BS ISO 16900-9:2015

BSI Standards Publication

Respiratory protective devices — Methods of test and test equipment

Part 9: Determination of carbon dioxide content of the inhaled gas

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National foreword

This British Standard is the UK implementation of ISO 16900-9:2015.

The UK participation in its preparation was entrusted to Technical Committee PH/4, Respiratory protection.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Respiratory protective devices — Methods of test and test equipment —

Part 9: Determination of carbon dioxide content of the inhaled gas

Appareils de protection respiratoire — Méthodes d'essai et équipement d'essai —

Partie 9: Dosage de la teneur en dioxyde de carbone du gaz inhalé

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Foreword

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

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

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

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

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

The committee responsible for this document is ISO/TC 94, *Personal safety — Protective clothing and equipment*, Subcommittee SC 15, *Respiratory protective devices*.

ISO 16900 consists of the following parts, under the general title *Respiratory protective devices — Methods of test and test equipment*:

— *Part 1: Determination of inward leakage*

— *Part 2: Determination of breathing resistance*

— *Part 3: Determination of particle filter penetration*

— *Part 4: Determination of gas filter capacity and migration, desorption and carbon monoxide dynamic testing*

— *Part 5: Breathing machine, metabolic simulator, RPD headforms and torso, tools and verification tools*

— *Part 6: Mechanical resistance/strength of components and connections*

— *Part 7: Practical performance tests methods*

— *Part 8: Measurement of RPD air flow rates of assisted filtering RPD*

— *Part 9: Determination of carbon dioxide content of the inhaled air*

— *Part 10: Resistance to ignition, flame, radiant heat and heat*

— *Part 11: Determination of field of vision*

— *Part 12: Determination of volume-averaged work of breathing and peak respiratory pressures*

— *Part 13: RPD using regenerated breathable gas and special application mining escape RPD: Consolidated test for gas concentration, temperature, humidity, work of breathing, breathing resistance, elastance and duration*

— *Part 14: Measurement of sound level*

Introduction

This part of ISO 16900 is intended as a supplement to the respiratory protective devices (RPD) performance standard. Test methods are specified for complete devices or parts of devices that are intended to comply with the performance standards. If deviations from the test method given in this part of ISO 16900 are necessary, these deviations will be specified in the performance standards.

The following definitions apply in understanding how to implement an ISO International Standard and other normative ISO deliverables (TS, PAS, IWA):

— "shall" indicates a requirement;

— "should" indicates a recommendation;

— "may" is used to indicate that something is permitted;

— "can" is used to indicate that something is possible, for example, that an organization or individual is able to do something.

3.3.1 of the ISO/IEC Directives, Part 2 (sixth edition, 2011) defines a requirement as an "expression in the content of a document conveying criteria to be fulfilled if compliance with the document is to be claimed and from which no deviation is permitted."

3.3.2 of the ISO/IEC Directives, Part 2 (sixth edition, 2011) defines a recommendation as an "expression in the content of a document conveying that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited."

Respiratory protective devices — Methods of test and test equipment —

Part 9: Determination of carbon dioxide content of the inhaled gas

1 Scope

This part of ISO 16900 specifies the test methods for determining the increased carbon dioxide content of the inhaled gas caused by wearing the RPD.

Closed circuit supplied breathable gas RPD are excluded from this part of ISO 16900.

NOTE See test method in ISO 16900-13.

2 Normative references

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

ISO 16972, *Respiratory protective devices — Terms, definitions, graphical symbols and units of measurement*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16972 apply.

4 Prerequisites

The performance standards shall indicate the conditions of the test. This includes the following:

a) the number of test specimens;

b) operating conditions of the RPD;

c) types of RPD head form;

d) any prior conditioning or testing;

e) breathing minute volumes (frequency and tidal volume);

f) carbon dioxide exhalation concentrations (average and peak);

g) any deviations from the test method(s).

5 General test requirements

Unless otherwise specified, the values stated in this part of ISO 16900 are expressed as nominal values. Except for temperature limits, values which are not stated as maxima or minima shall be subject to a tolerance of ±5 %. Unless otherwise specified, the ambient temperature for testing shall be between 16 °C and 32 °C and (50 ± 30) % RH. Any temperature limits specified shall be subject to an accuracy of ±1 °C.

Where the assessment of the pass/fail criterion depends on a measurement, an uncertainty of measurement as specified in Annex A shall be reported.

6 Principle

The respiratory interface is fitted to a RPD head form/torso. Any air or breathable gas supply is operated in the manufacturer's minimum condition, unless prescribed otherwise in the performance standards. Breathing gas containing a defined concentration of carbon dioxide is supplied at a specified rate from a breathing machine to the RPD head form/torso. The inhaled gas is analysed for carbon dioxide concentration. The test is also conducted without the RPD fitted to the RPD head form to determine the baseline carbon dioxide concentration for the test apparatus. This value is then subtracted from the value determined when the RPD is fitted, to determine the increase in inhaled carbon dioxide concentration caused by the RPD.

