NORSOK STANDARD

DIVING RESPIRATORY EQUIPMENT

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FOREWORD

NORSOK (The competitive standing of the Norwegian offshore sector) is the industry initiative to add value, reduce cost and lead time and remove unnecessary activities in offshore field developments and operations.

The NORSOK standards are developed by the Norwegian petroleum industry as a part of the NORSOK initiative and are jointly issued by OLF (The Norwegian Oil Industry Association) and TBL (Federation of Norwegian Engineering Industries). NORSOK standards are administered by NTS (Norwegian Technology Standards Institution).

The purpose of this industry standard is to replace the individual oil company specifications for use in future petroleum industry developments and operations, subject to the individual company's review and application.

The NORSOK standards make references to international standards. Where relevant, the contents of this standard will be used to provide input to the international standardisation process. Subject to implementation into international standards, this NORSOK standard will be withdrawn.

INTRODUCTION

This NORSOK standard is based on the "Guidelines for evaluation of breathing apparatus for use in manned underwater operations in the petroleum activities" which was published jointly by the Norwegian Petroleum Directorate and the Department of Energy (UK) 22 January 1991.

This NORSOK standard further supports the essential requirements of EU Council Directive of 21.12.89 relating to personal protective equipment (PPE) (89/686/EEC).

A given breathing apparatus can only be accepted by the recognised test centers when the individual components satisfy the requirements of the test specification which may be a complete standard or part of a standard, and practical performance tests have been carried out on complete apparatus where specified in the appropriate standard. If for any reason a complete apparatus is not tested then simulation of the apparatus is permitted provided the respiratory characteristics are similar to those of the complete apparatus.

1 SCOPE

This NORSOK standard applies to design and testing of breathing apparatus for use in manned underwater operations down to a depth of 400 meters. This standard may also be used for evaluating breathing apparatus used at depths exceeding 400 meters.

This NORSOK standard may be applied for testing and assessment of all breathing equipment for diving.

2 NORMATIVE REFERENCES

This NORSOK standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this NORSOK standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 132 Respiratory protective devices - Definitions

EN 134 Respiratory protective devices - Nomenclature of components

EN 135 Respiratory protective devices - List of equivalent terms

EN 144-1 Respiratory protective devices - Gas cylinder valves - Thread connection for insert connector

EN 148-1 Respiratory protective devices - Treads for facepieces - Standard thread connection

EN 148-2 Respiratory protective devices - Treads for facepieces - Centre thread connection

EN 148-3 Respiratory protective devices - Treads for facepieces - Thread connection M 45 x 3.

3 DEFINITIONS AND ABBREVIATIONS

3.1 Definitions

For the purpose of this NORSOK standard the following definitions apply. They are taken form EN 132 as far as possible.

Shall	Verbal form used to indicate requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted, unless accepted by all involved parties.
Should	Verbal form used to indicate 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.
May	Verbal form used to indicate a course of action permissible within the limits of the standard.
Can	Verbal form used for statements of possibility and capability, whether material, physical or casual.
Ambient pressure (PA):	Pressure in the surrounding environment at the level of the diver's mouth (Measured in kPa). (For test purposes the ambient pressure is equal to the test pressure.)
Breathing gas:	Air or gas mixture suitable for breathing at the ambient pressure.
Hydrostatic imbalance (Hl):	Pressure difference between the reference pressure (Pr) and the lung-centroid pressure (Plc), Hl = Pr - Plc (Measured in kPa). The hydrostatic imbalance may be positive, negative or zero, depending on the position of the demand valve (or equivalent device) and the orientation of the diver. The hydrostatic imbalance can only be measured when there is no respiratory gas flow.
Lung centroid pressure (Plc):	Pressure maintaining the normal resting volume of the lungs (Measured in kPa). The lung centroid pressure may be measured at a point 1.24 kPa inferior to and 0.7 kPa posterior to the suprasternal notch or 2.84 kPa inferior to and 1.4 kPa posterior to the mouth.
Manned underwater operation:	Activity where humans stay below surface and/or are exposed to increased ambient pressure.
Over/under-pressure:	Maximum and minimum pressure to which the diver may be exposed in the event of failure of the apparatus (Measured in kPa.). The pressure is related to the reference pressure and will provide design parameters for emergency relief valves, shutoff valves and flow fuses. This pressure is *not* working pressure for normal operations.
Primary breathing apparatus:	Breathing apparatus in the mode which is normally used by a diver in water.
Respiratory minute volume:	Volume of breathing gas exhaled by the diver in the course of one minute (Measured in l BTPS $\cdot$ min^{-1}).
Supply pressure:	The overpressure of the breathing gas at the end of the umbilical where it is connected to the breathing apparatus on the diver's body, related to the ambient pressure (Measured in kPa).
Respiratory pressure:	Differential pressure measure in the diver's mouth during

