uncertainty requires an impractical amount of testing. Therefore, combined standard uncertainty values are obtained in part using a component from measurements of stain length readings upon given exposure, thus implicitly combining random variation in the pump stroke volume, stain length, and its reading.

The effect of interferences cannot be treated in general and shall be considered on a case-by-case evaluation.

7.2.1.2 Detector tube intra-batch stain component

Specifically, for any one of the three test gas concentrations used for evaluation specified in Clause 6 it is supposed that the detector tube readings for each of the 10 detector tubes are made by reading stain lengths. The detector tube intra-batch standard deviation ("imprecision") is then given by Formula (3):

$$s_s = \sqrt{\frac{1}{9}\sum_{t=1}^{10}\left(C_t - \bar{C}\right)^2} \quad (3)$$

where

s_s is the detector tube intra-batch standard deviation;

C_t is the detector tube reading of the concentration for the t^{th} detector tube, with t = 1 to 10;

$\bar{C}$ is the detector tube intra-batch concentration mean.

The detector tube intra-batch means, $\bar{C}$, are calculated from Formula (4):

$$\bar{C} = \frac{1}{10}\sum_{t=1}^{10} C_t \quad (4)$$

The relative standard uncertainty associated with the detector tube intra-batch stain component, u_s, is then given by Formula (5):

$$u_s = \frac{s_s}{C} \times 100\,\% \quad (5)$$

where

s_s is the detector tube intra-batch standard deviation;

C is the test gas concentration.

7.2.1.3 Bias

The detector tube intra-batch means will generally be slightly biased. A value of bias relative to the test gas concentration used for evaluation can be given by Formula (6):

$$B = \frac{\left|\bar{C} - C\right|}{C} \times 100\,\% \quad (6)$$

where

B is the (value of) bias;

$\bar{C}$ is the detector tube intra-batch concentration mean;

C is the test gas concentration.

If the magnitude of the bias is found to exceed 20 %, it is recommended to contact the manufacturer of the detector tube for appropriate calibration.

The relative standard uncertainty associated with bias, u_{B}, can be estimated by Formula (7):

$$u_{\mathrm{B}} = B \tag{7}$$

7.2.2 Pump-stroke volume

The uncertainty associated with the pump-stroke volume is estimated by the standard deviation of the pump stroke volumes of the five detector tube pumps.

This standard deviation can be calculated from Formula (8):

$$s_{\mathrm{P}} = \sqrt{\frac{1}{4}\sum_{p=1}^{5}\left(V_p - \bar{V}\right)^2} \tag{8}$$

where

s_{P} is the standard deviation of the pump stroke volumes;

V_{P} is the pump stroke volume of the p^{th} detector tube pump tested, where p = 1 to 5;

$\bar{V}$ is the pump stroke volume mean.

The pump stroke volume mean $\bar{V}$ is given by Formula (9):

$$\bar{V} = \frac{1}{5}\sum_{p=1}^{5} V_p \tag{9}$$

The relative standard uncertainty associated with the pump stroke volume, u_{P}, is then given by Formula (10):

$$u_{\mathrm{P}} = \frac{s_{\mathrm{P}}}{\bar{V}} \times 100\,\% \tag{10}$$

where

s_{P} is the standard deviation of the pump stroke volumes;

$\bar{V}$ is the pump stroke volume mean.

7.2.3 Effect of temperature

The effect of uncertainty in temperature, T, is treated as bias uncertainty. $C_{\mathrm{T,cor}}{}^{-1} \cdot \Delta C_{\mathrm{T,cor}} / \Delta T$, the relative change per degree Celsius (°C) of the (temperature-corrected) detector tube reading of concentration $C_{\mathrm{T,cor}}$ upon temperature shift ΔT is measured and approximated as independent of $C_{\mathrm{T,cor}}$. An uncertainty component is then constructed assuming that the temperature ranges at most from 15 °C to 30 °C in application of the detector tube. Then the relative estimate falls at most in a range $\left|C_{\mathrm{T,cor}}{}^{-1} \cdot \Delta C_{\mathrm{T,cor}} / \Delta T\right| \times 15\,°\mathrm{C}$. The relative standard uncertainty associated with the effect of temperature, u_{T}, is then given by Formula (11). For use at ambient temperatures from 15 °C to 30 °C, the variance ${\sigma_T}^2$ may be taken as $\frac{1}{4\cdot 3}(15\ ^\circ\text{C})^2$, corresponding to an assumed uniform distribution between 15 °C and 30 °C.

