BS EN 45544-4:2016

BSI Standards Publication

Workplace atmospheres — Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours

Part 4: Guide for selection, installation, use and maintenance

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National foreword

This British Standard is the UK implementation of EN 45544-4:2016. It supersedes BS EN 45544-4:2000 which is withdrawn.

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Workplace atmospheres - Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours - Part 4: Guide for selection, installation, use and maintenance

Atmosphères des lieux de travail - Appareillage électrique utilisé pour la détection directe des vapeurs et gaz toxiques et le mesurage direct de leur concentration - Partie 4: Guide de sélection, d'installation, d'utilisation et d'entretien

Arbeitsplatzatmosphäre - Elektrische Geräte für die direkte Detektion und direkte Konzentrationsmessung toxischer Gase und Dämpfe - Teil 4: Leitfaden für Auswahl, Installation, Einsatz und Wartung

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European foreword

This document (EN 45544-4:2016) has been prepared by CEN/CENELEC Joint Working Group "Continuous Measuring Instruments" (JWG CMI).

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This document supersedes EN 45544-4:1999.

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Introduction

National laws and regulations based on European Directives require the assessment of the potential exposure of a worker to chemical agents in workplace atmospheres.

EN 45544, Workplace atmospheres – Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours, consists of the following parts:

- *Part 1: General requirements and test methods;*
- *Part 2: Performance requirements for apparatus used for exposure measurement;*
- *Part 3: Performance requirements for apparatus used for general gas detection;*
- *Part 4: Guide for selection, installation, use and maintenance.*

1 Scope

This European Standard gives guidance on the selection, installation, use and maintenance of electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours in workplace atmospheres. The primary purpose of such apparatus is to measure the concentration of a toxic gas or vapour in order to provide an exposure measurement and/or detection and warning of its presence.

This European Standard is applicable to apparatus whose primary purpose is to provide an indication, alarm and/or other output function to give a warning of the presence of a toxic gas or vapour in the atmosphere and in some cases to initiate automatic or manual protective actions. It is applicable to apparatus in which the sensor automatically generates an electrical signal when gas is present.

This European Standard is not applicable, but may provide useful information, for apparatus

- used for the measurement of oxygen,
- used only in laboratories for analysis or measurement,
- used only for process measurement purposes,
- used in car parks or tunnels (fixed apparatus only),
- used in the domestic environment,
- used in environmental air pollution monitoring,
- used for the measurement of combustible gases and vapours related to the risk of explosion.

It also does not apply to open-path (line of sight) area monitors.

For apparatus used for sensing the presence of multiple gases, this European Standard applies only to the detection of toxic gas or vapour.

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.

EN 482:2012+A1:2015, *Workplace exposure – General requirements for the performance of procedures for the measurement of chemical agents*

EN 45544-1:2015, *Workplace atmospheres - Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours - Part 1: General requirements and test methods*

EN 45544-2:2015, *Workplace atmospheres - Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours - Part 2: Performance requirements for apparatus used for exposure measurement*

EN 45544-3:2015, *Workplace atmospheres - Electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours - Part 3: Performance requirements for apparatus used for general gas detection*

3 Terms and definitions

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

3.1
toxic gas
general term for any gas or vapour that can be harmful to human health

Note 1 to entry: The term “gas” is used for both gases and vapours

3.2
interfering gases
any gas other than the gas to be detected, including water vapour, which affects the indication

3.3
clean air or zero gas
air free of gases to which the sensor is sensitive, or which influences the performance of the sensor

3.4
standard test gas
test gas with a composition specified for each apparatus and gas to be tested

3.5
volume fraction (v/v)
quotient of the volume of a specified component and the sum of the volumes of all components of a gas mixture before mixing

3.6
limit value
occupational exposure limit of the time-weighted average of the concentration of a chemical agent in the air within the breathing zone of a worker in relation to a specified reference period

[SOURCE: Council Directive 98/24/EC Art. 2(d) [1]]

Note 1 to entry: Limit values are mostly set for reference periods of 8 h, but can also be set for shorter periods or concentration excursions, e.g. short-term exposure limit (STEL). Limit values for gases and vapours are stated in terms independent of temperature and air pressure variables in ml/m^3, and in terms dependent on those variables in mg/m^3 for a temperature of 20 °C and a pressure of 101,3 kPa.

3.7
exposure (by inhalation)
situation in which a chemical agent is present in air that is inhaled by a person

3.8
time weighted average (TWA) concentration
concentration of gas in air integrated over time and divided by the specified reference period

3.9
fixed apparatus
apparatus intended to have all parts permanently installed

3.10
transportable apparatus
apparatus not intended to be a portable apparatus, but which can readily be moved from one place to another

3.11
portable apparatus
apparatus that has been designed to be readily carried from place to place and to be used while being carried

Note 1 to entry: Portable apparatus is generally battery powered.

3.12
personal apparatus
portable apparatus attached to a person that monitors the atmosphere in their breathing zone so that their exposure to toxic gases can be determined

Note 1 to entry: Also known as a personal monitor.

3.13
aspirated apparatus
apparatus that samples the atmosphere by drawing it to the sensor

EXAMPLE A hand operated or electric pump can draw gas to the sensor.

3.14
alarm-only apparatus
apparatus having an alarm but not having a display or other device to indicate the measured gas concentration

3.15
sensing element
part of the sensor that is sensitive to the gas/vapour to be measured

3.16
sensor
assembly in which the sensing element is housed and which can contain associated circuit components

3.17
remote sensor
sensor that is not an integral part of the apparatus

Note 1 to entry: A remote sensor is connected to a control unit or to a gas detection transmitter.

3.18
gas detection transmitter
fixed gas detection apparatus that provides a conditioned electronic signal or output indication to a generally accepted industry standard, intended to be utilized with separate control units, or signal processing data acquisition, central monitoring and similar systems which typically process information from various locations and sources including, but not limited to, gas detection apparatus

EXAMPLE An example of a generally accepted industry standard for an electronic signal or output indication is 4 mA - 20 mA.

3.19
control unit
apparatus intended to provide display indication, alarm functions, output contacts and/or alarm signal outputs when operated with remote sensor(s) and/or gas detection transmitter(s)

3.20
alarm set point
setting of the apparatus at which the measured concentration will cause the apparatus to initiate an indication, alarm or other output function

3.21
fault signal
audible, visible or other type of output, different from the alarm signal that permits, directly or indirectly, a warning or indication that the apparatus is not working satisfactorily

3.22
sample line
means by which the gas being sampled is conveyed to the sensor including accessories

EXAMPLE Examples of accessories: filter, water trap.

3.23
sampling probe
separate sample line that is attached to the apparatus as required

Note 1 to entry: It can be supplied with or without the apparatus. It is usually short (e.g. of the order of 1 m) and rigid, although it can be telescopic. It can also be connected by a flexible tube to the apparatus.

3.24
field calibration kit
means of calibrating or adjusting the apparatus

EXAMPLE This can be a calibration mask.

Note 1 to entry: The field calibration kit can also be used for verifying the operation of the apparatus.

3.25
zero indication
indication given by an apparatus when exposed to zero gas in normal operating conditions

3.26
indication range
range of measured values of gas concentration over which the apparatus is capable of indicating

Note 1 to entry: See Figure 2.

3.27
zero scale indication
smallest value of the measured quantity within the indication range

Note 1 to entry: This is typically zero.

Note 2 to entry: See Figure 2.

3.28
full scale indication
largest value of the measured quantity within the indication range

Note 1 to entry: See Figure 2.

3.29
measuring range

range of measured values of gas concentration over which the accuracy of the apparatus lies within specified limits

Note 1 to entry: For apparatus conforming to EN 45544–2, the requirements for expanded uncertainty in EN 482:2012+A1:2015, Table 1, are met. For apparatus conforming to EN 45544–3, the requirements for accuracy in EN 45544–3 are met. The measuring range is a subset of the indication range.

Note 2 to entry: See Figure 2.

3.30
lower limit of measurement

smallest value of the measured quantity within the measuring range

Note 1 to entry: Indications below the lower limit of measurement will not necessarily meet the uncertainty requirements of this European Standard.

Note 2 to entry: See Figure 2.

3.31
upper limit of measurement

largest value of the measured quantity within the measuring range

Note 1 to entry: Indications above the upper limit of measurement will not necessarily meet the uncertainty requirements of this European Standard.

Note 2 to entry: See Figure 2.

3.32
expanded uncertainty

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

3.33
zero uncertainty

quantity defining an interval about the zero that might be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurement in clean air

Note 1 to entry: In Figure 3, the mean value of the measured values in clean air is not equal to the zero scale indication to illustrate that there can be an offset due to drift. The mean value can be above or below the zero scale indication.

3.34
selectivity

degree of independence from interfering gases

3.35
averaging time

period of time for which the measuring procedure yields an averaged value

3.36
drift

variation in the apparatus indication with time at any fixed gas volume fraction under constant environmental conditions

3.37

time of recovery (t_x)

time interval, with the apparatus in a warmed-up condition, between the time when an instantaneous decrease in volume fraction is produced at the apparatus inlet and the time when the response reaches a stated indication of x % of the initial indication

Note 1 to entry: For alarm-only apparatus, the stated indication can be represented by the de-activation of the alarm set at a stated value.

3.38

time of response (t_x)

time interval, with the apparatus in a warmed-up condition between the time when an instantaneous increase in volume fraction is produced at the apparatus inlet and the time when the response reaches a stated indication of x % of the final indication

Note 1 to entry: For alarm-only apparatus, the stated indication can be represented by the activation of the alarm set at a stated value.

3.39

warm-up time

time interval, with the apparatus in a stated atmosphere, between the time when the apparatus is switched on and the time when the indication reaches and remains within the stated tolerances

Note 1 to entry: See Figure 1.