	inhalation and exhalation, in relation to the reference pressure (Measured in kPa).
Reference pressure:	Pressure in the diver's mouth with relaxed muscles of respiration and no breathing gas flow (Measured in kPa).
Return pressure:	The underpressure of the breathing gas in the return hose at the end of the umbilical where it is connected to the breathing apparatus on the diver's body, related to the ambient pressure (Measured in kPa).
Temperature of inspired gas:	Temperature of the breathing gas inhaled by the diver (Measured at the diver's mouth in °C).
Test depth:	Depth measured at the level of the diver's mouth (Measured in metres of sea water, msw).
Test pressure:	Pressure at test depth. For test purposes set equal to the ambient pressure (Measured in kPa or MPa).
Tidal volume:	Volume of breathing gas exhaled by the diver in each breath (Measured in l BTPS).
Work of breathing (W):	Additional external work required in order to use the breathing apparatus (Measured in J l^{-1}). Ref. 5.2.1 of this standard.

3.2 Symbols and abbreviations

BA	Breathing apparatus
BIBS	Built in breathing system
BTPS	Body temperature, ambient pressure, saturated with water vapour
Hl	hydrostatic imbalance
l	litre
msw	meters of sea water, relative density equal to 1.01972
ms	milliseconds
min	minute
RMV	respiratory minute volume
PA	ambient pressure
W	work of breathing
P	respiratory pressure
Pr	reference pressure
STPD	Standard temperature and pressure dry gas (0°C, 101.3 kPa and 0 kPa water vapour)

4 DESIGN REQUIREMENTS

4.1 General

In order to find out if breathing apparatus is suitable for the purpose, a complete evaluation shall be carried out. A complete evaluation of the breathing apparatus shall include assessment of factors such as:

a) performance,
b) test criteria,
c) ergonomics,
d) noise, with reference to damage to hearing and quality of communication,
e) suitability of materials,
f) reliability,
g) maintenance and hygiene routines,
h) safety analysis,
i) evaluation of the total supply/return system,
j) manned testing,
k) quality assurance,
l) oxygen content in breathing gas.

This NORSOK standard describe a minimum standard and do not cover all the above factors, only partly the first three. It is of great importance that the other factors are also included in a total evaluation.

All the requirements listed in this NORSOK standard may not be possible to meet for all types of breathing apparatus. There will normally be different criteria for the assessment of breathing apparatus depending on whether the equipment is a primary or a secondary system. The most/least critical parameters shall be defined, and in such cases the function of the system shall be given priority. An example may be breathing apparatus to be used by a standby diver, which must be easy to put on, and this requirement is more important than for instance the requirement concerning noise with reference to damage to hearing.

Every new type of breathing apparatus and any apparatus which has been modified in any way that may affect the test results, shall be tested in accordance with this NORSOK standard. The final testing shall be carried out on units from a series production line. Testing of mechanics of breathing should be carried out on minimum five units. Prototype testing is not sufficient as final tests.

Testing of each individual set of breathing apparatus will normally not be required if the manufacturer has in operation a satisfactory quality assurance system during production. A satisfactory initial evaluation according to this NORSOK standard may then be acceptable. This NORSOK standard should, inter alia, be used to:

a) give advice on design parameters for equipment,
b) determine procedures for unmanned testing,
c) provide a basis for comparison in the evaluation of breathing apparatus.

This NORSOK standard assume that breathing apparatus is designed for safe operation and that appropriate and compatible materials are used.

It is important that breathing apparatus is subjected to satisfactory unmanned and manned testing before being used operationally. Parameters to be considered for manned testing have not been included in this NORSOK standard.

In the assessment of types of equipment other than primary underwater breathing apparatus, such as BIBS, welding masks and emergency breathing equipment, modified acceptance criteria based on this NORSOK standard may be applied (some are specified in this NORSOK standard).

5 PERFORMANCE REQUIREMENTS

5.1 General

This clause describes mainly the minimum requirements to the performance of the breathing apparatus based on physiological factors.

5.2 Work of breathing

5.2.1 Calculation of work of breathing

The work of breathing (W) carried out during testing of breathing apparatus is determined on the basis of pressure and volume measurements. The area inside the pressure-volume diagram represents the work of breathing according to this standard.