$$u_T = C_{T,cor}^{-1} \left| \left(\frac{\Delta C_{T,cor}}{\Delta T} \right) \right| \times 15\ ^\circ\text{C} \times \frac{1}{2\sqrt{3}} \tag{11}$$

where

$C_{T,cor}$ is the (temperature-corrected) detector tube reading of concentration;

$\Delta C_{T,cor}/\Delta T$ is the relative change of the (temperature-corrected) detector tube reading of concentration per degree Celsius (°C) of temperature T upon temperature shift

7.2.4 Effect of relative humidity

The effect of uncertainty in the relative humidity, H, is treated as bias uncertainty. The relative change ${C_{H,cor}}^{-1} \cdot \Delta C_{H,cor} / \Delta H$ per % relative humidity of the (humidity-corrected) detector tube reading of concentration $C_{H,cor}$ upon relative humidity shift ΔH is measured and approximated as independent of $C_{H,cor}$. An uncertainty component is then constructed assuming that the relative humidity in application of the detector tube varies at most within 20 % to 80 %. Then the relative estimate falls at most in a range $\left| {C_{H,cor}}^{-1} \cdot \Delta C_{H,cor} / \Delta H \right| \times 60\,\%$. The relative standard uncertainty associated with the effect of relative humidity, u_H, is then given by Formula (12):

$$u_H = C_{H,cor}^{-1} \left| \frac{\Delta C_{H,cor}}{\Delta H} \right| \times 60\,\% \times \frac{1}{2\sqrt{3}} \tag{12}$$

where

$C_{H,cor}$ is the (humidity-corrected) detector tube reading of concentration;

$\Delta C_{H,cor}/\Delta H$ is the relative change of the (humidity-corrected) detector tube reading of concentration per percentage (%) of relative humidity H upon relative humidity shift.

7.2.5 Test gas concentration used for evaluation

Evaluation of detector tube systems of differing manufacture is likely to occur on separate days, and inter-day variation of the test gas concentration from nominal values, either as determined from generation or from an independent method, can occur. Therefore, the measured bias in detector tube readings can itself be biased, negligible in the average over evaluations, though with uncertainty characterized by an inter-run variance either estimated or measured by an independent thorough evaluation of the exposure chamber (see Type B evaluation according to ISO 20988[3]). The relative standard uncertainty associated with the test gas concentration used for evaluation, u_{EC}, is then given by Formula (13) as

$$u_{EC} = \frac{1}{C}\sqrt{s_R^2} \tag{13}$$

where

s_R^2 is the inter-run variance;

C is the test gas concentration (used for evaluation).

7.2.6 Stain-length reading

This uncertainty component shall be estimated by measuring the standard deviation of readings of a stain. The effect is not included in the calculation of combined standard uncertainty, as it is already contained implicitly in the relative standard uncertainty associated with the detector tube intra-batch stain component, u_s (see 7.2.1.2).

7.2.7 Analytical phenomena

Variation in the chemical analysis affecting stain length can exist, for example related to the homogeneity of the reactive column within the detector tube. The effect is not included in the calculation of combined standard uncertainty, as it is already contained implicitly in the relative standard uncertainty associated with the detector tube intra-batch stain component, u_s (see 7.2.1.2).

7.2.8 Atmospheric pressure

The effect of atmospheric pressure is not considered here. For atmospheric pressure correction see instructions for use.