7 Apparatus

7.1 General

Details of the RPD head forms, airway openings, and sampling ports shall be given.

The breathing machine shall exhale carbon dioxide with peak and average carbon dioxide concentrations as defined by the performance standards. This ensures that the dead space of the respiratory interface is flushed with carbon dioxide rich gas in the same way as would occur when the RPD is worn by a person.

The inhaled gas shall be analysed for carbon dioxide content. The results can be presented as average inhaled carbon dioxide concentration and/or equivalent dead space.

Three alternative test methods are specified in 7.2, 7.3, and 7.4 and shown in Figures 1, 2, and 3. They employ different practical ways of exhaling carbon dioxide enriched gas and different ways to determine the inhaled carbon dioxide concentration. All three methods have been shown to be suitable for the determination of the carbon dioxide concentration of the inhaled breathable gas. Combinations of these methods or other methods may be used if shown to be equivalent, but shall use an appropriate RPD head form/torso.

The accuracy of the inhaled carbon dioxide concentration measurement is determined using the verification volumes (working standards) which are either (250 ± 50) ml or (500 ± 50) ml.

The carbon dioxide exhalation concentration shall be adjustable to be within the limits given in the performance standards.

In order to ensure that the RPD inhales laboratory air containing a minimum concentration of carbon dioxide, an auxiliary fan (not shown in Figures 1 to 3) is arranged so that it blows the exhaled air emerging from the RPD away from the RPD inlet.

NOTE The auxiliary fan method is not required when carrying out tests on devices which have their own independent breathable gas supply (e.g. compressed airline devices).

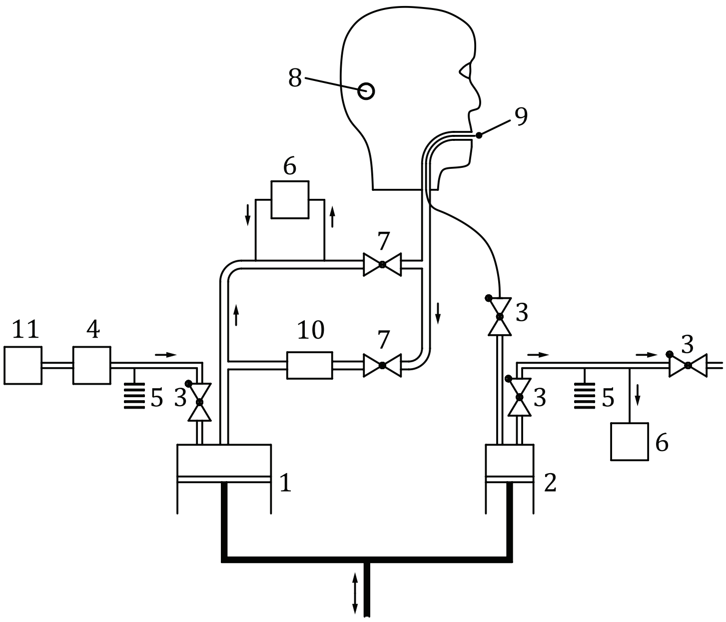
Good laboratory ventilation is required to maintain the ambient laboratory carbon dioxide concentration below 0,1 % during testing.

For RPD with an independent breathable gas supply, the carbon dioxide concentration in the supply shall be less than 0,1 %.

7.2 Test method 1

7.2.1 Breathing machine

A single cylinder breathing machine meeting shall be used. In order to avoid errors in the measurement of carbon dioxide in the inhaled gas, it is important that the solenoid valves (see Figure 1) make a good seal on closing and are actuated at precisely the same time. In order to avoid upsetting the pressure balance within the system, the solenoid valve actuation should always occur at a time when the piston's movement is at a minimum. Valves shall have a response time of not more than 5 ms from triggering to fully open/closed. The effective tubing volume between the output of the breathing machine to the mouth of the RPD head form shall not exceed 4 l.



Key

1	breathing machine	7	solenoid valve
2	auxiliary piston	8	RPD head form
3	non-return valve	9	sampling tube for inhalation gas
4	carbon dioxide flow controller	10	carbon dioxide absorber
5	volume compensator	11	carbon dioxide supply
6	carbon dioxide analyser		

Figure 1 — Schematic of a typical single cylinder arrangement for testing carbon dioxide content of the inhalation gas

7.2.2 Carbon dioxide analyser

A carbon dioxide analyser with a resolution of 0,01 % is recommended. For the exhaled and inhaled carbon dioxide measurements, separate analysers may be used.