Additional work of breathing may occur in very special cases. This is represented by the area (B) between the pressure-volume diagram and the volume axis, cf. the figure below. This work is associated with possible positive pressures during inhalation and is subtracted from the total work of breathing in this standard. In practice this means that the area B is not included in the calculation of the work of breathing in this standard.

The respiratory system will only gain from positive assistance during inhalation to a certain degree. Therefore if the defined work of breathing (A) inside the pressure-volume diagram or the hydrostatic imbalance is close to the upper limit, the magnitude of this additional work (B) shall be taken into consideration. Positive or negative contributions during inhalation as well as exhalation should similarly be described if they contribute significantly to the calculation of the total work of breathing.

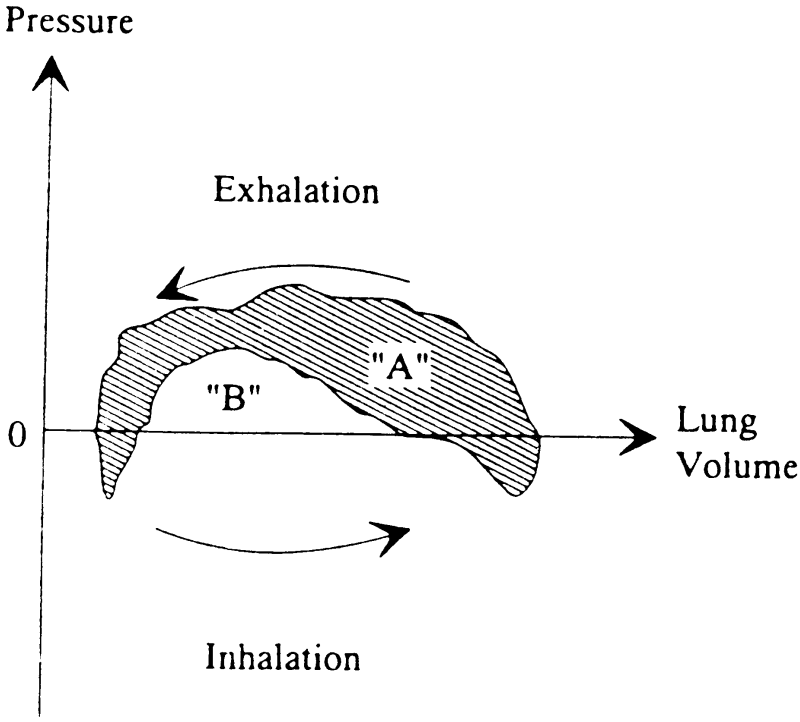

Figure 1: Graphic illustration showing the work of breathing as a function of the breathing pressure and the tidal volume.

Area «A» = Work of breathing (W)
Area «B» = Additional work normally not included in the definition of work of breathing in these guidelines.

5.2.2 Relation between work of breathing and respiratory minute volume

The work of breathing when breathing apparatus is in use may vary with the respiratory minute volume.

Work of breathing should be as low as possible. Figure 2 indicates work of breathing at respiratory minute volumes between 7.5 and 90.0 l BTPS min^{-1}.

