Annex to: QinetiQ/24865/003
Dated: 3 June 2014

Unmanned testing of JJ-CCR DiveCAN Re-breather

3 June 2014

1. Introduction

1.1 General

This report covers unmanned testing of the JJ-CCR DiveCAN Re-breather, conducted by QinetiQ Maritime Life Support (MLS) at Haslar within the Diving and Hyperbaric Test Centre (DHTC), Life Support Systems Laboratory (LSSL). This laboratory is able to test apparatus in a range of simulated environments and operational conditions. Monitoring uses instrumentation and software that give results in real time.

The apparatus was evaluated for compliance with the requirements of BS EN 14143:2013 for diving re-breathers with reference to Norsok U-101:2012 for diving respiratory equipment; in respect of:

- Breathing performance
  - automatic volume addition (demand actuated) system
  - optimised breathing circuit
- Carbon dioxide (CO_2) absorbent canister endurance
- Volume weighted average inspired CO_2 ($VWAICO_2$)
- Hydrostatic imbalance
  - diver roll
  - diver pitch
- Resistance to temperature
  - testing after storage
  - testing in pre-dive operation

1.2 Apparatus designation

Two apparatus were received for evaluation; tests were undertaken with each, as follows:

- Serial Number: 03-14-5180
  - Breathing performance
  - CO_2 absorbent canister endurance
  - $VWAICO_2$
- Serial Number: 04-14-5205
  - Hydrostatic imbalance
  - Resistance to temperature

2 Procedures

2.1 General

For the testing, the apparatus was supplied with the following gases, at nominal pressures of 50 bar (oxygen) and 100 bar (diluent); except where cylinder pressures were specified by BS EN 14143:2013:

- oxygen
- oxygen-in-nitrogen diluent (*i.e.* air, with an oxygen content of 20.9 %)
- trimix diluent (11 % oxygen: 65 % helium: 24 % nitrogen)

All gas supplies were from external regulated sources, except for the hydrostatic imbalance tests, where oxygen and trimix diluent were supplied from the integral cylinders of the apparatus.

A sample line was integrated to the mouthpiece-end of the inhalation hose of the apparatus; analysis of the gas within the breathing circuit was carried out by a fast response mass spectrometer.

Prior to each test, the axial CO_2 absorbent canister was filled (by QinetiQ staff) with Molecular Products Limited 1.0 – 2.5 mm soda lime granules (Commercial brand: Sofnolime 797, Military designation: CS 2580B Grade D).

All breathing simulator ventilation settings used during testing are shown in Table 2-1.

BREATHING SIMULATOR VENTILATION SETTINGS (litres per minute ($l \cdot min^{-1}$))	TIDAL VOLUME (l) (± 3 %)	BREATHS PER MINUTE (± 3 %)
15.0	1.5	10
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

Table 2-1: Breathing simulator ventilation settings

Three different units for pressure are used extensively in this report. It is common to use metres (m) to describe the pressure a diver is exposed to; *i.e.* depth below the water surface. Gas supply pressures are measured in bar. Any other pressures mentioned have been quoted in the S.I. unit of Pascal (Pa). Throughout the work carried out to produce this report it has been assumed that a pressure change of 100 kilo Pascal (kPa) = 1 bar = 10 m (assuming a density of seawater of 1.01972 at 4 degrees centigrade (°C)) and that the air pressure at sea level = 0 m = 101.3 kPa (one standard atmosphere).

Note that the procedures and results are not presented in chronological order.

2.2 Closed-circuit breathing performance

No gas heating and humidification was employed during the breathing performance evaluation.

Testing was carried out within the hyperbaric chamber, under the following conditions of use:

- apparatus angle, diver pitch +74 °
- fresh water temperature, 4 °C (± 1 °C)
- ventilation rates, 15 – 90 $l \cdot min^{-1}$
- automatic volume addition (demand actuated)
  - simulated depth, 40 m; air diluent
  - simulated depth, 100 m; trimix diluent
- optimised breathing circuit.
  - simulated depth, 100 m; trimix diluent

2.3 Carbon dioxide absorbent canister endurance

Testing was carried out within the hyperbaric chamber, under the following conditions of use:

- apparatus angle, diver pitch +74 °
- fresh water temperature, 4 °C (± 1 °C)
- exhale gas temperature, 32 °C (± 4 °C)
- 40 m simulated dive profile
  - air diluent
  - ventilation rate, 40 $l \cdot min^{-1}$
    CO_2 injection rate, 1.6 $l \cdot min^{-1}$
- 100 m simulated dive profile
  - trimix diluent
  - ventilation rate, 40 $l \cdot min^{-1}$
    CO_2 injection rate, 1.6 $l \cdot min^{-1}$
- 6 m constant simulated depth
  - air diluent
  - ventilation rate, 40 $l \cdot min^{-1}$
    CO_2 injection rate, 1.6 $l \cdot min^{-1}$
  - with two 5 min periods of 75 $l \cdot min^{-1}$
    CO_2 injection rate, 3.33 $l \cdot min^{-1}$

2.4 Volume-weighted average inspired carbon dioxide

No gas heating and humidification was employed during the $VWAICO_2$ evaluation.

Testing was carried out within the hyperbaric chamber, under the following conditions of use:

- apparatus angle, diver pitch +74 °
- fresh water temperature, 6.5 °C (± 1.0 °C)
- simulated depth, 100 m
- trimix diluent
- ventilation rates, 15 – 75 $l \cdot min^{-1}$

2.5 Automatic diluent valve activation

The activation (cracking pressure) of the automatic diluent addition valve (ADV), of both received apparatus, was monitored as a nominal - 20 mbar.

2.6 Hydrostatic imbalance

No gas heating and humidification was employed during the hydrostatic imbalance evaluation.