7.2.3 Carbon dioxide sampling

A sample of the inhaled gas is taken from the mouth (see Figure 1, key 9) by an auxiliary lung driven by the breathing machine and in phase with it. It is set to inhale a known sample volume (a chosen percentage of the inhalation volume of the breathing machine) during the inhalation stroke of the breathing machine. This apparent "loss" in inhalation volume of the breathing machine is compensated for by the volume of carbon dioxide fed via the flow meter into the breathing machine on its inhalation stroke. It is therefore important that these two volumes are equal.

The exhaled gas is monitored for carbon dioxide content at the flow rate required by the analyser. This shall be performed before and after each test, or continuously throughout the test. The sample point is immediately before the solenoid valve in the exhalation circuit. To maintain equilibrium, the sample is returned to the circuit upstream of the sample point.

The carbon dioxide absorber is necessary to prevent build-up of carbon dioxide in the test equipment circuit. The volume compensators allow constant conditions to be maintained for particular parts of the test circuit. The effectiveness of the carbon dioxide absorber shall be verified before and after the test.

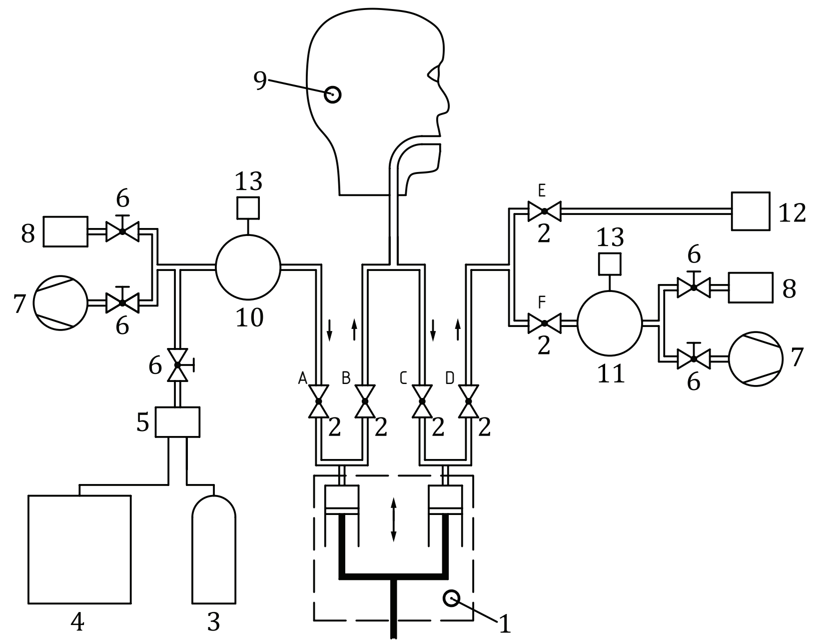
7.2.4 RPD head form/torso

An appropriate RPD head form/torso, including the sampling tube, shall be used.

7.3 Test method 2

7.3.1 Breathing machine and ancillary equipment

A breathing machine with twin identical cylinders shall be used. Figure 2 gives a schematic diagram of the breathing machine and ancillary equipment, including pipe work and solenoid valves that are necessary for this test method. Externally triggered valves shall have a response time of not more than 5 ms from triggering to fully open/closed. The effective tubing volume between the output of the breathing machine to the mouth of the RPD head form shall not exceed 4 l.



Key

1 breathing machine
2 solenoid valve
3 carbon dioxide cylinder
4 air compressor
5 test gas controller
6 stop valve
7 suction pump
8 carbon dioxide analyser
9 RPD head form
10 exhalation reservoir, with overflow valve, if required
11 inhalation reservoir
12 exhaust
13 pressure relief valve

Solenoid valve	Stage 1: During preliminary conditioning of 15 breaths		Stage 2: During sampling of inhaled gas for 5 breaths		Stage 3: After completion of sampling of inhaled gas	
	Inhalation phase	Exhalation phase	Inhalation phase	Exhalation phase	Inhalation phase	Exhalation phase
A	O[a]	X[b]	O	X	X	X
B	X	O	X	O	O	O
C	O	X	O	X	O	X
D	X	O	X	O	X	O
E	X	O	X	X	X	O
F	X	X	X	O	X	X

NOTE Solenoid valves A, B, C, D, E, and F (see key 2) have either state of open or close corresponding to breathing phases.

[a] Open.

[b] Close.

Figure 2 — Schematic diagram of a typical twin cylinder arrangement for testing carbon dioxide content of the inhalation gas

7.3.2 RPD carbon dioxide analyser

A carbon dioxide analyser with a resolution of 0,01 % is recommended. Separate analysers may be used for the exhaled and inhaled carbon dioxide measurements.