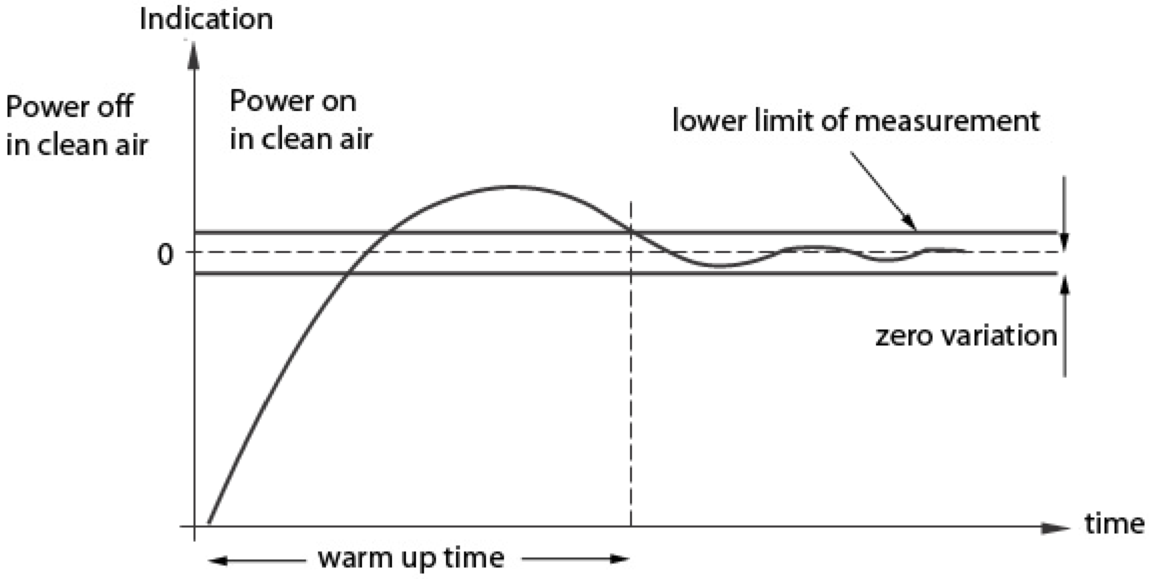

Figure 1 — Example of warm-up time in clean air

3.40

calibration

procedure that establishes the relationship between a measured value and the volume fraction of a test gas

3.41
adjustment
procedure carried out to minimize the deviation of the measured value from the test gas volume fraction

Note 1 to entry: When the apparatus is adjusted to give an indication of zero in clean air, the procedure is called 'zero adjustment'.

3.42
special state
all states of the apparatus other than those in which monitoring of gas concentration and/or alarming takes place, for example warm-up, calibration mode or fault condition

4 Properties and detection of toxic gases and vapours

4.1 Properties and detection

In Clause 4, a distinction is drawn between gases, which remain gaseous at typical ambient pressures and temperatures, and vapours where liquid can also exist at any relevant pressure or temperature.

Toxic gases typically become harmful at low concentrations (limit values typically range from ppb to 1 % v/v levels). At distances far from the source of toxic gas release, the relative density of such a gas mixture is not significantly different from that of air. However, close to the source, the relative density can be significantly different.

Gases and mixtures with relative densities between 0,8 and 1,2 should generally be considered to behave like air and are therefore capable of propagating in all directions.

High pressure leaks can generate gas clouds that propagate over significant distances from the source before mixing. This can occur for sources where the gas can be of any density.

Spillage of liquids can result in toxic vapour clouds that can disperse over long distances and accumulate in trenches, drains, tunnels etc. This is a result of liquid and vapour flow under gravity, cooling due to evaporation, and densities greater than air. The vapour cloud tends to stay close to the ground until well mixed with air. Nevertheless, concentrations in the breathing zone can approach harmful levels.

Gases and vapours fully mix with each other by diffusion over time or if stirred, e.g. by convection or mechanical ventilation. Once they have been mixed, they will remain mixed, unless a component is removed chemically or is absorbed, for instance on a charcoal filter. Additionally, in the case of vapours, the concentration can be lowered by condensation due to increased pressure or reduced temperature. Some gases can react chemically with each other on mixing, e.g. nitric oxide and oxygen.

Air movement by convection, mechanical ventilation or wind can have a marked effect on gas distribution. A heat source in an enclosed space, for example, can create a circular flow where the heated gas rises, runs along the ceiling and falls as it cools, then runs along the floor back to the heat source.

Flow patterns can become very complicated and voids may well exist in which the gas may accumulate. Consequently, each workplace scenario could be different. The use of smoke tubes, mathematical modelling or scale models placed in wind tunnels may help to optimize the location of fixed detectors.

Small environmental changes can modify the composition of the atmosphere significantly. For example, where a liquid is present, the rate of evaporation of vapour will increase with temperature, which will significantly increase the toxic vapour concentration. Also, a decrease in pressure will increase toxic vapour concentration.

Some gases tend to stick (sorb) on surfaces, which leads to a decrease of their concentration in air. This behaviour can be significant, especially with low gas concentrations and for reactive gases. Sorbed gases can desorb and produce a response even when there is no gas present in the monitored air. The sorption/desorption properties of each gas should be considered before the measurement task is undertaken. This is particularly important where sampling probes or sample lines are used to convey the gas to the apparatus. The gas flow rate, temperature, length, diameter and material from which the probe or line is made are important factors.
Hygroscopic gases can form aerosols, which could be hazardous. A detector, which is only capable of measuring gas phase concentrations, will underestimate the true hazard.

These properties of gases should be taken into account, in particular when locating detectors or deciding on a sampling strategy, in order to obtain representative indications. Failure to take proper consideration of these gas properties may lead to failure to alarm and failure to take appropriate action or false alarms and incorrect action. It may also lead to false estimates of exposure.

4.2 Effects of water vapour on detection

Water vapour can cause problems for cold apparatus and sampling equipment that is suddenly exposed to a hotter and humid atmosphere. Examples of this situation are leaving a cold store and entering a normal atmosphere, or leaving an air-conditioned environment and entering a humid atmosphere. A fall in temperature or increase in pressure can also cause condensation of water vapour on the sensor inlet or sample line.

Water can condense in or on a sensor or sampling equipment causing a temporary loss of sensitivity or other effect (e.g. increase in response time), until the apparatus warms up and the water evaporates. For example, a film of water condensed onto the cold sensor membrane of an electrochemical sensor may cause temporary inhibition of the measurement. The sensitivity may then recover slowly until the sensor reaches ambient temperature and the film evaporates. During this period, the performance of the apparatus may be impaired and the apparatus may not be able to give an alarm when the gas concentration exceeds the alarm set point.

Sudden changes in humidity, either increasing or decreasing, may cause transient deviations in the indication of an apparatus.

The indication of an apparatus depends on the humidity for most measuring principles. Any effect on the zero indication or sensitivity to the toxic gas may depend on various factors, particularly the measurement gas, type of sensor and exposure period to the humidity level.

4.3 Detection by oxygen deficiency measurement

Oxygen deficiency measurement should never be used to detect toxic gases. The reduction in oxygen concentration by harmful levels of toxic gases is negligible when compared to other effects on oxygen measurement, e.g. variation of ambient temperature.

An oxygen deficient atmosphere can, for example, be created by several different sources of carbon dioxide. Such sources can be leakage causing displacement of the air, combustion consuming oxygen or aerobic bacterial or chemical action. These all result in different reductions in oxygen concentrations for a given carbon dioxide concentration. The limit value for carbon dioxide is 0,5 % (v/v) which corresponds to a reduction of the oxygen concentration of only 0,1 % (v/v) when the air is displaced by carbon dioxide, which is less than the variation caused by other effects on oxygen measurement, e.g. temperature or humidity changes.

5 Measurement tasks

5.1 General

There are an extensive number of workplace conditions where a wide range of toxic gases may be present. An individual process can involve a number of different conditions and job functions, each of which can result in different exposure conditions. Distance from an emission source and physical parameters (release rate, environmental conditions, ventilation) can also have a significant influence on exposure. Rapid fluctuations in concentration or large variations over small distances are common place, therefore the location, timing and duration of measurement are of great importance.

Many types of electrical apparatus are fitted with visual and audible alarms to warn the user of high concentrations of toxic gases. Workplace conditions vary and there are also widely differing light and noise levels in the working environment. It is important to check that the alarm indicators can be seen and/or heard in the actual conditions.

The apparatus will only give a reading for the location where the sensor is positioned or the sampling point if a sampling system is used. A toxic gas atmosphere can build up a few metres from the sampling point. Measurements shall be therefore be carried out all around the intended area of work to minimize risk of exposure.

The readings are only valid for the time they are taken as circumstances can change. Frequent readings are recommended.

A sensor for a specific toxic gas will in general not be able to detect other toxic gases with a specified accuracy. Suitable apparatus should be used for all toxic gases that could be present.

Two basic measurement tasks can be identified where direct-reading apparatus is used:

- general gas detection, e.g. safety warning, leak detection;
- exposure measurement according to EN 482.

5.2 General gas detection

General gas detection includes but is not limited to the following measurement tasks:

- providing visual and audible alarms to warn personnel of potentially harmful toxic gas concentrations (such alarms may be derived from instantaneous or time weighted average measured values);
- area monitoring to provide continuous information on the concentration of toxic substances over a site;
- measurements to monitor the effectiveness of protection systems, e.g. extraction systems;
- spot reading measurements, e.g. to obtain a gas free work permit;
- leak detection in industrial and commercial environments.

Toxic gas detection apparatus may also provide alarm output signals that may be used to initiate subsequent actions such as operation of a ventilation system, shutdown of processes or safe evacuation of the premises.

The following actions should be taken for a gas-free work permit:

a) the gas detector should be checked with clean air and a known concentration of the toxic gas just prior to use in conjunction with a gas free permit;

b) initial measurements should be taken to confirm the absence of the toxic gas throughout the work area;

c) continuous monitoring should be used to confirm the continued absence of the toxic gas;

d) adequate operational procedures should be in place which identify the actions to be taken when toxic gas is detected.