Testing was carried out within the Hydrostatic and Extreme Temperature Tank (HETT), under the following conditions of use:

- fresh water temperature, 11.5 °C (± 1.0 °C)
- trimix diluent
- ventilation rate, 62.5 $l\cdot min^{-1}$
- 360 ° rotation, (22.5 ° increments): diver roll and pitch (re-optimised between tests)

The counterlung relief valve was not adjustable; note was made of any gas venting that occurred.

One additional hydrostatic imbalance test at diver pitch -90 ° (optimised at diver pitch +45 °) was also conducted, with the ADV closed (*i.e.* without the ability to add gas to the breathing circuit).

2.7 Resistance to temperature

2.7.1 Testing after storage

Testing was carried out within an environmental cabinet, under the following conditions of use:

- trimix diluent
- 5 min ventilation at 40 $l\cdot min^{-1}$
- simulated oxygen consumption, 1.78 $l\cdot min^{-1}$
- + 70 °C, ≥ 3 hour (h); return to ambient, ≥ 3 h
- - 30 °C, ≥ 3 h; return to ambient, ≥ 3 h
- 10 min ventilation at 40 $l\cdot min^{-1}$
- simulated oxygen consumption, 1.78 $l\cdot min^{-1}$

Following each period of storage, the function of the apparatus and visibility of the diver displays were assessed.

2.7.2 Testing in pre-dive operation

Testing was carried out within the Environmental Cabinet, under the following conditions of use:

- trimix diluent
- + 55 °C, ≥ 3 h
- - 20 °C, ≥ 3 h

Following each period of pre-dive conditioning, the high pressure (HP) gas supplies were established; the HP and medium pressure (MP) systems were checked for leakage.

3 Results

3.1 Closed-circuit breathing performance graphs

3.1.1 Automatic volume addition

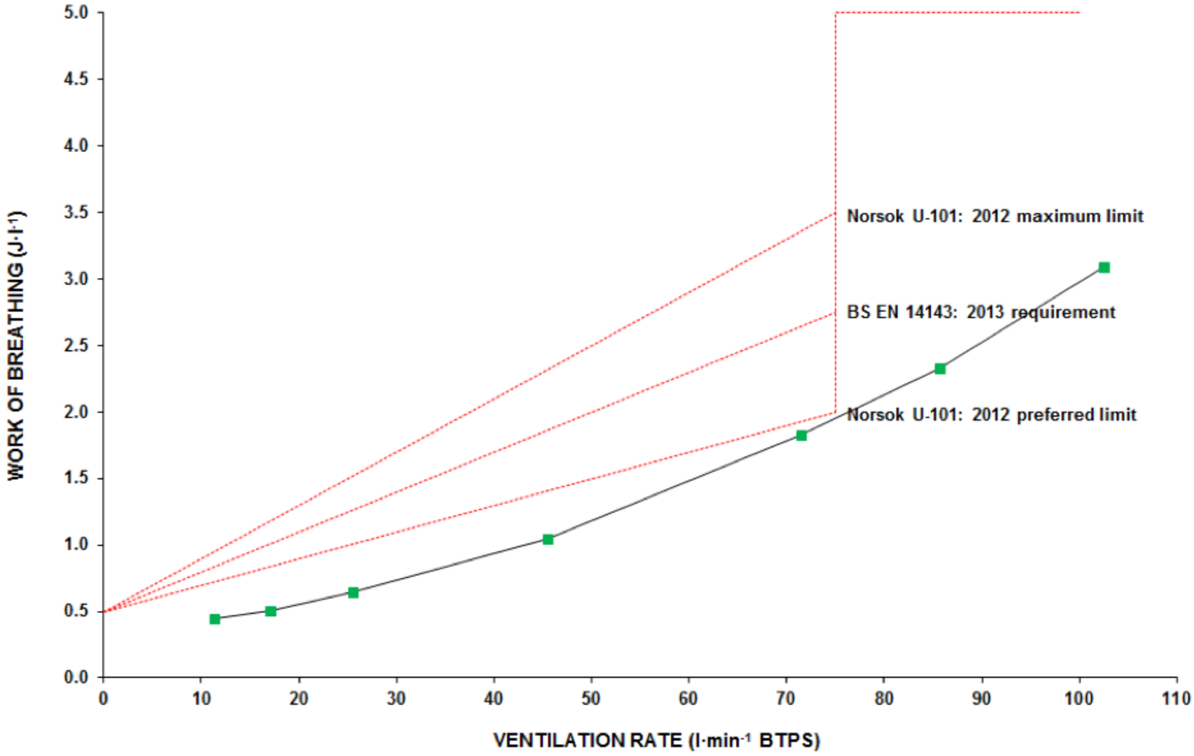

Figure 3-1: Work of breathing; 40 m, air diluent BS EN 14143: 2013; Norsok U-101: 2012 (LSSL reference: 201406-02)