7.3.3 RPD head form/torso

An appropriate RPD head form/torso, including the sampling tube, shall be used.

7.3.4 Test gas

The test gas is produced by mixing air (which may be from a compressed air source or a filtered clean air source) with carbon dioxide. The carbon dioxide is supplied from a cylinder containing pure or diluted carbon dioxide. The flow rates of carbon dioxide and air are adjusted in order to obtain the target carbon dioxide percentage concentration specified in the performance standards.

7.3.5 Exhalation and inhalation reservoirs

7.3.5.1 Exhalation supply reservoir

The exhalation supply reservoir is an enclosure, which may be flexible, and which has a volume at least twice that of the maximum tidal volume of the breathing machine required during the test sequences. It is permissible to have a large flexible reservoir that contains enough carbon dioxide/air mixture to complete each sequence of the test without replenishment. Alternatively, the reservoir may be replenished during the test sequence with the correct carbon dioxide/air mixture concentration from the test gas source. In this case, the reservoir is fitted with an overflow valve to prevent overpressure inside the reservoir.

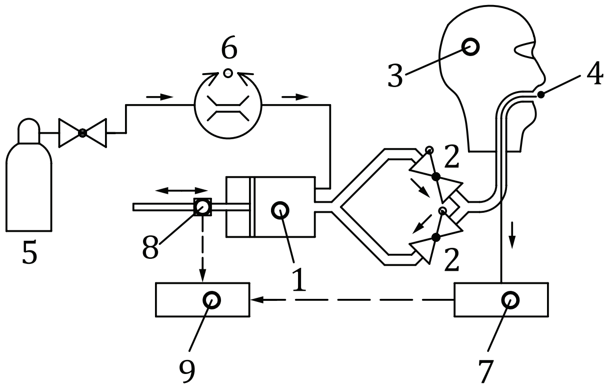
7.3.5.2 Inhalation sampling reservoir

The inhalation sampling reservoir collects inhalation gas flowing from the RPD head form during the inhalation cycle for analysis before the inhalation gas is exhausted to the atmosphere. The reservoir volume shall be at least twice that of the maximum tidal volume of the breathing machine required during the test sequences.

7.4 Test method 3

7.4.1 Breathing machine

A single cylinder breathing machine, equipped with volume transducer, (see Figure 3) shall be used. Carbon dioxide is continuously injected into the breathing machine where mixing takes place.



Key

1 breathing machine (drive mechanism not shown)
2 non-return valve
3 RPD head form
4 sampling point
5 carbon dioxide supply
6 mass flow regulator
7 carbon dioxide analyser
8 volume transducer
9 computer

Figure 3 — Method 3: Schematic diagram of a single cylinder arrangement for testing carbon dioxide content of the inhalation gas using high speed breath analyser

7.4.2 Carbon dioxide analyser

A carbon dioxide analyser with a response time of less than 100 ms (0 % to 90 %) is required. A resolution of 0,01 % is recommended.

7.4.3 RPD Head form/torso

An appropriate RPD head form/torso.

7.4.4 Carbon dioxide and volume signal synchronisation

The continuous sample of gas is drawn via a narrow capillary tube at the flow rate determined by the analyser from the airway opening to the carbon dioxide analyser (see Figure 3). It is analysed and the concentration value is displayed as a function of volume (see Figure B.1).

The display of the volume signal and that of the corresponding carbon dioxide measurement signal may be offset in time because of measurement techniques. The two signals shall be synchronised prior to analysis.

The time delay of the carbon dioxide signal can be measured by producing a rapid change in the carbon dioxide level at the airway opening and determining the length of time it takes before the change is seen in the data acquisition system. Alternatively, the delay can be adjusted such that the calculation of the anatomical dead space matches the known anatomical dead space.

7.4.5 Data acquisition

A sampling frequency of at least 100 Hz for carbon dioxide concentration measurement and volume measurement is required. This is necessary to allow for fine adjustments of the delay time.

8 Test procedures

8.1 General

8.1.1 Test sequences

For each test method, the test sequences specified below are performed both with and without the RPD fitted to the RPD head form. The increase in inhaled carbon dioxide concentration caused by the RPD is the difference between the two measurements. If required, the tests are also performed at different breathing machine settings, in accordance with the requirements of the performance standards, as part of the validation regime.

8.1.2 Testing RPD with respiratory interface type L

When testing RPD with respiratory interface type L, it is necessary to ensure that the pressure within the hood, when fitted to the RPD head form/torso, is similar to the pressure within the hood when it is worn. The method for determining the pressure within the hood is as follows.