5.3 Exposure measurement

A workplace monitoring strategy involves various measurement and calculation procedures. General performance requirements for procedures for measurement of chemical agents in workplace atmospheres are specified in EN 482. The following paragraphs give a brief outline of the content of EN 482.

The general requirements referred to in EN 482 apply to all measurement procedures, irrespective of the physical form of the chemical agent (gas, vapour, airborne particles) and irrespective of the measurement method used. EN 482 is applicable to measurement procedures with separate sampling and analysis stages and to direct-reading apparatus. The performance requirements include unambiguity, selectivity and expanded uncertainty for minimum specified measuring ranges and averaging times.

NOTE 1 For direct-reading apparatus, the averaging time is related to the internal electrical time constant of the apparatus and the time constant of the sensor. For other procedures, it is normally equal to the sampling time.

NOTE 2 Different countries have different requirements and may use different values for describing safe levels of potentially toxic substances, e.g. GESTIS is a collection of publicly available databases on hazardous substances.

Three basic measurement tasks are defined in the standard. These are:

a) Screening measurements of time weighted average concentration

   Used to obtain relatively crude quantitative information on exposure levels. Such information is used to identify potential health hazards, and to estimate the risk to health based on the likely severity of harm and the probability of its occurrence. These measurements can also determine if the exposure is significantly below or significantly above the (occupational exposure) limit value.

b) Screening measurements of variation of concentration in time and/or space

   Used to

   1) provide information on the likely pattern of the concentration of chemical agents in the air,

   2) identify locations and periods of elevated exposure,

   3) provide information on the location and intensity of emission sources, and

   4) estimate the effectiveness of ventilation or other technical measures.

c) Measurements for comparison with (occupational exposure) limit values and periodic measurements

   Measurements for comparison with (occupational exposure) limit values are used to obtain results of known uncertainty for the average concentration of a chemical agent in the air in a worker’s breathing zone. Periodic measurements are used to determine whether exposure conditions have changed since the measurements for comparison with limit values were performed, or whether control measures remain effective.

The performance requirements for each of these measurement tasks are defined in EN 482 and are translated into performance requirements for electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours in EN 45544-1 and EN 45544-2.

6 Selection of the apparatus

6.1 General

The performance requirements of EN 45544-1 and EN 45544-2 are based on EN 482, which specifies general performance requirements for procedures for measuring the concentration of chemical agents in workplace atmospheres, while EN 45544-1 and EN 45544-3 cover general gas detection. These performance requirements are intended to apply under environmental conditions present at the workplace. However, because a wide range of environmental conditions are encountered in practice, EN 45544-1 to EN 45544-3 specify requirements that shall be fulfilled by measuring procedures when tested under prescribed laboratory conditions.

Important information on the performance characteristics of an apparatus can be obtained from various sources. These include the following:

- apparatus' instruction manual;
- apparatus' manufacturers and suppliers;
- published commercial technical information;
- technical and research publications;
- users' groups;
- test reports.

The selection of electrical apparatus for the direct detection and concentration measurement of toxic gases in workplace atmospheres will depend on many factors. These factors include

a) the measurement task (see Clause 5),

b) the toxic gas(es) which the apparatus is required to detect,

c) the measuring range and indication range (see 6.3),

d) the type of apparatus: fixed, transportable, portable or personal (see Clauses 7 and 8),

e) the limits of operation and the sensitivity to environmental change (see 6.5),

f) electromagnetic environment,

g) requirements for functional safety, if applicable,

h) robustness and shock-resistance,

i) whether combustible gases or oxygen are also to be detected,

j) remote sampling (see 7.4),

k) compliance with the national regulations which require the fulfilment of the performance requirements of EN 45544-1, EN 45544-2 and/or EN 45544-3,

l) visual and/or audible alarm,

m) use in areas where there is a risk of explosive atmospheres (see 6.2),

n) selectivity to the target gases and sensitivity to interfering gases (see 6.4),

o) operating principle and characteristics of the sensor or instrumental technique (see Annex A),

p) time of response, time of recovery and time to alarm (see 6.6 and 6.7),

q) warm-up time,

r) long-term stability (see 8.3.2),

s) mains and/or battery powered,

t) operating time for battery powered apparatus,

u) data logging facilities (see 6.8),

v) frequency of functional checks (see 7.2.4 and 7.3.3.3),

w) frequency of maintenance and calibration (see Clause 8),

x) fitness for purpose, for example, size, weight and durability,

y) training requirements for the reliable operation, maintenance and calibration (see Clause 9),

z) total cost of purchase and operation including calibration and maintenance.

6.2 Performance and electrical tests

For apparatus for the detection of toxic gases, there are three independent categories of tests:

— performance tests to ensure that an apparatus is suitable for the detection of those gases and measuring ranges it is designed for;

— tests for electrical apparatus intended to be used in potentially explosive atmospheres to prevent the ignition of the explosive atmospheres by the apparatus itself, if applicable;

— tests for electrical safety, if applicable.

It is recommended that the performance of the apparatus is tested according to EN 45544-1, EN 45544-2 and EN 45544-3 and that the results are considered for the intended application.

It is a requirement for electrical apparatus intended to be used in potentially explosive atmospheres that they conform to the respective European legislation.

6.3 Indication range, measuring range and uncertainty of measurement

6.3.1 General

The measuring range is defined as the range within which the measured values meet the performance requirements in EN 45544-2 or EN 45544-3. The measuring range is not necessarily identical with the indication range of the measuring apparatus, see Figure 2. This implies that the apparatus can indicate values that do not meet these performance requirements. The apparatus should therefore only be used over the measuring range for which the performance requirements are met.

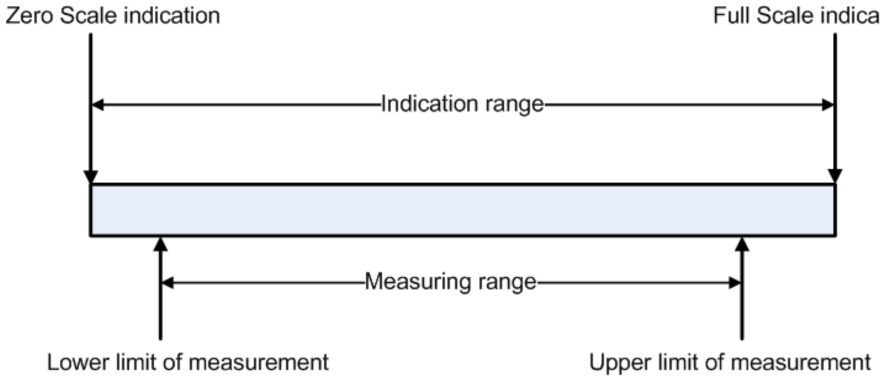

Figure 2 — Apparatus scale showing ranges, indications and limits

6.3.2 Apparatus conforming to EN 45544-2

EN 45544-2 details the performance requirements outlined in EN 482 specifically for electrical apparatus used for the direct detection and direct concentration measurement of toxic gases and vapours intended for exposure measurement. This includes requirements for the lower and upper limits of measurement and requirements for the uncertainty of measurement expressed as the relative expanded uncertainty.

The lower limit of measurement is the smallest value of the measured quantity within the measuring range. It is derived from the zero uncertainty of the apparatus resulting from the variation of measured values in clean air, see Figure 3. Values below the lower limit of measurement are therefore not necessarily an indication that gas is present. The calculation of the lower limit of measurement is described in EN 45544-1.

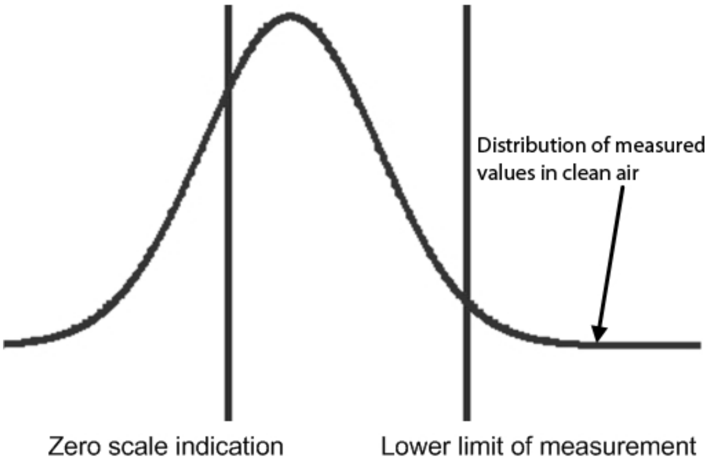

Figure 3 — Example of zero uncertainty

Minimum requirements for the measuring range and relative expanded uncertainty are given in EN 482 for measurements for comparison with limit values and periodic measurements, as shown in Table 1. Apparatus conforming to EN 45544-2 fulfil the requirements of EN 482.

Table 1 — Expanded uncertainty requirements for apparatus conforming to EN 45544-2 for measurements for comparison with limit values and periodic measurements

Reference period	Measuring range	Relative expanded uncertainty
Short-term (e.g. 15 min)	0,5 times to 2 times limit value	≤ 50 %

Long-term	0,1 times to < 0,5 times limit value	≤ 50 %
Long-term	0,5 times to 2 times limit value	≤ 30 %

6.3.3 Apparatus conforming to EN 45544-3

EN 45544-3 details the performance requirements for general gas detection apparatus, e.g. safety warning, leak detection, screening measurements according to EN 482. The measuring range is defined by the manufacturer. In general, the performance requirements for EN 45544-2 apparatus are more stringent than those for EN 45544-3 apparatus.

6.4 Selectivity requirements

Many types of apparatus are not selective to a specific gas. The presence of other gases can influence the measured value by decreasing or increasing it. A decrease should be avoided when the interfering gases are likely to occur. A significantly higher measured value is also not desirable, but can be acceptable in some cases. EN 45544-1 requires that the manufacturer of the apparatus indicate in the instruction manual known interfering gases likely to affect the measurement. This information can be helpful when selecting the apparatus. However, there may be additional interfering gases that are not described by the manufacturer. The selectivity of the apparatus can be enhanced by the use of selective filters where available.