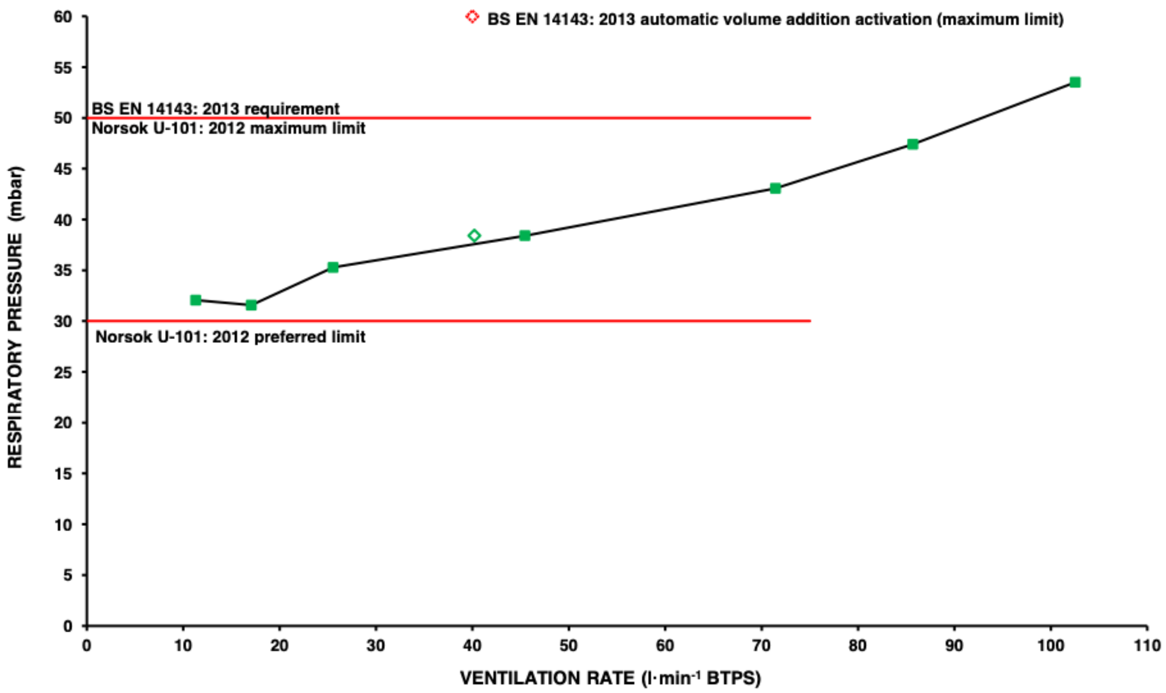

Figure 3-2: Peak-to-peak respiratory pressures; 40 m, air diluent BS EN 14143: 2013; Norsok U-101: 2012 (LSSL reference: 201406-02)

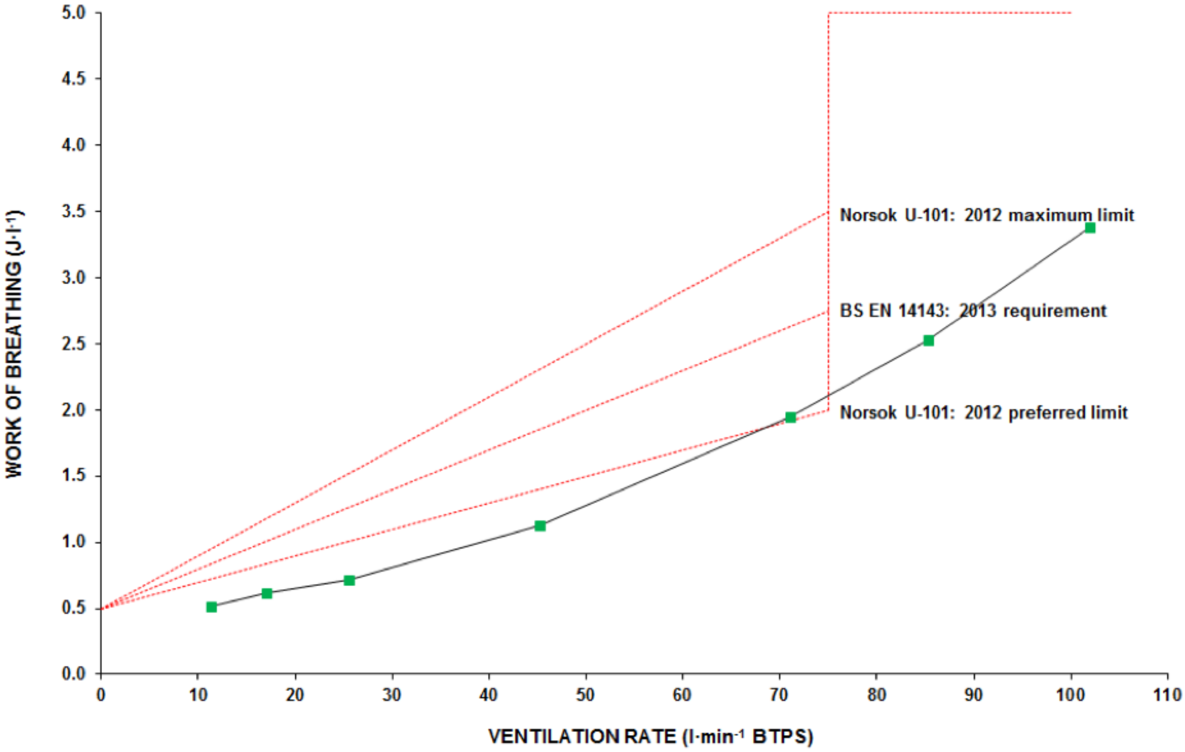

Figure 3-3: Work of breathing; 100 m, trimix diluent BS EN 14143: 2013; Norsok U-101: 2012 (LSSL reference: 201406-05)