A test subject dons and operates the RPD in accordance with the information supplied by the manufacturer and at the maximum flow rate. The test subject holds their breath, and the pressure within the respiratory interface is noted. The test is repeated by two further test subjects and the average value of the pressure over the minimum of three wearing's is recorded. The respiratory interface is then fitted to the RPD head form according to the information supplied by the manufacturer. With the RPD operating, but the breathing machine not operating, the fitting of the respiratory interface is adjusted in such a way that the pressure within the respiratory interface is equal to the average of the pressures measured on the three subjects.

8.2 Test method 1 — Method for measurement of carbon dioxide in inhalation gas

8.2.1 Calculation of breathing machine settings

In this test method, the auxiliary lung piston displacement is such that the volume of gas drawn off by the auxiliary lung compensates for the volume of carbon dioxide added to the main breathing machine lung. The principle is specified in 7.2.1.

The calculation of settings is given in Table 1.

Table 1 — Calculation of settings

Action	Symbol	Unit
Breathing machine frequency	A	[cycles/min]
Breathing machine tidal volume	B	[l/cycle]
Required Exhaled carbon dioxide	C	[%]
Volume of input carbon dioxide/cycle	V = (C × B/100)	[l/cycle]
Flow rate of input carbon dioxide	V × A	[l/min]
Inhalation sample volume/cycle (auxiliary piston displacement)	E = V × 1 000	[ml/cycle]

8.2.2 Operation of breathing machine

Switch on the breathing machine (together with the auxiliary lung and valves) and operate at the parameters specified in the performance standards.

8.2.3 Auxiliary fan

Switch on the auxiliary fan. The fan is arranged to deliver air at a speed of 0,3 m/s to 0,7 m/s when measured at a point 50 mm in front of the RPD inlet. Ensure that the air is directed away from the RPD inlet(s).

8.2.4 Exhaled carbon dioxide concentration

Adjust the carbon dioxide supply into the breathing machine to achieve a concentration of carbon dioxide in the exhaled gas as defined in the performance standards, called "C_a" in Formula (1) (see 8.2.8). Check the carbon dioxide concentration in the exhaled gas on a dry basis and adjust as necessary to achieve a stabilized level of C %.

8.2.5 RPD carbon dioxide level

Without the RPD fitted to the RPD head form/torso, draw off a sample of the inhaled gas during the inhalation phase by the auxiliary piston set at a rate of "*E*" ml displacement/stroke (where the sample stroke to breathing machine inhalation stroke volume ratio is the same as the exhaled carbon dioxide volume fraction). Measure the carbon dioxide concentration in the sample by means of the analyser. Continue the test until a steady value is obtained. Record this value as the carbon dioxide baseline level C_b in the inhaled gas of the test apparatus.

8.2.6 Fitting the RPD

Fit the respiratory interface or complete RPD, in accordance with the information supplied by the manufacturer, to the appropriate size of RPD head form/torso, and, where appropriate, operate the RPD at the parameters specified in the performance standard. Repeat the operations specified in 8.2.2 to 8.2.5, except that the RDP is fitted to the RPD head form/torso, to measure C_a.

8.2.7 Adjusting baseline carbon dioxide concentration when testing supplied breathable gas RPD

When testing supplied breathable gas RPD, it is necessary to adjust the carbon dioxide baseline level C_b for any differences between the carbon dioxide concentration in the supplied breathable gas source and the laboratory air. Measure the reference level of carbon dioxide in the supplied breathable gas source (C_{supply}) and in the laboratory air (C_{lab}) and calculate the difference between the two measurements. Adjust the value of C_b for this difference: $C_b = C_{supply} - C_{lab}$.

8.2.8 Calculation of carbon dioxide increase

The carbon dioxide increase in inhalation gas, *D*, caused by a test specimen, is calculated using Formula (1).

$$D = C_a - C_b \qquad (1)$$

where

C_a is the carbon dioxide concentration, percentage by volume, with a test specimen;

C_b is the carbon dioxide baseline concentration, percentage by volume, (i.e. without a test specimen).

8.2.9 Completion of test sequences

Repeat the test, where necessary, until all tests have been performed at the conditions required by the performance standards.

8.3 Test method 2 — Method for measurement of carbon dioxide in inhalation gas

8.3.1 Exhaled Carbon dioxide concentration

Set the carbon dioxide concentration of the exhaled gas to the level given in the performance standards by adjusting the flow rates from the gas sources. Measure the carbon dioxide concentration of the exhaled gas stream and make adjustments to the source gas flow rates if necessary to obtain the correct concentration.

8.3.2 Exhalation reservoir

Fill the exhalation reservoir with the carbon dioxide mixture and confirm that the concentration is in the range specified in the performance standards. Where necessary, ensure that the overflow valve is functioning correctly and direct excess carbon dioxide mixture away from the test area, so that the background carbon dioxide concentration in the laboratory air is not artificially increased.