7.2.9 Diffusive leakage into detector tube

The effect of diffusive sampling in addition to the convective sampling from the detector tube pump is not considered here. Through choice of sufficiently small detector tube cross-sectional area, sufficiently long front air-space length, and the normally high pumped sampling flow rate, the effect of diffusive sampling can be made entirely negligible, as the maximum diffusive bias, $B_{max,d}$, is given by Formula (14):

$$B_{max,d} = \frac{1}{e^{[Q_p/Q_d]}-1} \tag{14}$$

where

Q_p is the pumped sampling flow rate;

Q_d is the initial diffusive sampling rate.

The initial diffusive sampling rate, Q_d , at diffusion coefficient, D, is given by Formula (15):

$$Q_d = \frac{D \cdot A}{L_0} \tag{15}$$

where

D is the diffusion coefficient;

A is the detector tube cross-sectional area;

L_0 is the front air-space length of the detector tube.

NOTE Diffusive effects in handling the detector tube at start or end of sampling are also coincidently controlled.

7.2.10 Non-constant sampling flow

Most detector tube pumps produce an instantaneous flow rate that begins high and drops to zero during the sampling period of the order of 1 min. This has a major effect on sampling many non-constant concentrations, for example, a pulsed concentration within the sampling period. However, as detector tubes are generally used for estimating grab-sampled concentrations that are closely constant over times of the order of 1 min, this effect is not considered here.

7.3 Combined standard uncertainty

The combined standard uncertainty, u_C, is calculated from the individual uncertainty components according to Formula (16) as follows:

$$u_C = \sqrt{u_s^2 + u_T^2 + u_H^2 + u_B^2 + u_P^2 + u_{EC}^2} \tag{16}$$

where

u_S is the relative standard uncertainty associated with the detector tube intra-batch stain component;

u_T is the relative standard uncertainty associated with the effect of temperature;

u_H is the relative standard uncertainty associated with the effect of relative humidity;

u_B is the relative standard uncertainty associated with the bias;

u_P is the relative standard uncertainty associated with the pump stroke volume;

U_{EC} is the relative standard uncertainty associated with the test gas concentration used for evaluation.

7.4 Expanded uncertainty

Finally, the expanded uncertainty U is calculated from Formula (17) as follows:

$$U = k \times u_c \tag{17}$$

where

k is the coverage factor typically ranging from 2 to 3;

u_c is the combined standard uncertainty.

NOTE 1 For simplicity, this practice adopts the traditional coverage factor $k = 2$.

NOTE 2 An example for calculation of expanded uncertainty is provided in Annex C.

8 Test report

8.1 Detector tubes

The test report shall include at least the following information:

a) a reference to this International Standard, i.e. ISO 17621;

b) the type of detector tube;

c) the type of detector tube pump used;

d) the measuring range where the detector tube fulfils the requirements for measurement uncertainty;

e) the specification and uncertainty of the test gas mixtures;

f) the independent method;

g) the test results;

h) if the acceptance criteria were met;

i) any unusual features noted during the determinations;

j) any operation not included in this International Standard that can have influence on the results.

8.2 Detector tube pumps

The test report shall include at least the following information:

a) a reference to this International Standard, i.e. ISO 17621;

b) the type of detector tube pump;

c) the test results;

d) if the acceptance criteria were met;

e) any unusual features noted during the determinations;

f) any operation not included in this International Standard that can have influence on the results.

9 Marking

9.1 Boxes

Each box of detector tubes shall be marked with the following information:

a) the manufacturer's name or trademark and a type identifying mark;

b) the number of this International Standard;

c) an indication of the gas(es) or vapour(s) for which the tubes may be used and the measuring ranges;

d) the manufacturer's batch number;

e) the shelf life;

f) recommended storage conditions;

g) number of detector tubes.

9.2 Detector tubes

Each tube shall be marked with the following information:

a) the manufacturer's name or trademark and a type identifying mark;

b) an indication of the gas(es) or vapour(s) for which the tubes is designed to be used;

c) an indication of the direction of gas flow;

d) scales and measuring units;

e) the number of pump strokes or sampling volume.

9.3 Detector tube pumps

Each detector tube pump shall be marked with at least the following information:

a) the manufacturer's name or trademark and a type identifying mark;

b) identification number and/or month and year of manufacture;

c) number of this International Standard.

The number of this International Standard may be marked on the package of the detector tube pump.