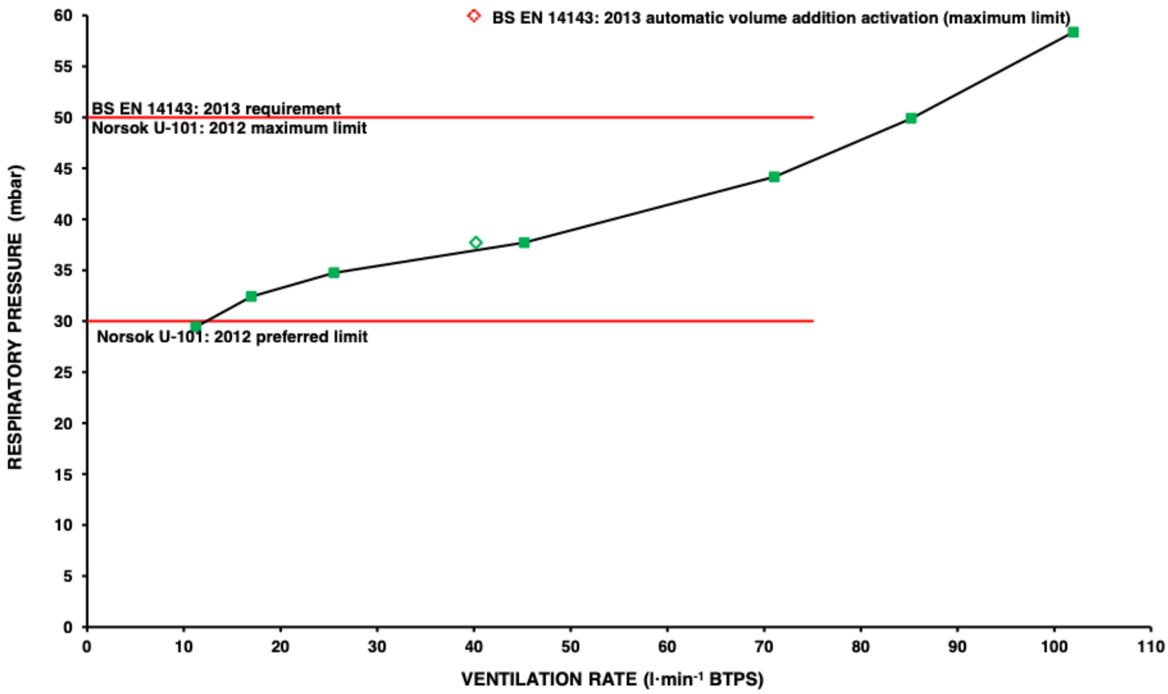

Figure 3-4: Peak-to-peak respiratory pressures; 100 m, trimix diluent BS EN 14143: 2013; Norsok U-101: 2012 (LSSL reference: 201406-05)

3.1.2 Optimised breathing circuit

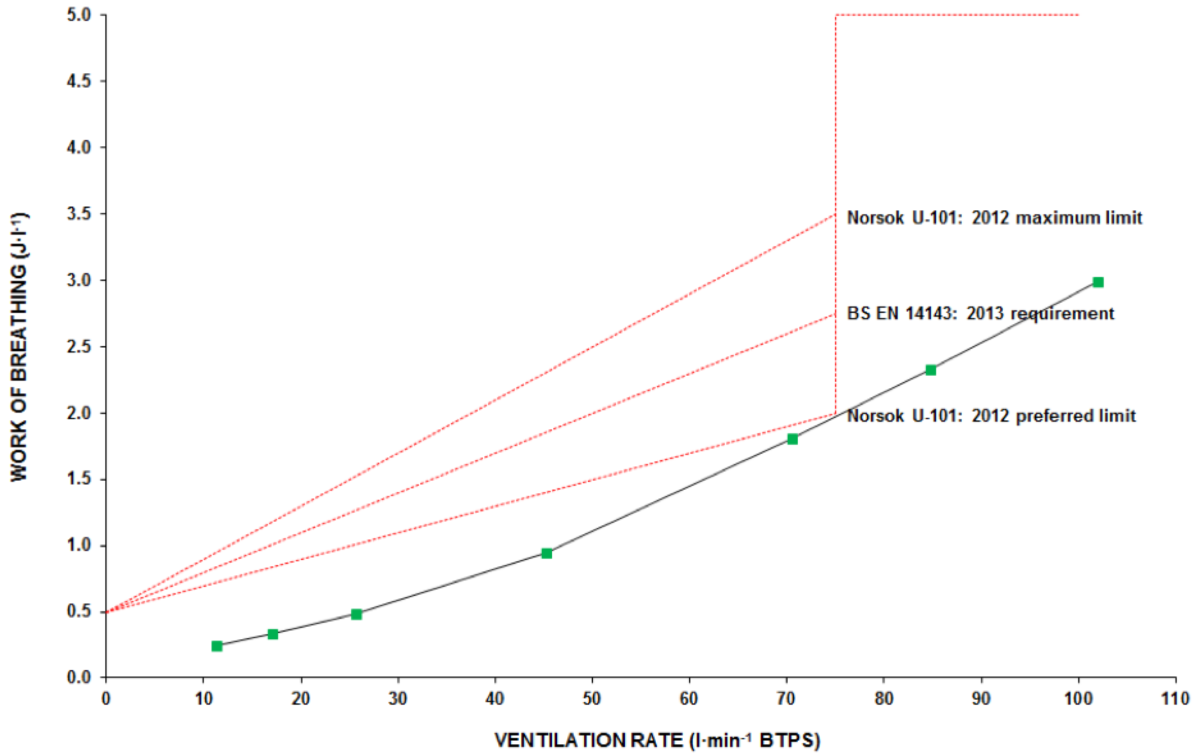

Figure 3-5: Work of breathing; 100 m, trimix diluent BS EN 14143: 2013; Norsok U-101: 2012 (LSSL reference: 201406-04)