8.3.3 Inhalation reservoir

Empty the inhalation reservoir by means of the suction pump to prevent contamination from the previous test.

8.3.4 Operation of breathing machine

Switch on the breathing machine and operate at the parameters specified in the performance standards.

8.3.5 Auxiliary fan

See 8.2.3.

8.3.6 Inhaled carbon dioxide concentration

Without the RPD fitted to the RPD head form/torso, and after the initial stabilization period of 15 breaths, switch to stage 2. Collect the gas from the inhalation cylinder in the sampling bag (reservoir). After a further 5 breaths, switch to stage 3. Measure the carbon dioxide concentration (C_b) of the gas collected in the inhalation sampling bag (reservoir) with the carbon dioxide analyser.

8.3.7 End of each test sequence

At the end of each test sequence, empty the inhalation and exhalation reservoirs.

8.3.8 Fitting the RPD

Fit the respiratory interface or complete RPD, in accordance with the information supplied by the manufacturer, to the appropriate size of RPD head form/torso, and, where appropriate, operate the RPD at the parameters specified in the performance standards. Repeat the operations specified in 8.3.1 to 8.3.7, except that the RDP is fitted to the RPD head form/torso, to measure C_a.

8.3.9 Calculation of carbon dioxide increase

See 8.2.7.

8.3.10 Adjusting baseline carbon dioxide concentration when testing supplied breathable gas RPD

See 8.2.8.

8.3.11 Completion of test sequences

See 8.2.9.

8.4 Test method 3 — Method for measurement of carbon dioxide in inhalation gas

8.4.1 Operation of breathing machine

Switch on the breathing machine and operate at the parameters specified in the performance standards.

8.4.2 Auxiliary fan

See 8.2.3.

8.4.3 Setting of initial carbon dioxide flow rate

Without the RPD fitted to the RPD head form/torso, set the initial carbon dioxide flow rate of in order to achieve the required carbon dioxide concentration at the end of the exhalation cycle as specified in the performance standards.

8.4.4 Data recording

Record the data from the carbon dioxide analyser and volume transducer. It is recommended that the data be plotted as shown in Figure B.1.

NOTE For further information, see References [1] and [2].

8.4.5 Calculation of inspired carbon dioxide

The volume of inspired carbon dioxide, $V_{\mathrm{in,CO_2}}$, is calculated using Formula (2).

$$V_{\mathrm{in,CO_2}} = \sum F_{\mathrm{CO_2}} \times \Delta V \qquad (2)$$

where

$F_{\mathrm{CO_2}}$ is the measured fraction of carbon dioxide at a given time;

ΔV is the corresponding volume change (measured in litres) at that time.

The average inspired carbon dioxide fraction, $F_{\mathrm{in,ave\ CO_2}}$, is calculated using Formula (3).

$$F_{\mathrm{in,ave\ CO_2}} = \frac{V_{\mathrm{in,CO_2}}}{V_{\mathrm{T}}} \qquad (3)$$

where

V_{T} is the tidal volume.

The carbon dioxide concentration (percent by volume) of the inspired gas, $C_{[CO_2]in}$, is calculated using Formula (4).

$$C_{[CO_2]in} = 100 \bullet F_{in,aveCO_2} \quad (4)$$

The flow of carbon dioxide does not have to be adjusted to exactly match a target carbon dioxide concentration at the end of the expiration (end-tidal carbon dioxide), F_{ET,CO_2}. The $F_{in,ave\ CO_2}$ can be corrected if the F_{ET,CO_2} was not as required by the following relationship [see Formula (5)].

$$F_{in,ave\ CO_{2,cor}} = F_{in,ave\ CO_{2,act}} \times \frac{F_{ET,CO_{2,req}}}{F_{ET,CO_{2,act}}} \quad (5)$$

where

$F_{in,ave\ CO_{2,act}}$ and $F_{ET,CO_{2,act}}$	are the actual measured values;
$F_{ET,CO_{2,req}}$	is the required F_{ET,CO_2}.

8.4.6 Fitting the RPD

Fit the respiratory interface or complete RPD in accordance with the information supplied by the manufacturer to the appropriate size of RPD head form/torso, and, where appropriate, operate the RPD at the parameters specified in the performance standards. Repeat 8.4.1 to 8.4.5, except that the RDP is fitted to the RPD head form/torso, to measure C_a.

8.4.7 Calculation of carbon dioxide increase

See 8.2.7.

8.4.8 Adjusting baseline carbon dioxide concentration when testing supplied breathable gas RPD

See 8.2.8.

8.4.9 Completion of test sequence

See 8.2.9.