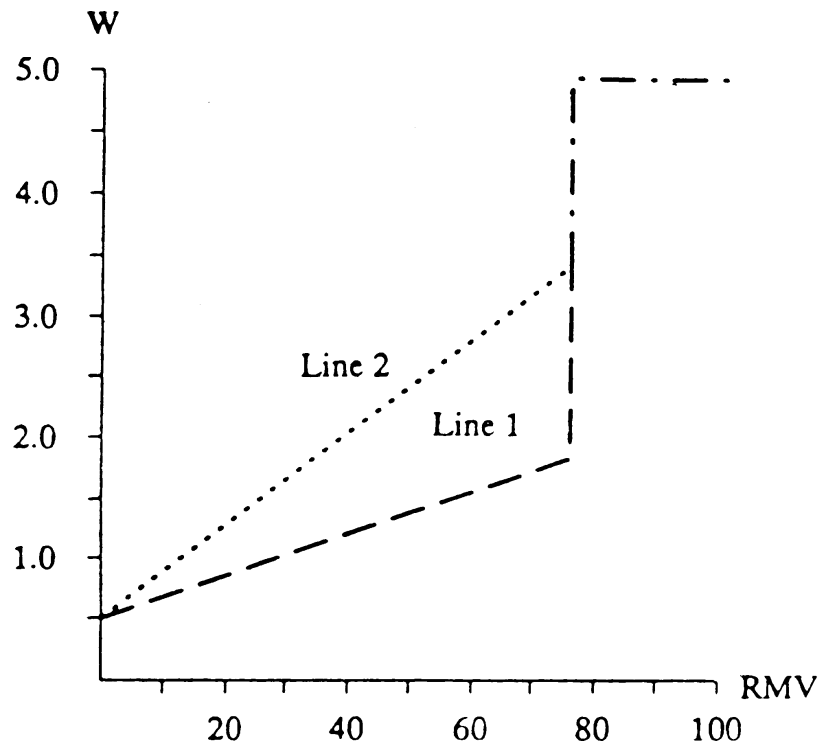

Figure 2: Relation between the work of breathing and the respiratory minute volume

Line 1 represents preferred values for work of breathing (W). In the case of deep diving (depths exceeding 180 msw) line 1 will represent maximum values. Line 1 is derived from the equation:

$$W = k + (f \cdot RMV)$$

when $k = 0.5$ J $\cdot l^{-1}$, $f = 0.02$, RMV= 7.5 -75 l BTPS $\cdot$ min^{-1}.

Line 2 represents maximum values for work of breathing (W) at diving depths less than 180 msw, and is derived from the equation:

$$W = k + (f \cdot RMV)$$

when $k = 0.5$ J l^{-1}, $f = 0.04$, RMV = 7.5 -75 l BTPS $\cdot$ min^{-1}.

Work of breathing in the range RMV = 75-90 l BTPS $\cdot$ min^{-1} or equivalent upper RMV-range for equipment other than the primary underwater BA, shall be less than 5 J $\cdot$ l^{-1}.

In the assessment of types of equipment other than primary underwater breathing apparatus, such as emergency breathing equipment, modified acceptance criteria for work of breathing may be considered (see clause 5.3).

5.3 Respiratory minute volume

The breathing apparatus shall function satisfactorily within the maximum and minimum limits stipulated by these guidelines, at a respiratory minute volume from 15 to 75 l BTPS · min^{-1}.

Maximum work of breathing for the interval 75 to 90 l BTPS · min^{-1} shall be less than 5 J · 1^{-1}. For other breathing equipment than the primary modified requirements may be applied as follows: For BIBS corresponding RMV ranges are 7.5 to 40 l BTPS · min^{-1} and 40 to 62.5 l BTPS · min^{-1}. : For welding mask and escape equipment corresponding RMV ranges are 15 to 40 l BTPS · min^{-1} and 40 to 62.5 l BTPS · min^{-1}. For lung powered survival equipment corresponding RMV ranges are 7.5 to 22.5 l BTPS min^{-1}.

5.4 Tidal volume

The breathing apparatus shall function satisfactorily within the maximum and minimum limits stipulated by this NORSOK standard at a tidal volume of approximately 1.0 to 3.0 1. For certain types of apparatus the tidal volume may have a significant effect on the performance of the equipment. Consideration should be given to whether there is a need to require that the breathing apparatus must function at a smaller/greater tidal volume than that indicated in this section. Recommended upper limit for primary breathing apparatus is 4.0 l, while the tidal volume range for BIBS is 0.75 to 2.0 l, for welding mask and escape equipment 1.0 to 2.0 l, and for lung powered survival equipment 0.75 to 1.5 l.

5.5 Respiratory pressure

The respiratory pressure (P) should ideally be limited to ± 1.5 kPa and shall not exceed ± 2.5 kPa relative to the reference pressure (Pr) during a breathing cycle.

5.6 Hydrostatic imbalance

The hydrostatic imbalance (Hl) varies with the orientation of the diver and the position of the demand valve and may affect the total load on the diver. The difference between the reference pressure (Pr) and the lung centroid pressure (Plc) should be as small as possible.

The reference pressure shall be between minus 2.0 and plus 1.0 kPa relative to the lung centroid pressure, or if applicable to the suprasternal notch. This limit applies whether the diver is standing in upright position or is lying face down.

5.7 Maximum over/under-pressure

In the event of equipment failure, the over/under-pressure shall not exceed ± 6.0 kPa.

5.8 Carbon dioxide content of inspired gas

The design of the breathing apparatus shall be such as to minimise the inspired concentration of carbon dioxide. The volume weighted partial pressure of carbon dioxide in the breathing gas should if possible be limited to 1.0 kPa and shall never exceed 2.0 kPa when tested under conditions as specified in clause 6.4.