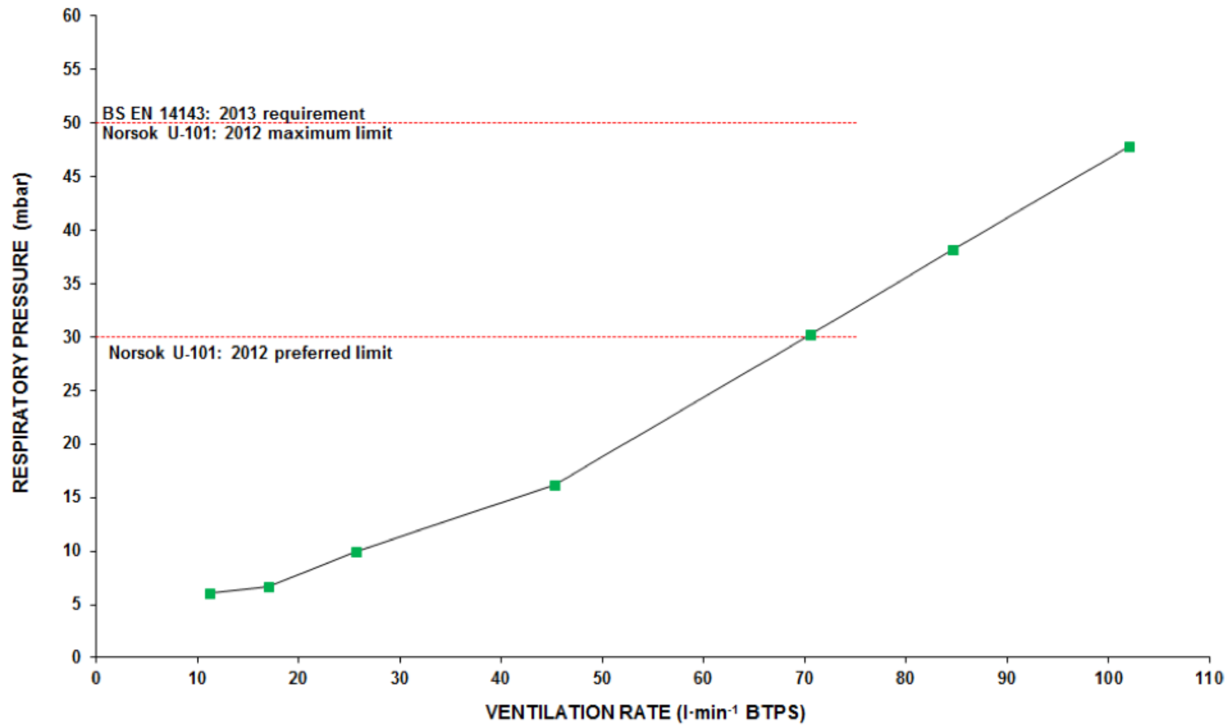

Figure 3-6: Peak-to-peak respiratory pressures; 100 m, trimix diluent BS EN 14143: 2013; Norsok U-101: 2012 (LSSL reference: 201406-04)

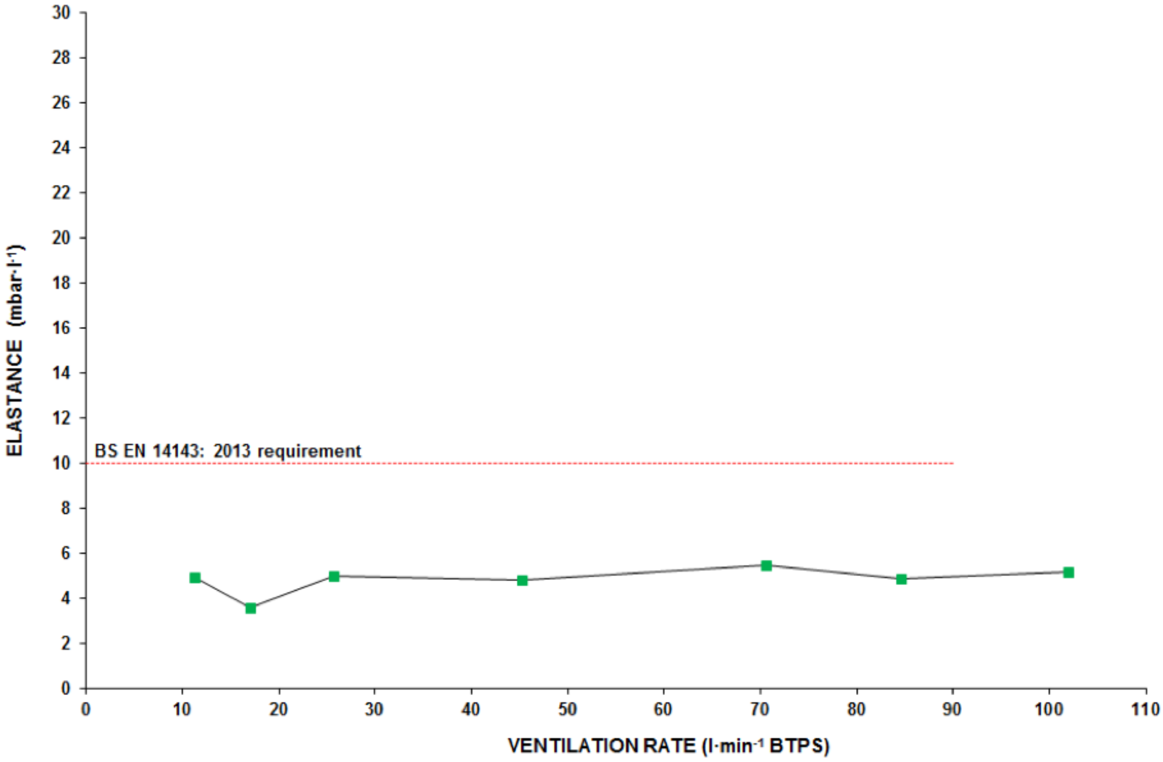

Figure 3-7: Elastance; 100 m, trimix diluent BS EN 14143: 2013 (LSSL reference: 201406-04)