9 Test report

The test report shall include at least the following information:

a) identification of RPD (model, sizes, etc.);

b) number of specimens tested;

c) any prior conditioning or testing;

d) selection of RPD head form/torso;

e) breathing minute volume;

f) test method used (1, 2, 3);

g) the value of the corrected carbon dioxide content of the inhaled gas for each test sample;

h) any deviations from the method(s);

i) uncertainty of measurement (see Annex A).

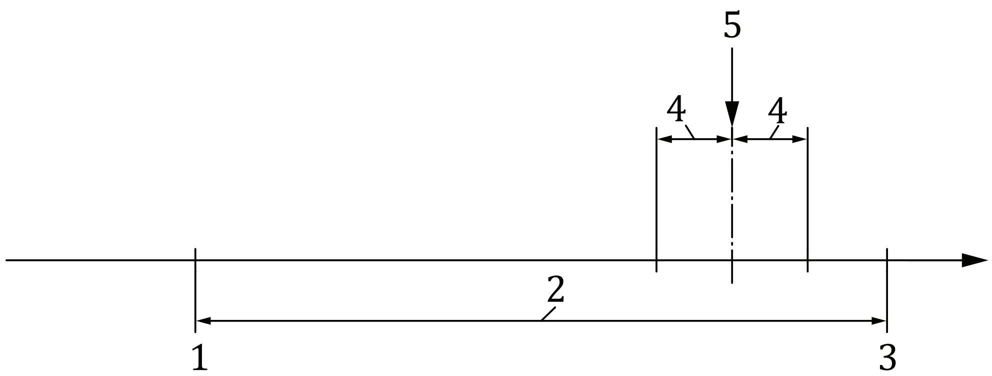
Annex A
(normative)

Application of uncertainty of measurement

A.1 Determination of compliance

In order to determine compliance or otherwise of the measurement made in accordance with this test method, when compared to the specification limits given in the performance standard, the following protocol shall be applied.

If the test result ± the uncertainty of measurement, *U*, falls completely inside or outside of the specification zone for the particular test given in the performance standard, then the result shall be deemed to be a straightforward pass or fail (see Figures A.1 and A.2).



Key

1 lower specification limit

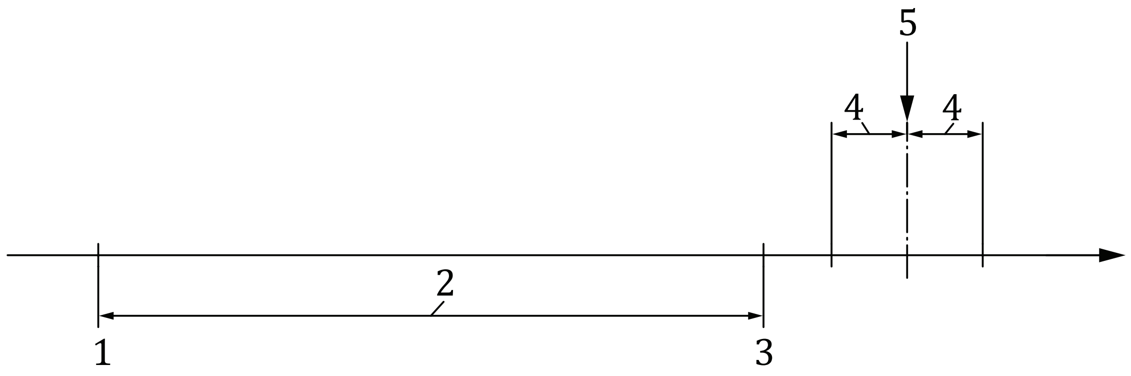
2 specification zone

3 upper specification limit

4 uncertainty of measurement, *U*

5 measured value

Figure A.1 — Result pass

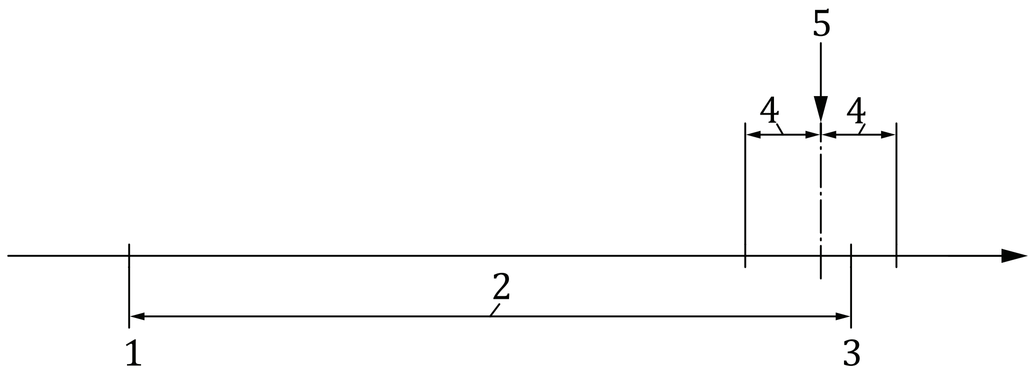


Key

1 lower specification limit
2 specification zone
3 upper specification limit
4 uncertainty of measurement, *U*
5 measured value

Figure A.2 — Result fail

If the test result ± the uncertainty of measurement, *U*, overlaps a specification limit value (upper or lower) for the particular test given in the protective device standard, then the assessment of pass or fail shall be determined on the basis of safety for the wearer of the device; that is, the result shall be deemed to be a fail (see Figure A.3).