Selectivity requirements can vary from case to case, depending on what is known in advance about the air composition:

a) If the air composition is not fully known in advance, then the apparatus should have a high selectivity taking into account the likely interfering gases. If there are doubts about the validity of the measured values then an additional, higher selectivity analytical technique should be used to verify the measured values from the direct-reading apparatus and/or to identify the interfering gases. This information should be used to decide whether the apparatus can be used.

b) If the composition of the atmosphere is qualitatively known prior to the measurement and there is no known interfering gas for the apparatus, then the selectivity requirement will be low.

6.5 The influence of environmental conditions

Environmental conditions in workplaces vary widely. In general, changes in environmental conditions, e.g. temperature, pressure, relative humidity and air velocity, influence the measurement.

The ranges of environmental conditions where the apparatus complies with the performance requirements of EN 45544-2 or EN 45544-3 are specified in the instruction manual. The manual may also specify extended ranges of environmental conditions where the apparatus can be used but will not comply with these performance requirements.

It should be noted that the ranges of environmental conditions in the instruction manual are specified for constant or slowly changing conditions. Sudden changes in environmental conditions could cause transient responses. For example, transferring portable apparatus from a cold storage area to much warmer conditions could cause significant deviations in measured values until the apparatus stabilises. If sudden changes in humidity can cause transient effects, then EN 45544-1 requires that these are described in the instruction manual.

Apparatus mounted on machinery or exposed to similar levels of vibration should be designed to withstand such vibration or provided with suitable vibration isolation mountings.

6.6 Time of response and time of recovery

The times of response (t_{50} and t_{90}) are measured as the times to reach 50 % and 90 % of the final indication for an increase in concentration, see Figure 4. Similarly, the times of recovery (t_{50} and t_{10}) are the times to reach 50 % and 10 % of the initial indication for a decrease in concentration. The times of response and times of recovery are specified in the instruction manual and their maximum values are specified in EN 45544-2 and EN 45544-3.

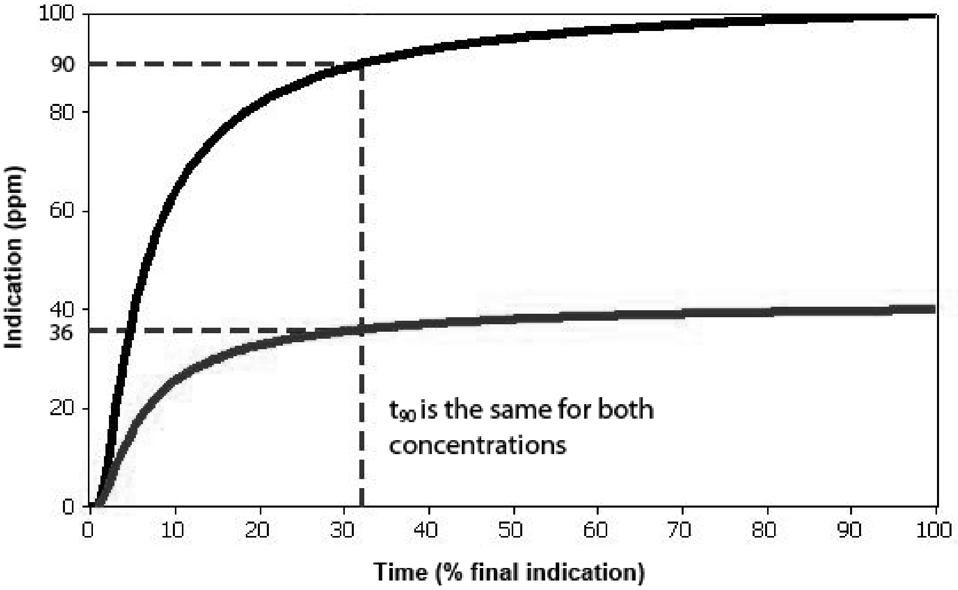

Figure 4 — Gas response curves for test gas volume fractions of 40 ppm and 100 ppm

EN 45544-2 and EN 45544-3 require that the times of response t_{50} and t_{90} do not exceed 60 s and 150 s. However, for some critical applications e.g. warning of acute health hazards, the response time should be as short as possible.

EN 45544-2 and EN 45544-3 require that the times of recovery t_{50} and t_{10} do not exceed 60 s and 300 s. Recovery times to t_{10} are often much longer than response times t_{90}, for example due to gas sorbed on the surfaces of materials at or near the gas inlet of the apparatus or from sample lines or sampling probes.

The addition of a sampling line or probe will cause an additional delay. A maximum delay of 3 s per metre length of sample line or probe is allowed by EN 45544-2 and EN 45544-3.

Special designs of probes, e.g. flotation devices, water traps, may create a dead space that can increase the response time. Appropriate information may be found in the instruction manual.

Within the measuring range, the time of response is generally independent of the gas concentration, as shown in Figure 4. However, for gases that sorb strongly on the sensor and sampling lines, the time of response can increase significantly at low concentrations. Thin films of water or contamination on surfaces can greatly increase the time of response, especially for water soluble gases, e.g. ammonia, chlorine.

6.7 Time to alarm

The time to alarm is the time taken to activate the alarm following a step change from clean air to test gas. The time to alarm is not independent of the gas concentration for a given alarm set point as shown in Figure 5.

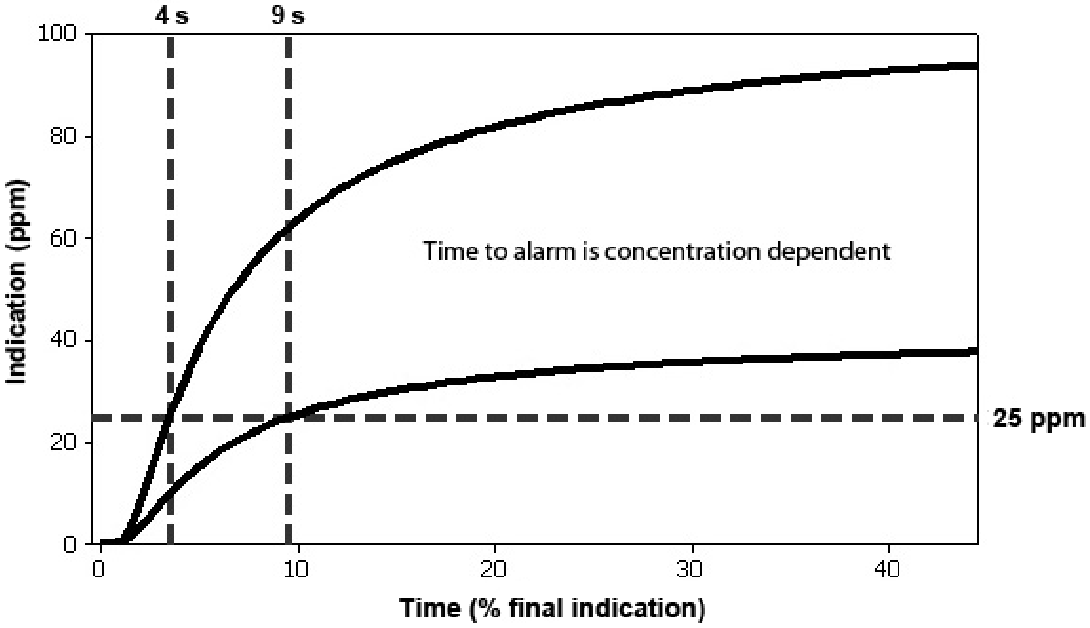

Figure 5 — Time to alarm at 25 ppm set point for test gas volume fractions of 40 ppm and 100 ppm

The following factors influence the time to alarm:

a) alarm set point and gas concentration;

b) delay time of the sampling system, if any;

c) response time of the sensor;

d) signal processing algorithms;

e) transmission times between system components;

f) delay time of alarm devices and switching outputs.

6.8 Data logging

Apparatus fitted with a data logger can be used to provide information on the pattern of exposure. They can be used to measure:

- personal exposure for comparison with limit values, either short-term or long-term;
- exposure pattern during the working shift, to show the maximum concentration and time of exposure peaks;
- variation of concentration in time and/or space to provide information on the pattern of exposure and to identify locations and work activities that give rise to increased exposure.

The following factors should be considered when operating the data logger:

a) the frequency of recording and the size of the memory array

In most electronic data loggers, the frequency of recording is adjustable. The maximum practical frequency is limited by the time constant of the sensor and electronic system and the minimum is related to the measurement task and the rate of concentration changes.

The time period over which data is recorded is related to the frequency of measurement and the memory size. In most apparatus, the size of the memory array is usually fixed and increasing the frequency of measurement will reduce the time period over which the measured values are recorded. Care should be taken to ensure that the data logger will record data over the selected time period.

The mode of operation of the data logger should be known to ensure that no data are lost for example by over-writing.

b) recording of measured values

   Recorded values can be:

   1) individual consecutive values;
   2) individual values but only one out of 'n' values recorded;
   3) individual values that are rounded up or down;
   4) the average of a number of values;
   5) maximum or minimum values.

c) recording of other data

   A variety of information relating to the operation of the apparatus can also be recorded, e.g. alarm status, values above a threshold, faults, calibration information, battery status, location.

d) averaging routines

   Time weighted average values can be determined with respect to the period of measurement or to the reference period of the limit value, usually 15 min (STEL) and/or 8 h (TWA). Typically, the running average of the measured values over the reference period is calculated.

   In cases where data logger information is transferred and recorded on computer, the appropriate identification data, e.g. date, time, apparatus type, serial number, should be recorded and transferred to the data file.

6.9 Instruction manual

Each gas detection apparatus or group of apparatus is provided with an instruction manual. The manual should be available in a language the user can understand. EN 45544-1 requires that it contains complete, clear, and accurate instructions for safe installation, use and maintenance of the apparatus.