5.9 Temperature of inspired gas

The temperature of the inspired breathing gas shall be capable of being kept stable and shall have sufficient accuracy for adjustment in order to avoid irritation of the airways due to cold or heat.

The gas temperature shall never exceed 37°C. If the inspired gas is not fully humidified, the maximum temperature shall be lowered.

In the case of dry breathing gas the gas temperature shall not exceed 32°C. The table in clause 6.4.10 shows comfortable temperatures with dry breathing gas.

6 TESTING

6.1 General

This section describes the test procedures which shall be followed for unmanned testing of breathing apparatus.

Unmanned tests shall be carried out at a test centre using suitable equipment and competent personnel.

The test centre shall provide documentation to show that the equipment and procedures used comply with these guidelines or with equivalent recognised standard. The performance characteristics of the breathing simulator shall be defined by calibration and other pertinent procedures.

6.2 Requirements for the breathing simulator

6.2.1 Rigging for testing of breathing apparatus

The equipment shall be tested as realistically as possible and with operational parameters in accordance with the recommendations of the manufacturer. The simulator shall allow the breathing apparatus to be tested in different positions.

Position of the demand valve in relation to the suprasternal notch etc. and other relevant factors having effect on the test results shall be described in the test documents.

6.2.2 Test environment

The equipment shall be tested with the gas and in the environment in which it is intended to be used (e.g. heliox, water, air etc.) as documented by manufacturer. When tested in water, the equipment shall be immersed to a depth sufficient to preclude surface effects. It shall be ensured that the conditions during testing reflect the most unfavourable operational conditions of the equipment.

6.2.3 Wave form

The breathing simulator shall be able to exhibit a sinusoidal wave form with a maximum variation of ± 5 %. If this wave form greatly effects the results for certain types of equipment, a more realistic wave form may be used in any additional tests that may be carried out.

6.2.4 Pressure measurement

Respiratory pressure shall be measured with pressure variations up to 5 Hz with less than 3 dB dampening. This in order to establish whether the breathing apparatus complies with the requirements specified in clause 5.5. Measurements shall be carried out with an accuracy better than 0.1 kPa.

In order to measure high frequency pressure variations in the breathing apparatus, the measuring equipment shall be capable of registering this at frequencies up to 50 Hz with less than 3 dB dampening.

The test depth shall be maintained within ± 1% throughout the breathing cycle.

6.2.5 Temperature measurement

The temperature of the inspired gas shall be measured with an accuracy of ± 0.25°C and a time constant (63%) of 150 ms or better.

6.2.6 Heat recovery

When the breathing apparatus makes use of heat from the diver's exhaled gas, the breathing simulator shall have the capacity to provide this heat. This heat is part of the total heat input required to attain the temperature stipulated in clause 6.4.10.

6.2.7 Ambient test temperature

The temperature of the water surrounding the equipment in the test chamber shall be kept at 5°C, ± 2°C.

The temperature and the relative humidity of the breathing gas affect the freezing properties of the breathing apparatus when in use.

6.2.8 Carbon dioxide measurement

The partial pressure of carbon dioxide shall be measured in the gas inhaled by the breathing simulator.

Volume weighted average values shall be based on measurements with a time constant (63%) of 150 ms or better and shall be corrected for time delay and response in the measuring system.

Measuring shall be carried out with an accuracy of ± 0.1 kPa. If alternative measuring methods are used, achievement of equivalent or better accuracy shall be documented.

6.2.9 Injection of carbon dioxide

The breathing simulator shall have the capability to inject carbon dioxide into the breathing gas as specified in clause 6.4.8. This is done to simulate the production of carbon dioxide from a diver.

6.2.10 Humidity in the inspired and expired gas

If a humidifier is incorporated into the breathing apparatus, the equipment shall be tested with the humidifier in operation in accordance with the recommendations of the manufacturer.

The breathing simulator shall be designed in such a way that breathing gas expired from the simulator can be practically fully saturated with water vapour. In addition it shall be possible to measure the level of humidity in the breathing gas.

6.3 Test procedures

6.3.1 Test depths

Tests are to be performed at ambient pressures corresponding to the test depths stipulated below.

- With air or corresponding breathing gas preferred test depths are: 0, 10, 30 and 60 msw.
- With heliox or corresponding breathing gas preferred test depths are: 0, 50,100, 200, 300 and 400msw.

Testing of the equipment shall include tests at:

- a depth equal to or less than the minimum depth at which the equipment is intended to be used.
- a depth in excess of the maximum depth at which the equipment is intended to be used.