3.1.3 Closed-circuit breathing performance; tabulated values

SIMULATED DEPTH (m) LSSL REFERENCE	VENTILATION RATE (BTPS) ($l \cdot min^{-1}$)	WORK OF BREATHING ($J \cdot l^{-1}$)	PEAK-TO-PEAK RESPIRATORY PRESSURE (mbar)	ELASTANCE ($mbar \cdot l^{-1}$)
Automatic volume addition				
40 201406-02	11.3	0.45	32.06	NA
	17.1	0.51	31.57	
	25.6	0.65	35.28	
	45.5	1.05	38.40	
	71.5	1.83	43.07	
	85.7	2.33	47.41	
	102.5	3.09	53.51	
100 201406-04	11.2	0.52	29.44	NA
	17.0	0.62	32.42	
	25.5	0.72	34.74	
	45.2	1.13	37.71	
	71.1	1.95	44.16	
	85.2	2.53	49.90	
	102.0	3.38	58.36	
Optimised breathing circuit				
100 201406-05	11.2	0.24	6.04	4.94
	17.0	0.33	6.70	3.61
	25.6	0.49	9.94	5.04
	45.2	0.95	16.13	4.86
	70.5	1.81	30.30	5.52
	84.7	2.33	38.20	4.90
	102.0	2.99	47.82	5.18

Table 3-1: Breathing performance values

3.2 Carbon dioxide absorbent canister endurance

3.2.1 40 m simulated dive profiles

The results of the three 40 m dive profiles are graphically presented in Figure 3-8 and tabulated in Table 3-2.

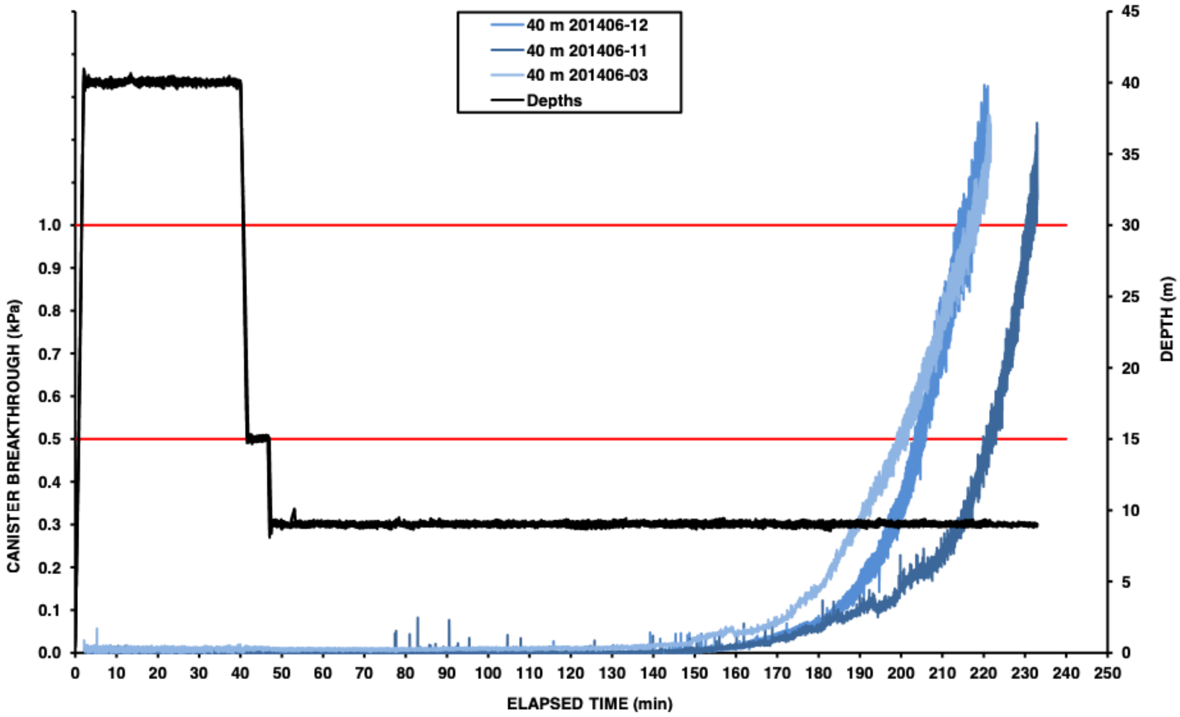

Figure 3-8: CO_2 absorbent canister endurance results; 40 m dive profiles

3.2.1 100 m simulated dive profile

The result of the 100 m dive profile is graphically presented in Figure 3-9 and tabulated in Table 3-2.