7 Operation of toxic gas detection apparatus

7.1 Alarm setting

Alarms and the measures to be taken when an alarm is activated should be specifically defined by the employer for each scenario as a result of a risk assessment. For many substances, the conditions for alarm activation (e.g. set point, time weighted average values and their reference periods) are defined by guidance documents for the particular application.

Gas detection apparatus usually have at least two independent, instantaneous alarms that are usually operated as a pre-alarm and a main alarm. These alarms are activated when the measured value exceeds the respective set point. The pre-alarm allows for taking early intervention options before the gas concentration reaches the main alarm set point. One example is the activation of a ventilation system, which limits an increase in concentration by diluting with air. Activation of the main alarm requires further action, e.g. evacuation. The main alarm is usually latching and the pre-alarm non-latching.

NOTE A latching alarm is an alarm that, once activated, requires deliberate action for deactivation.

Portable and personal apparatus usually have, in addition to instantaneous alarms, time weighted average (STEL and TWA) alarms. These alarms are activated when the calculated time weighted average value exceeds the respective set point. Typically, instantaneous alarms are used to warn against acute exposure to a dangerous concentration of toxic gas (safety), whereas STEL and TWA alarms may be used to warn against longer term health effects.

The alarm set points of the apparatus should be set specifically for the application. The set point should be low enough that associated protective measures can be effective. Conversely, they should be set high enough that false alarms are avoided as far as possible. Frequent false alarms may lead to alarms being ignored. It is recommended that the lowest alarm set point should not be set below two times the lower limit of measurement for apparatus conforming to EN 45544-2 or below 10 % of the measuring range for apparatus conforming to EN 45544-3.

When determining the alarm set points, all delays, e.g. due to gas transport, time of response of the apparatus, the protective measures taking effect, should be taken into account. Lower settings of the alarm set points lead to earlier alarm activation.

7.2 Operation of personal and portable apparatus

7.2.1 General

Effective operation of toxic gas detection apparatus depends not only on its performance but also on the user having a basic knowledge of its correct usage. The performance of the apparatus is affected by its condition, e.g. cleanliness, dryness, and appropriate maintenance.

The user responsible for the apparatus should read the instruction manual thoroughly and follow the instructions on functional check, calibration and other maintenance. All apparatus require~~s~~ inspection and functional checks, as well as maintenance, including calibration and adjustment, to be carried out at regular intervals by a competent person. Calibration and adjustment could require specialist equipment and reliable methods for generating known concentrations of gases. If the user is unable to carry out any of these activities the manufacturer or other competent persons or organisations will be able to advise on appropriate action.

Personnel required to use apparatus should be properly instructed in their use and the actions to be performed in the case of alarm. Personal apparatus should be worn close to the breathing zone. Personal and portable apparatus should be located such that the ambient atmosphere has free access to the sensor inlet.

Apparatus should be handled with care in order to perform reliably. Dropping the apparatus and subjecting it to unnecessary vibrations or extremes of temperature or humidity should be avoided. If the apparatus is dropped, it will be necessary to carry out inspection and functional checks (see 7.2.4) before the apparatus is used further.

High concentrations of gases above the indication range of the apparatus can affect its reliable operation for a short or long time. If such exposure occurs, remove the apparatus and operate it in a clean air environment until the measured value has stabilised. Calibration and adjustment should then be carried out. The sensor performance can still be affected afterwards, e.g. longer time of response. Any additional information in the instruction manual should be followed.

Users should ensure that the apparatus is suitable for use in the expected environmental conditions, see 6.5. The apparatus should be protected from precipitation and dust.

Where sampling pumps and lines are used, it is good practice to use water traps to avoid the intake of water.

At low temperatures, e.g. below 0 °C, batteries have a smaller capacity which reduces the operating time of the apparatus. The operating time remaining after low battery indication can also be shortened.

7.2.2 Transportation

Care should be taken when transporting apparatus to and from the workplace. It is good practice to protect the apparatus from:

a) large temperature changes;

b) large humidity changes;

c) unnecessary vibrations and mechanical shock;

d) direct sunlight;

e) low pressure, e.g. less than 80 kPa, and rapid changes of pressure;

f) precipitation and dust.

7.2.3 Storage

It is important that the apparatus is stored in appropriate conditions. Factors to consider include:

- cleanliness of the storage environment;
- temperature and humidity of the storage environment;
- absence of substances that could impair the performance of the sensor, such as solvents or known sensor poisons.

It should be considered that parts of the apparatus can deteriorate with age, in particular sensors and batteries.

During storage, the apparatus should be tested on a regular basis and batteries charged as appropriate. Some types of batteries, e.g. nickel hydride, can discharge fully in a short time. Rechargeable batteries should be charged in accordance with the recommendations in the instruction manual.

After prolonged storage, a functional check and calibration should be undertaken.

7.2.4 Inspection and functional checks

Inspection and functional checks are intended to verify that the apparatus is in a working state. It is strongly recommended that these checks are performed before each day of use.

For certain applications, e.g. emergency response, there may not be sufficient time to conduct inspection and functional checks before use. In this case, an alternative plan for inspection and functional checks should be implemented which provides an equivalent level of safety.

The routine inspection and functional checks should include:

a) a check that the apparatus is within its calibration period;

b) a visual inspection of the carrying case, apparatus housing and sensor inlet for damage and contamination;

c) a visual inspection that all accessories are in good condition and free from contamination;

EXAMPLE Typical accessories are cables, sample lines and sample probes.

d) a check for aspirated apparatus that there are no leaks in the sampling system;

e) a check to ensure that the batteries have sufficient charge;

f) a check of the zero reading in clean air. A significant non-zero reading can indicate a drift in sensor response or a malfunction of the electronics;

g) a simple function test of the apparatus’ response to gas. This can be undertaken by using a field calibration kit with the target gas or a surrogate gas subject to the manufacturer’s recommendation;

h) a check of the display and audible and/or visual alarms, if fitted. This test can be undertaken in conjunction with g).

The results of the routine inspection and functional checks should be recorded and any remedial action should be completed and verified prior to use.

7.3 Operation of transportable and fixed apparatus

7.3.1 General

Effective operation of transportable and fixed toxic gas detection apparatus depends not only on its performance but also on the user having a basic knowledge of its correct usage, appropriate location and gas properties. The performance of the apparatus is affected by its condition, e.g. cleanliness, dryness, and appropriate maintenance.

Fixed apparatus is used for area monitoring to provide information on the concentration of toxic gases over a site. For exposure measurements or personal protection, additional measures may be required, e.g. portable apparatus. The following types of fixed systems are commonly used:

a) Systems consisting of gas detection transmitters that are connected to a central control unit. These systems are suitable for the majority of industrial site monitoring applications. The response time of the whole system is mainly determined by the response time of the transmitter.

b) Systems where the gas is transported from the sampling point to the measuring equipment by a sample line. The response time of the whole system is determined by the response time of the central measuring equipment, the sampling flow rate and the sample line length.

c) Systems such as b) but with more than one sampling point. The gas from each sampling point is sampled sequentially by the central measuring equipment. These systems should only be used where comparatively static process conditions are found. The response time of the system should be adequate for its intended use. The response time of the system is dependent on the number of sampling points and the measuring time at each sampling point. The measuring time at each sampling point is determined by the response time of the central measuring equipment, the sampling flow rate and the sample line length. It should be recognized that high concentration peaks of short duration will not necessarily be detected because the concentration at a single sampling point is not continuously measured.

The response time of the gas detection system should be sufficiently short to provide an alarm and/or executive action before a hazardous concentration of toxic gas occurs.

For the reliable operation of a fixed gas detection system, each transmitter or sampling point should be placed in a suitable location according to its individual application. Many factors should be considered when specifying the monitoring site and determining the number of sensors required, including industry standards and/or regulatory authority requirements. It is important that the manufacturer's installation manual is read thoroughly and the instructions followed.

High concentrations of gases above the indication range of the apparatus can affect its reliable operation for a short or long time. Exposure to poisons can also adversely affect their operation.

If such exposure occurs, the apparatus should be allowed to recover until the measured value is close to zero. A calibration should then be carried out. Any additional information in the instruction manual should be followed.

7.3.2 Installation

Gas detection apparatus should be installed and operated in such a way that only authorized personnel have access to functional controls of the apparatus.

Gas detection transmitters and sampling points should be placed such that gas accumulations are detected before they create a significant hazard. The placement of the transmitters and sampling points should be determined following the advice of experts having specialist knowledge of gas dispersion, experts having knowledge of the process plant system and equipment involved, and health and safety and engineering personnel. The agreement reached on the location of transmitters and sampling points should be recorded.

Transmitters and sampling points should be installed in locations such that they are not vulnerable to mechanical damage or water damage from normal operations in the area. Transmitters and sampling points should be readily accessible to permit regular calibration, maintenance and electrical safety inspection. If it is impossible to achieve regular access to the transmitter and sampling points then a remote gas calibration facility should be provided.

The location of transmitters and sampling points requires a detailed knowledge of many factors. The following are some, but not all, of the important factors to consider when choosing the location:

a) site design, e.g. position of plant and equipment, whether it is an indoor or outdoor site, and the topography of the site;

b) the potential sources of release, the location and nature of the potential gas sources (e.g. high pressure pipelines, pipelines containing liquids, storage vessels, quantity of chemicals used or stored, source temperature, density and distances) and its dispersion;

c) access points such as doorways, windows, tunnels, trenches;

d) possible ingress of gas into a building or enclosure from an external source;

e) structural arrangements (e.g. walls, troughs, partitions, equipment) which could allow gas to accumulate in compartments;

f) localized ventilation equipment;

g) chemical and physical data on the chemicals used, e.g. volatility, density;

h) local environmental conditions, e.g. wind speed, direction, precipitation;

i) siting to limit the chance of tampering;

j) access for inspection and maintenance.

Gas detection transmitters in exposed sites should have adequate weather protection measures. They can be adversely affected by driving rain, snow, ice, dust and steam. Certain materials, although otherwise suitable for sample lines or weather guards, can deteriorate due to the effects of sunlight or other environmental conditions.