Tests at intermediate depths shall be carried out if the test results show that interpolation is not possible between them. The following test depths should then preferably be selected:
3, 20, 40, 50, 150, 250, 350 and 450 msw.

6.3.2 Effects of variations in supply/return pressure

If the breathing apparatus performance is variable with variations in the supply or return pressure and/or the diver's depth in relation to the diving bell, additional tests shall be carried out to establish any such effects.

6.3.3 Respiratory minute volume

The tests are to be carried out at a respiratory minute volumes that are relevant (see 5.3) of 7.5, 15.0, 22.5, 40.0, 62.5, 75.0 and 90.0 l BTPS $\cdot$ min^{-1}.

Tests at the highest RMV will indicate whether the equipment is functioning during extreme ventilation. The equipment shall be tested at a lower respiratory minute volume after the RMV test to see that the apparatus still functions satisfactorily. It is important to include this in the total evaluation of the breathing apparatus.

6.3.4 Tidal volume

Breathing apparatus shall be tested at the tidal volumes stipulated in the table below.

RMV	Tidal Volume	Breathing Rate
(l BTPS $\cdot$ min^{-1})	(l BTPS)	(n min^{-1})
7.5	0.75	10
15.0	1.0	15
22.5	1.5	15
40.0	2.0	20
62.5	2.5	25
75.0	3.0	25
90.0	3.0	30

6.3.5 Hydrostatic imbalance

Breathing apparatus should be assessed and if applicable tested to establish the circumstances under which the hydrostatic imbalance may increase.

6.3.6 Maximum over/under-pressure

Testing of maximum over/under-pressure can be a part of the testing in the breathing simulator, but it can also be carried out separately, depending on the design of the breathing apparatus.
An adequate number of tests shall be carried out to establish maximum over/under-pressure.

6.3.7 Work of breathing

Work of breathing is to be determined at each RMV tested.

6.3.8 Carbon dioxide content of inspired gas

The partial pressure of carbon dioxide is to be measured at a point corresponding to a diver's mouth opening during inhalation.

Carbon dioxide corresponding to a volume weighted average partial pressure of approximately 4.0 kPa is to be injected into the breathing gas in the simulator according to relevant combinations of the following table:

RMV	CO_2-injection
(l BTPS · min^{-1})	(l STPD · min^{-1})
7.5	0.3
15.0	0.6
22.5	0.9
40.0	1.6
62.5	2.5
75.0	3.0
90.0	3.6

6.3.9 Testing of integral CO2 absorber

Testing of an integral CO_2 absorber is dependent on the design of the unit itself and the performance of the absorbent. The performance of the absorbent shall be established with regard to variations in humidity, temperature, pressure and gases.

The CO_2 absorber shall be tested a sufficient number of times with the same absorbent in order to establish the capacity of the unit.

NOTE: The maximum operational lifetime may be determined by means of the established capacity of the CO_2 absorber and given safety factors. The safety factors to be used will depend on the type of breathing apparatus, diving operation etc.

6.3.10 Temperature of inspired gas

Tests at depths less than 150 msw shall be carried out without active heating of the inspired gas.
At test depths of 150 msw or more the temperature of the inspired gas shall be in accordance with the following values:

Depth in (msw)	Gas temperature in (°C)
150	20 ± 2
200	20 ± 2
300	25 ± 2
400	30 ± 2

6.3.11 Heating device

When the breathing apparatus has a device for of heating the breathing gas, the equipment shall be tested to establish the following:

a) maximum and minimum of gas temperature obtained
b) accuracy of temperature control
c) ability to maintain a stable temperature.

The performance of the heating device shall be tested at the depths mentioned in items 2.5.1 and as a minimum at respiratory minute volumes of 15 and 40 l BTPS $\cdot$ min^{-1}, if these are included in the RMV range for the actual BA.

6.4 Documentation

The documentation shall include the following:

a) summary of conclusions
b) precise and comprehensive documentation from the manufacturer which as a minimum shall include information to accompany every BA and/or sub-assembly enabling trained and qualified persons to assemble and use it in a safe way and a general description of the BA including maximum depth, supply and return pressure, assembly, permissible components and connections, required safety devices, possible incompatibility of safety devices when used together, risk assessment (temperature/heating conditions, visibility, type of work), check lists, donning, removal, adjustments, maintenance (including hygiene), storage (including shelf life and inspections intervals), gas purity requirements
c) technical description of rigging and testing equipment
d) test procedures
e) deviations from these guidelines
f) test results
g) comments if any