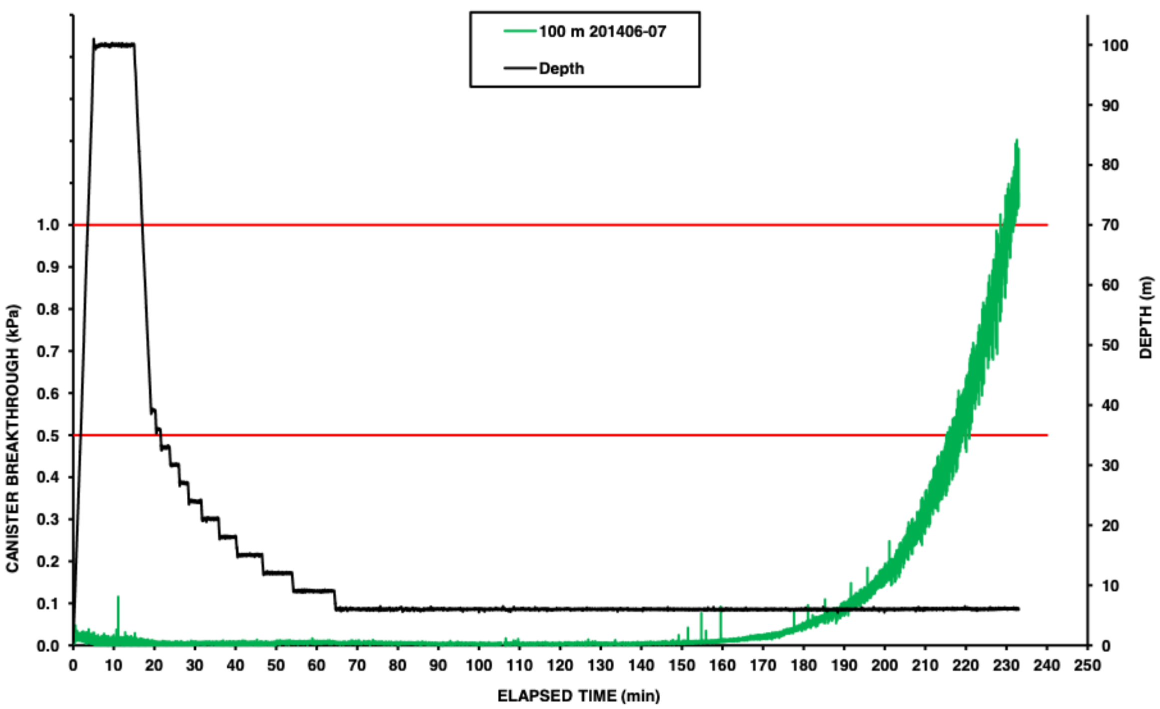

Figure 3-9: CO_2 absorbent canister endurance results; 100 m dive profile

3.2.1 6 m constant depth

The result of the 6 m constant depth endurance is graphically presented in Figure 3-10 and tabulated in Table 3-2.

No increase of partial pressure of carbon dioxide (PCO_2) was detected during the two periods of high ventilation (ventilation rate, 75 l·min^{-1}; CO_2 injection rate, 3.33 l·min^{-1}) at elapsed times of 75 and 95 min.

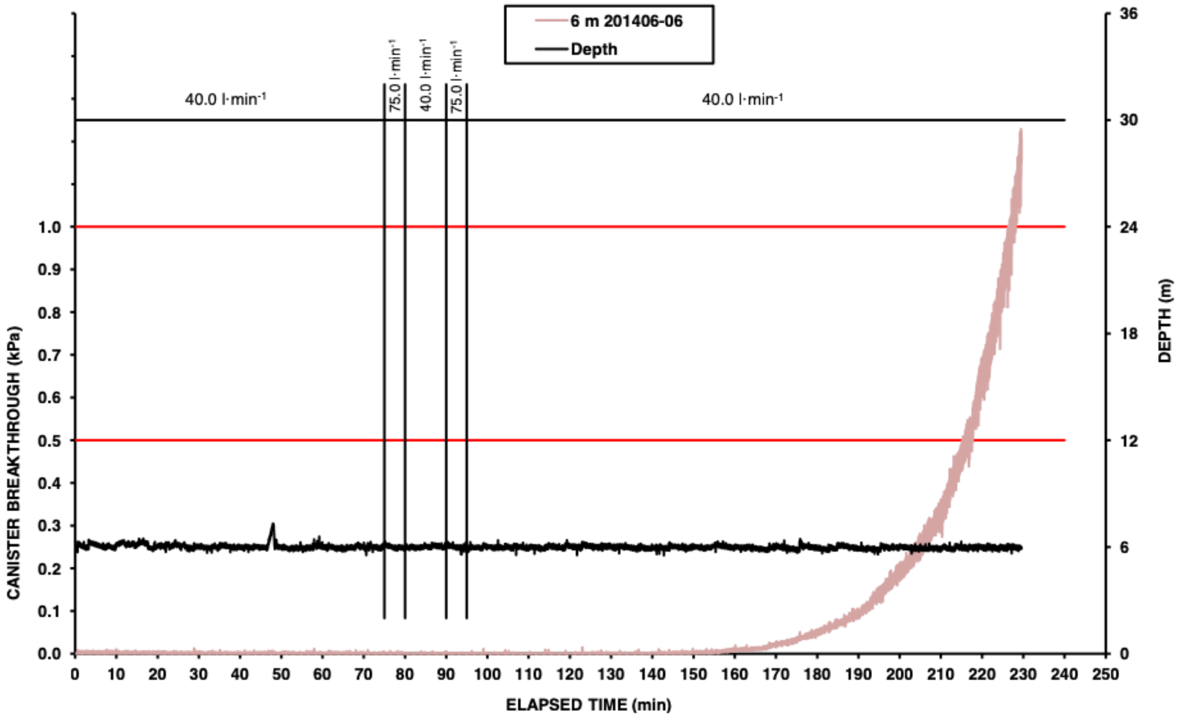

Figure 3-10: CO_2 absorbent canister endurance results; 6 m constant depth

LSSL REFERENCE	DEPTH (m)	SODA LIME FILL WEIGHT (g)	ENDURANCE TIMES (min) 0.5 kPa	ENDURANCE TIMES (min) 1.0 kPa	REQUIRED CO_2 FLOW (l·min^{-1})	CO_2 FLOW (WEIGHT-LOSS CALCULATION) (l·min^{-1})
201406-03	40 (profile)	2698.6	202	219	1.6	1.59
201406-11	40 (profile)	2742.1	223	233		1.60
201406-12	40 (profile)	2709.8	206	219		1.59
201406-07	100 (profile)	2720.4	220	232		1.60
201406-06	6 (constant)	2711.6	218	229		1.60 (40 l·min^{-1})

Table 3-2: CO_2 absorbent canister endurance results; all dive profiles

3.3 Partial pressure of oxygen control

Although full simulated metabolic oxygen consumption was not carried out during the endurance tests, the diver displays were monitored at all times; the apparatus attained and maintained the PO_2 satisfactorily at either 0.7 or 1.3 bar.

3.4 Volume-weighted average inspired carbon dioxide

The results of the VWAICO_2 evaluation are graphically presented in Figure 3-11 and tabulated in Table 3-3.