Aerosols, such as dust, liquid droplets and adhesive sprays, can block sensor inlets or sample lines and their filters, causing loss of sensitivity or function. Such contamination may require regular cleaning or similar maintenance. Sample extraction and filtration may be required.

If the fixed system does not operate due to failure of individual elements of the system, fault of the power supply or maintenance activities, then the safety of the premises should be maintained by other measures, e.g. portable apparatus.

7.3.3 Commissioning and regular inspection

7.3.3.1 General

It is recommended that an initial gas calibration (7.3.3.2) is carried out after installation. Subsequently, both inspection (7.3.3.3) and calibration (8.3) should be periodically performed to ensure correct operation.

7.3.3.2 Commissioning and initial calibration

The complete gas detection system including all ancillary equipment should be inspected prior to use to ensure that the design and installation has been carried out in a satisfactory manner. A full set of operating instructions, plans and records for the complete system should be supplied. The instructions should include details on use, testing, calibration and operation.

For maintenance and record purposes, plans of the installation should be provided that show the locations of all parts of the system (control units, gas detection transmitters, sampling points, etc.) together with the routes and specifications of all cables. The records should be updated when any changes are made to the installation.

After installation on site, each sensor should be calibrated and adjusted by a competent person according to the instruction manual.

7.3.3.3 Regular inspection

The gas detection system should be regularly inspected by a competent person. The inspection should be in accordance with the instruction manual and the specific requirements of the application. The intervals can be specified by the manufacturer or by any local regulations.

The inspection should include the following:

a) a check that the apparatus is within its calibration period;

b) visual inspection of gas detection transmitters for mechanical damage;

c) visual inspection of the gas inlets or sample lines (e.g. for contamination by dust or dirt);

d) visual inspection of all accessories, e.g. sampling probe, weather protection, to ensure that they are in good condition and free from contamination;

e) visual inspection of the control unit to ensure that the system is fully operational; e.g. inspection of the fault signals and alarm status of all the gas detection transmitters;

f) triggering of test functions for display and visual indicators during operation without triggering switching outputs.

The manufacturer’s instructions should be followed with regard to:

- periodic cleaning of filters, optical components, etc.;
- assembly of required materials, e.g. auxiliary gas for some apparatus;
- safe operation of the system.

The results of the routine inspection should be recorded and any remedial action should be initiated immediately.

7.4 Sample lines and sampling probes

Sample lines are usually permanently installed in fixed installations. Sampling probes associated with transportable and portable apparatus are usually short (of the order of 1 m) and rigid, however, they can be telescopic and can be connected to the apparatus by a flexible tube. In the following, the term sample line includes sampling probe.

Consideration should be given to water condensation that can block the sample line, or lower the concentration and hence the measured value due to the gas sample dissolving in the liquid. This effect can be minimized by heating the sample line. It is a requirement for electrical equipment intended to be used in potentially explosive atmospheres that it conforms to the respective European legislation.

The material of the sample lines should be selected to avoid sorption or reaction of the gas being detected.

Any leakage in or out of the sample line should be prevented.

Sample lines should be as short as possible since the response time is determined by the overall length. Moreover, concentration peaks will be broadened by long sample lines. In addition, care should be taken to avoid dilution of the sample by leakage of air into the sample line.

The flow rate through the sample line should be monitored. A flow failure indication should be given when the flow rate falls below the minimum value required to meet the time to alarm necessary for the application.

Hazards arising from venting exhaust gas from the sampling system should be avoided.

Filters may be used to protect the apparatus from dust and interfering gases or poisoning substances. A particulate filter may be required at each sampling point so that the sample line is kept clean internally. Additional devices are required for this purpose where mists may be sampled.

7.5 Accessories

The use of any accessory, e.g. collecting cones, windshields, splashguards, chemical selective filters is likely to have some effect on the measurements. Normally, the main effect is on the sensitivity, time of response and time of recovery. The user should only use accessories for which the effect on the apparatus’ characteristics is known. This information can be obtained either from the manufacturer or from validation.

Filters can be used to protect the apparatus from dust and interfering gases or poisoning substances. Filters increase both the time of response and the time of recovery.

The lifetime of filters is dose (the product of gas concentration and time) dependent for both dust and interfering gases. They should be checked and replaced regularly. For details, refer to the instruction manual.

Condensation, which can be liquid or frozen, can completely block the filter.

Accessories located near the sensor inlet, such as collecting cones and splashguards, should be cleaned regularly in order to avoid absorption resulting in false measurements.

8 Maintenance and calibration

8.1 General

Sensors have limited lifetimes and their sensitivity can change over time. Furthermore, some gases, vibration and shock during transport can cause certain types of sensors to deteriorate. Dust and dirt can also impair gas transport to the sensor. This is a major reason for requiring frequent inspection and functional checks (see 7.2.4 and 7.3.3.3), maintenance and calibration of gas detection apparatus.

Inspection and functional checks on portable apparatus and regular inspection of transportable and fixed apparatus may be carried out by the user.

Maintenance and calibration of all types of apparatus should only be undertaken by trained personnel. If the user does not have a maintenance and calibration facility or trained personnel to carry out the work, then it should be performed by the manufacturer or another qualified organization.

8.2 Maintenance

The manufacturer’s instructions should be followed regarding the replacement of consumable parts and fitting of spare parts. Both types of parts should meet the specifications and tolerances of the original in order to maintain the specified performance of the gas detection apparatus, and therefore its conformity to EN 45544-1, EN 45544-2 and EN 45544-3, and to maintain its electrical safety in explosive atmospheres, if applicable.

Consumables (e.g. filters) should be checked and replaced regularly.

Spare parts (e.g. electrochemical sensors) and consumables (e.g. filters) can require specific storage conditions. Such spare parts and consumables can deteriorate in storage owing to unsuitable conditions or ageing.

The guidance on storage conditions and lifetime in the instruction manual should be followed. Spare parts and consumables should be used before any expiry date on the packaging.

8.3 Calibration

8.3.1 Procedure

Calibration should be carried out in accordance with the instruction manual. Target gas should preferably be used for calibration. However, if recommended by the manufacturer, this calibration may be performed with a surrogate gas to which the apparatus responds in a defined way. The use of surrogate gas introduces additional tolerances due to variability in the sensor manufacturing process. Relative sensitivities between surrogate gas and target gas can change over time. Information from the manufacturer concerning additional tolerances and any time limits on use of surrogate gas for calibration should be followed.

The calibration of an apparatus involves:

a) Preparation of calibration gas mixture(s)

   The preparation of gas mixtures in the concentration range of interest is often difficult. The easiest and most common method is to use a gas cylinder with a certified gas concentration. The expiry date of the gas mixture should be complied with. Note that different gas mixtures have different lifetimes. For gases that can adsorb on the cylinder walls, it is important to consider the minimum usable pressure, which is typically user-defined. If a test gas mixture is not available in a gas cylinder, then the recommendation of the gas detector manufacturer should be followed. Alternative methods of generating calibration gas mixtures include gas generators and permeation tubes.

b) Exposing the apparatus to the calibration gas mixture(s)

   The manufacturer will generally provide a suitable calibration mask as an accessory for diffusion type apparatus. An alternative for some gases is the use of an exposure chamber. For aspirated apparatus, the gas should be applied at the gas inlet of the sample line (if any). For certain gases, however, due to difficulty of handling, calibration by the user is not advised by the manufacturer.

c) Adjusting the apparatus zero and span

   Gas detection apparatus should be installed and operated in such a way that unauthorized persons have no access to the controls. Software-based apparatus usually have password-protected access. For the reliable operation of gas detection apparatus, passwords or special access tools should only be accessible to authorized persons.

   The apparatus is usually calibrated in two stages. Firstly, the sensor is exposed to zero gas and the zero adjusted to give the zero scale indication. Secondly, the sensor is exposed to the gas concentration for which the most accurate measurement is required or where the main alarm is set. The span is then adjusted to give the concentration reading.

During the calibration procedure, the indication before any adjustment should be recorded and the values should be compared with those of previous calibrations. If this comparison leads to a result clearly different from the previous calibrations, appropriate remedial action should be taken, for example, shortening the calibration period or replacement of the sensor. In this case, all measurements subsequent to the last calibration should be questioned.

8.3.2 Calibration period

The calibration and, if necessary, adjustment procedures demonstrate that the gas detection apparatus is able to measure the target gas with sufficient accuracy. However, between the calibrations, the performance of the apparatus is unknown and the deviations are likely to increase with time. The calibration period should therefore be chosen appropriately.

When choosing the calibration period, factors such as sensor characteristics, type of apparatus, static and dynamic conditions of temperature and humidity, dust, poisoning, corrosive atmospheres and experience of the user in similar situations, should be considered. Appropriate calibration periods can range from days to months.

It is good practice to determine the calibration period as follows:

a) if there is sufficient reliability and stability data available for the apparatus and sensors used in a specific application, the calibration period can be derived from this data for applications with similar operating conditions;

b) if sufficient data is not available, two calibrations should be conducted at short intervals following commissioning. If it is not necessary to adjust the apparatus at these calibrations, the interval can be increased. This procedure should be repeated until the calibration period specified in the instruction manual is reached;

EXAMPLE An appropriate short interval could be four weeks.

c) if adjustment is necessary at two successive calibrations, the calibration period should be shortened until no such adjustment is necessary. If, however, the final calibration period is unreasonably short, a more suitable sensor, apparatus or measuring principle should be considered.

An adjustment is necessary if the deviation of the measured value is outside the limits required by the application or if the minimum requirements for stability of the apparatus as defined in EN 45544-2 and EN 45544-3 are not met. EN 45544-2 states that the deviation within one calibration period should not exceed the lower limit of measurement in clean air and 20 % of the measured value in test gas. EN 45544-3 states that the deviation within one calibration period should not exceed 10 % of the measuring range in clean air and 20 % of the measured value in test gas.