Key

1 lower specification limit
2 specification zone
3 upper specification limit
4 uncertainty of measurement, *U*
5 measured value

Figure A.3 — Result fail

Annex B
(informative)

Profile of carbon dioxide concentration in the exhaled gas and use of verification volumes

B.1 Typical profile of carbon dioxide concentration in the exhaled gas

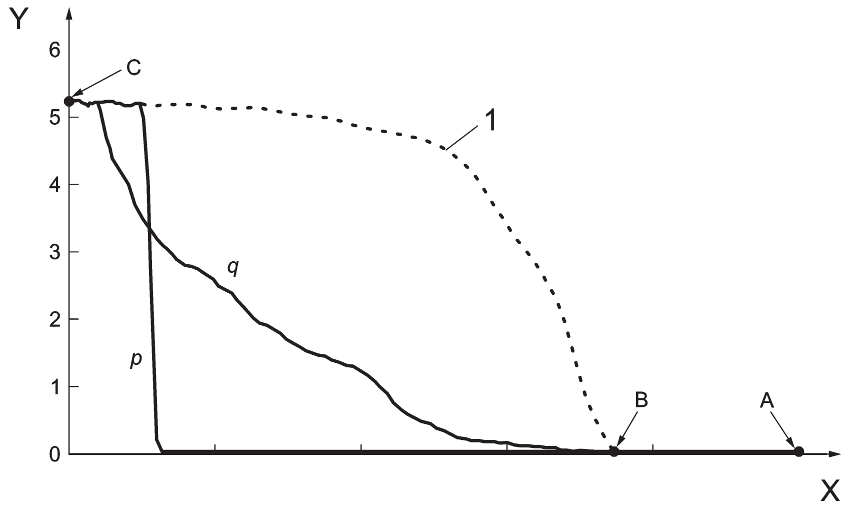
The typical profile of carbon dioxide from a person is shown in Figure B.1. Expiration starts at A where the (lung) volume is large and the carbon dioxide level in the RPD is low. After the anatomical dead space has been cleared (B), the carbon dioxide level increases rapidly (indicated by line 1) followed by a slow increase to reach its end-tidal value at C. In the absence of external dead space, the typical end-tidal value is 5,3 % and the volume-averaged exhaled carbon dioxide concentration is between 2,6 % and 3,4 %.

Inspiratory traces for two different types of respiratory interfaces are shown by line p and q.

In the first example (line p), the first part of an inspiration is the last part of the previous expiration, i.e. the trace moves backwards along the expiratory trace until fresh air enters and the carbon dioxide falls rapidly to the level in the inspired gas.

In the second example (line q), fresh gas reaches the wearer very quickly making the carbon dioxide level start to drop early in the inhalation. However, it takes some time before all the carbon dioxide has been cleared, as shown by the slow drop of the carbon dioxide trace.

It is normal that for some respiratory interfaces the carbon dioxide may remain elevated at the end of the inspiration cycle.



Key

A start of expiration

B clearing of dead space

C end-tidal value

p, *q* inspiratory traces for two different types of respiratory interfaces

X volume

Y carbon dioxide level, in percent

1 expiration

Figure B.1 — Example of tracing of carbon dioxide during an expiration (dotted line) and inspiratory traces from two types of common respiratory interfaces (solid lines)

B.2 Use of verification volumes

A tube of known volume, either (250 ± 50) ml or (500 ± 50) ml, is attached to the airway opening to determine V_{in,CO_2}. The dead space, V_D, can then be calculated using Formula (B.1):

$$V_D = \frac{V_{in,CO_2}}{F_{ET,CO_2}} \tag{B.1}$$

The calculated V_D is compared to the known volume.

Bibliography

[1] Dahlbäck G.O., & Fallhagen L.-G. A novel method for measuring dead space in respiratory protective equipment. Journal of the International Society for Respiratory Protection. 1987, **5** (1) pp. 12–17

[2] Warkander D.E., & Lundgren c.e.g. *Dead space in the breathing apparatus; interaction with ventilation*, Ergonomics vol. 38(9), 1995, pp. 1745 to 1758

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