8.4 Operation test

The operation test should demonstrate that the apparatus is able to perform its intended function. The operation test should include:

a) calibration (see 8.3);

b) test of the whole safety function, from the gas inlet or measuring point to the executive action (e.g. initiating mechanical ventilation, audible and visual alarms);

c) comparison of the response time or time to alarm of the apparatus (including sample line if fitted) with the specification;

d) verification of parameter settings;

e) a check of the signalling and recording devices;

f) a check that rechargeable batteries have sufficient charge;

g) a check of the condition of accessories and consumables (e.g. hoses, filters) which should be replaced if necessary.

The operation test should be performed at the time of commissioning and repeated at regular intervals, e.g. 1 year.

8.5 Records

It is good practice to record the use, maintenance and calibration of each apparatus. This comprises:

a) location for fixed apparatus and of any changes;

b) maintenance history;

c) calibration record;

d) record of regular inspections and functional checks;

e) record of operation tests;

f) record of the use of the apparatus, e.g. the date used, the measurement task, the name of the operator, etc.

9 Training

9.1 General

For most apparatus, training is required for both the operator and those responsible for its maintenance and calibration. A distinction is made between training for operators and training for those responsible for maintenance and calibration because, generally, those operating the apparatus will not be responsible for its maintenance and calibration.

Training should be performed by persons competent to train and knowledgeable about the apparatus and its use.

The training should also reflect the actual work environment and the responsibilities of the personnel concerned.

Periodic refresher training courses should be given.

Records should be kept of the training of personnel involved in the operation, maintenance and calibration of the apparatus.

9.2 Operator training

Operator training should be designed to ensure the full understanding of the operation of the apparatus including:

a) checks before use;

b) battery and functional checks;

c) the design of a fixed gas detection apparatus and the interactions between the individual components (e.g. control unit, transmitters, sampling system)

d) operation of the visual and audible warning systems;

e) whom to contact if the gas detection apparatus is believed to be malfunctioning.

It is particularly important that operators should have instructions to be followed in the event of a gas detector alarm, fault or other special state.

9.3 Maintenance and calibration training

Training should be designed for those charged with maintenance, calibration and adjustment of the gas detection apparatus. It should include details of:

a) basic knowledge of gas detection, covered by Clause 4, Clause 5, 6.3 to 6.7, Clause 7 and Clause 8 of EN 45544-4:2016;

b) basic knowledge of the measurement principle;

c) where appropriate, the design of a fixed gas detection apparatus and the interactions between the individual components (e.g. control unit, transmitters, sampling system);

d) the instruction manual(s);

e) the apparatus functions, e.g. controls, indications, alarm and special state indications and messages,;

f) the meaning of indications, alarm and special state indications and how to deal with them;

g) the test gases to be used, their properties and correct handling and storage, including climatic conditions;

h) how to perform calibration of the gas detection apparatus and how to interpret the results;

i) when and how to adjust the gas detection apparatus.

Annex A
(normative)

Commonly used measurement principles

A.1 General

Tables A.1 to A.11 give a brief description of the operating principles and the characteristics of commonly used apparatus. The information should only be used as a guide. Developments in both sensor and apparatus technologies are advancing all the time and new advances can make some of the information obsolete. The user should check the current operation parameters with the sensor or apparatus manufacturer. The list is ordered alphabetically.

A.2 Chemiluminescence

Table A.1 — Chemiluminescence

Characteristics	**Comments**
Operating principle	In some chemical reactions, intermediates or products are produced in an excited electronic state. Chemiluminescence is the characteristic emission of radiation from this state. The emission can be measured by a photometer and provide a selective means of measuring gas concentration. Chemiluminescence apparatus is primarily used for measurement of oxides of nitrogen and ozone. The apparatus requires a mixing chamber where the target gas interacts with reactant. The reactants are ozone for NO measurement (NO_2 is determined by prior reduction to NO) and ethylene for ozone measurement.
Typical measurement tasks	Measurement with fixed, transportable and portable apparatus.
Typical measurement range	From a few ppb (v/v) to thousands of ppm (v/v).
Time of response	From seconds to minutes.
Selectivity	High selectivity.
Influence of environmental parameters:	
Pressure	No (compensated)
Temperature	Yes
Humidity	No
Dust (other than inlet blockage)	No
Air speed (for diffusion systems)	No
Vibrations	No
Limitations	Requires reagent gas (e.g. ozone, ethylene).

A.3 Colorimetry

Table A.2 — Colorimetry

Characteristics	**Comments**
Operating principle	Gas adsorbs and reacts with a supported chemical reagent, usually in the form of a paper tape, resulting in a colour change of the reagent. The resulting stain is monitored electronically, commonly using a light scattering technique. High sensitivity is possible with an extended sampling period.
Typical measurement tasks	Suitable for a wide range of measurement tasks including exposure measurement and general gas detection. Paper tape apparatus are not suitable for personal exposure monitoring because of the size/weight of the apparatus. Often used to monitor isocyanates and inorganic hydrides.
Typical measurement range	From ppb (v/v) to low ppm (v/v)
Time of response	Of the order of minutes, can increase at low temperatures.
Selectivity	Depends on the gas or vapour.
Influence of environmental parameters:	
Pressure	No
Temperature	No
Humidity	Yes (for most substances at least 20 % relative humidity is necessary)
Dust (other than inlet blockage)	Yes
Air speed (for diffusion systems)	No
Vibrations	No
Limitations	a) Usually paper tapes have a limited shelf-life. b) Certain chemicals can act as bleaching agents and can destroy the colour change.

A.4 Electrochemical

Table A.3 — Electrochemical

Characteristics	**Comments**
Operating principle	Operation of an electrochemical sensor depends upon changes in the electrical parameters of electrodes (in contact with an electrolyte) due to redox reactions of the gas on the surface of the electrodes. These reactions are usually catalysed. Gas diffuses to the sensing electrode and is either oxidized (e.g. CO, H_2S, SO_2, NO, HCN, HCl) or reduced (e.g. NO_2, Cl_2). The electrodes and electrolyte are usually confined by semi-permeable membranes that allow the gas to permeate to the electrode-electrolyte interface. Typically, the diffusion of gas into the sensor is limited by a capillary or solid membrane.
Typical measurement tasks	Suitable for a wide range of measurement tasks including exposure measurement and general gas detection.
Typical measurement range	From ppb (v/v) to thousands of ppm (v/v)
Time of response	From a few seconds to minutes depending on the gas and temperature.
Selectivity	Not selective: other oxidizing or reducing gases can interfere.
Influence of environmental parameters:	
Pressure	Can be sensitive to static or transient changes in pressure
Temperature	Yes
Humidity	Can be sensitive to static or transient changes. Continuous low or high humidity can damage the sensor.
Dust (other than inlet blockage)	No
Air speed (for diffusion systems)	Yes
Vibrations	No
Limitations	a) The sensor can be affected by other gases resulting in a loss of sensitivity. b) Depending on the type of sensor and the gas to be measured, the sensor can gradually be consumed by the target gas. c) Depending on the sensor, the presence of oxygen can be required for operation.

A.5 Flame-ionization

Table A.4 — Flame-ionization

Characteristics	**Comments**
Operating principle	This detection principle utilizes electrical (ionization) changes in a hydrogen flame. Ionized atoms or molecules generated in the flame are collected on an electrode and measured as an electrical current. The electrical field is generated by applying a positive potential of up to a few hundred volts to an electrode near the flame (the gas jet acts as the counter electrode). A flame of pure hydrogen (and air) produces a negligible number of detectable ions giving a very low base current. The technique has a linear response over a wide concentration range.
Typical measurement tasks	Suitable for a wide range of measurement tasks including exposure measurement and general gas detection but not for personal exposure monitoring because of the size/weight of the apparatus.
Typical measurement range	From 100 ppb (v/v) to several % (v/v).
Time of response	Seconds, depends on detector design and flow rate.
Selectivity	Non-selective
Influence of environmental parameters:	
Pressure	Yes
Temperature	No (if heated)
Humidity	No
Dust (other than inlet blockage)	No
Air speed (for diffusion systems)	Not applicable
Vibrations	No
Limitations	a) Fuel (hydrogen) and clean air supply are required. b) The sensor is unsuitable for carbon monoxide and most inorganic gases. c) The sensor cannot be used with high concentrations of non-combustible gases that will extinguish the flame, e.g. halon. d) Halogenated hydrocarbons reduce the response when the apparatus is calibrated for measuring the total carbon content of the gas mixture. e) Silicon compounds can coat the electrodes which makes the sensor inoperative.

A.6 Gas chromatography

Table A.5 — Gas chromatography

Characteristics	**Comments**
Operating principle	Gas chromatography is a technique for separating multicomponent mixtures. A mixture of gases is injected into a gas stream and is separated into individual components by a specific chromatographic column. The individual gases elute from the column at characteristic times (retention time) and are detected by an appropriate non-selective detector. Examples of detector types used are flame ionization, photo ionization, electron capture, mass spectrometry and thermal conductivity. Chromatographic columns are typically long tubes made of metal, glass, PTFE or silica; typically with capillary columns with stationary phase adsorbent.
Typical measurement tasks	A range of measurement tasks. Transportable and portable gas chromatographs are available.
Typical measurement range	Depends on the type of detector used and chromatographic column.
Time of response	Slow response: depends on the time required to elute the gas from the chromatographic column.
Selectivity	Highly selective; selectivity depends on type of chromatographic column and operation parameters, and detector type.
Influence of environmental parameters:	
Pressure	No
Temperature	No (normally, sample injection port, column and sensor are temperature controlled)
Humidity	No
Dust (other than inlet blockage)	No
Air speed (for diffusion systems)	Not applicable
Vibrations	No
Limitations	Usually requires a “clean” dry carrier gas, e.g. air, nitrogen, helium, hydrogen. Hydrogen is also required when used with a FID.

A.7 Infrared photometry

Table A.6 — Infrared photometry

Characteristics	**Comments**
Operating principle	Infrared radiation (from a bulb lamp or a laser diode and usually modulated) is passed through a sample cell and is absorbed by the target gas. The optical path can have a length of several centimetres and can use multiple reflection. The radiation is measured by thermal, quantum or photo-acoustic detectors. The concentration of gas is usually measured by comparing a sample and reference in a single or double beam apparatus to compensate for changes in beam intensity. Non-dispersive (e.g. interference filters) and sometimes dispersive techniques are used to select the appropriate infrared wavelength. Many gases absorb in the middle infrared region (2 µm to 14 µm). There are no known poisoning effects. The principle of this type of apparatus allows the use of self- diagnostics to verify the response to the gas.
Typical measurement tasks	Suitable for a wide range of measurement tasks including exposure measurement and general gas detection.
Typical measurement range	ppm (v/v) to 100 % (v/v)
Time of response	From a few seconds to tens of seconds
Selectivity	Depends on technology, gas and selection of wavelength
Influence of environmental parameters:	
Pressure	Yes (can be compensated)
Temperature	Yes (can be compensated)
Humidity	Yes
Dust (other than inlet blockage)	Yes
Air speed (for diffusion systems)	Yes
Vibrations	Depends on technology
Limitations	Cannot detect certain molecules, e.g. Cl_2 and other halogens.

A.8 Ion mobility spectrometry

Table A.7 — Ion mobility spectrometry

Characteristics	**Comments**
Operating principle	Certain compounds are capable of being ionized in air (e.g. using a radioactive source such as ^{63}Ni which is a beta-particle emitter or corona discharge) to produce characteristic ionic species. Passage of ions is controlled by a gate potential to either pass or block their passage into the drift tube (usually of the order of a few centimetres in length) where they migrate in air at atmospheric pressure under an electrostatic potential of approximately 200 V/cm. The ions are detected at the end of the drift tube using an electrometer. Species can be separated according to their mobility, which is a function of their mass, charge and ionic state.
Typical measurement tasks	For general gas detection using with fixed, transportable and portable apparatus.
Typical measurement range	From ppb (v/v) to ppm (v/v).
Time of response	Of the order of seconds.
Selectivity	Selective (generally)
Influence of environmental parameters:	
Pressure	No (compensated)
Temperature	No (heated)
Humidity	Yes
Dust (other than inlet blockage)	No
Air speed (for diffusion systems)	Not applicable
Vibrations	Yes
Limitations	a) Limited number of gases detectable. b) Some types of apparatus require a radioactive source. c) Water vapour can affect sensitivity.

A.9 Mass spectrometry

Table A.8 — Mass spectrometry

Characteristics	**Comments**
Operating principle	Gases are injected or continuously aspirated into an ionization chamber where they undergo ionization and fragmentation. Fragment ions are separated according to their mass-to-charge ratio and detected by a Faraday cup or an electron multiplier. Relative intensities of the ions generated from a specific compound are constant under steady operating conditions. The whole system is under high vacuum.
Typical measurement tasks	Measurement of a wide range of gases in fixed, transportable and portable apparatus. Simultaneous multi- component identification and measurement.
Typical measurement range	Usually from ppb (v/v) to ppm (v/v) (depending on the gas and interferents).
Time of response	Depends on technology.
Selectivity	High selectivity, especially when coupled to a gas chromatograph.
Influence of environmental parameters:	
Pressure	No
Temperature	No
Humidity	No
Dust (other than inlet blockage)	No
Air speed (for diffusion systems)	Not applicable
Vibrations	Yes
Limitations	a) Complex apparatus. b) Extensive operator training may be required for more sophisticated apparatus. c) High concentrations can saturate the detector and produce memory effects impairing measurements of very low concentrations.

A.10 Photo-ionization

Table A.9 — Photo-ionization (PID)

Characteristics	**Comments**
Operating principle	The detection principle is based on ionization of gaseous compounds by ultraviolet radiation. The gas is radiated by a UV source with a lamp energy in the range 8 eV to 12 eV. Molecules are photo-ionized and the resulting ion current is measured across an applied electric field. Molecules having an ionization potential lower than the excitation energy of the lamp are detected. Substances with an ionization potential just below the energy of the UV lamp will induce a significantly lower signal than substances with a much lower ionization potential. In principle, as the measurements are performed in air, all substances having an ionization potential higher than oxygen (12,1 eV) cannot be detected. The sensor has a linear response over a wide concentration range.
Typical measurement tasks	Suitable for a wide range of measurement tasks including exposure measurement and general gas detection.
Typical measurement range	From 100 ppb (v/v) to thousands of ppm (v/v).
Time of response	Seconds, depends on detector design and flow rate
Selectivity	Non-selective.
Influence of environmental parameters:	
Pressure	Yes
Temperature	No
Humidity	Yes
Dust (other than inlet blockage)	Yes (in combination with high humidity)
Air speed (for diffusion systems)	No
Vibrations	No
Limitations	a) The lamp has a limited lifetime, especially higher energy (> 10,6 eV) lamps. b) Cannot detect carbon monoxide. c) High concentrations of methane (percentage levels) in the presence of the target gas reduce sensitivity by inhibiting ionization. d) The UV lamp may require regular cleaning.

A.11 Semiconductor

Table A.10 — Semiconductor

Characteristics	**Comments**
Operating principle	The sensor is based on electrical conductivity effects associated with chemisorption of gases on a semiconductor surface: they are effectively gas sensitive resistors. The gas concentration is monitored by measuring changes in the surface conductivity. Semiconducting material (commonly metal oxide often based on tin dioxide) is electrically heated to a few hundred degrees Celsius. Electrodes are implanted or otherwise mounted on the surface. Resistance changes can occur when the semiconducting element is exposed to gas other than air.
Typical measurement tasks	a) Semiconductors are mainly suitable for alarm-only apparatus for general gas detection. b) Used to measure a wide range of gases.
Typical measurement range	Sensors are used for the detection of gases and vapours over a wide range of concentrations but usually in the ppm (parts per million) range, e.g. 1 ppm (v/v) to 1 000 ppm (v/v). They have a non-linear response.
Time of response	Depends on gas
Selectivity	Generally non-specific and susceptible to interference.
Influence of environmental parameters:	
Pressure	No (generally)
Temperature	Yes
Humidity	Yes
Dust (other than inlet blockage)	No
Air speed (for diffusion systems)	Yes (generally)
Vibrations	No
Limitations	a) There can be a wide variation in sensitivity to particular gases between sensors. b) After exposure to high gas concentrations, the sensor can need a recovery time of several hours and can have irreversible changes to its zero gas reading and sensitivity. c) Exposure to basic or acidic compounds, silicones, organo-lead, sulphur compounds, cyanides and halogenated compounds can have a significant effect on the sensitivity. d) Oxygen concentration and humidity can have a significant effect on sensitivity. e) New sensors can need a long “burn in time“(up to weeks) for stabilization of zero and sensitivity before calibration. Further preconditioning can be necessary after long periods (more than one day) without power. f) Hydrogen sulphide sensors can require reactivation with the gas after operation for several months in clean air.

A.12 Ultra-violet visible photometry

Table A.11 — Ultra-violet/visible photometry

Characteristics	**Comments**
Operating principle	Ultra-violet or visible radiation (from a bulb lamp or LED and usually modulated) is passed through a sample cell and is absorbed by the target gas. Detection is usually by quantum detectors. The spectral region of interest is 200 nm to 800 nm. Some gases, e.g. NO_2, SO_2, Cl_2, O_3, unsaturated organic compounds, absorb strongly in this region.
Typical measurement tasks	Suitable for a wide range of measurement tasks including exposure measurement and general gas detection but not for personal exposure monitoring because of the size/weight of the apparatus.
Typical measurement range	From ppb (v/v) to thousands of ppm (v/v).
Time of response	Seconds
Selectivity	Depends on gas and selection of wavelength but less selective than infrared photometry.
Influence of environmental parameters:	
Pressure	Yes
Temperature	Yes
Humidity	Yes
Dust (other than inlet blockage)	Yes
Air speed (for diffusion systems)	Not applicable
Vibrations	Depends on technology
Limitations	a) Optical components may require regular cleaning. b) Certain organic vapours can interfere.

Annex B
(informative)
Table of significant changes in comparison to EN 45544-4:1999

	Type		
	Minor and editorial changes	**Extension**	**Substantial change**
Introduction shortened. The references to EN 45544-2 and EN 45544-3 have been re-titled as these standards have recently been revised. Part 2 defines requirements for apparatus used for exposure measurement according to EN 482. Part 3 defines requirements for apparatus used for general gas detection.			X
Normative references reduced in number.			X
Definitions modified and extended. In particular, new definition of Gas Detection Transmitter and Control Unit; definitions of uncertainty modified in line with latest version of EN 482; Fig 1 now shows Warm up time in clean air rather than standard test gas; definitions added for Adjustment and Special State.			X
Clause 4 now covers Properties and detection of toxic gases and vapours. New material added and sections incorporated from old Clause 12.			X
Clause 5 now covers Measurement tasks. It describes apparatus defined in the current version of EN 45544-2, whose requirements are based on the current version of EN 482, and in the current version of EN 45544-3.			X
Clause 6 now covers Selection of the apparatus. Expanded text with figures on Indication range, measuring range and uncertainty of measurement (6.3) including revised text on apparatus conforming to EN 45544-2 (6.3.2) and EN 45544-3 (6.3.3); Time of response and time of recovery (6.6); Time to alarm (6.7).			X
Clause 7 now covers Operation of toxic gas detection apparatus. It contains new text on Alarm setting (7.1), and additional text on Sample lines and sampling probes (7.4).			X
Clause 8 now covers Maintenance and calibration with additional text on Calibration (8.3) and revised text on Operation test (8.4).			X

Clause 9 now covers Training and contains revised and additional text.			X
Annex A now describes commonly used measurement techniques which were previously in the main body of the text. The number of techniques has been reduced from 16 to 11, reflecting current usage, and their descriptions revised.			X
A Bibliography has been added.			

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