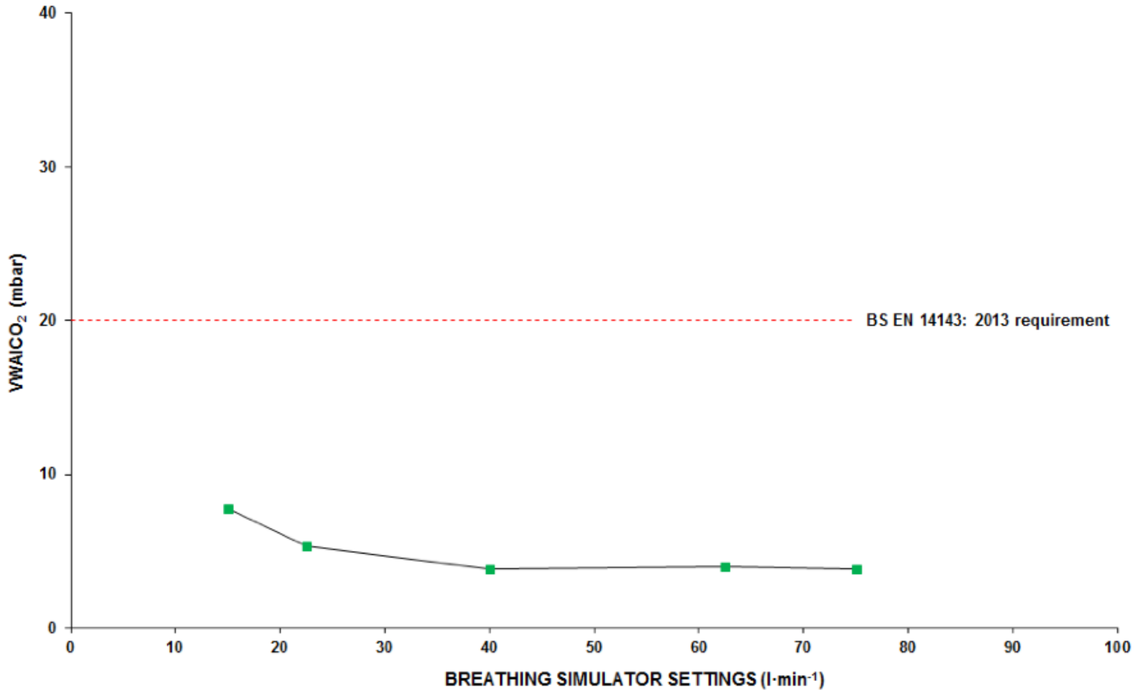

Figure 3-11: VWAICO_2 results

VENTILATION RATE ($l \cdot min^{-1}$)	15.0	22.5	40.0	62.5	75.0
VWAICO_2 (mbar)	7.75	5.32	3.86	3.98	3.87

Table 3-3: VWAICO_2 results

3.5 Hydrostatic imbalance

The results of the hydrostatic evaluation, with the ADV activation at - 20 mbar and referenced to the suprasternal notch, are graphically presented in Figures 3-12 and 3-13 and tabulated in Table 3-4.

The result of the single test carried out with the ADV closed is also presented in Table 3-4.

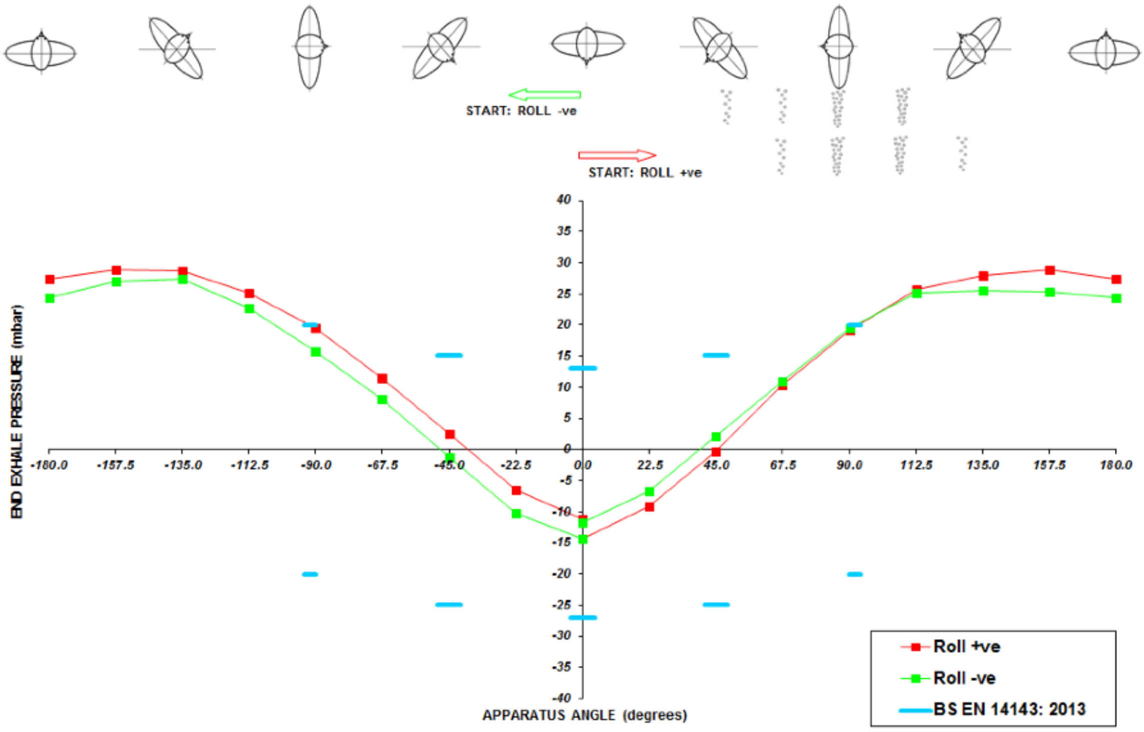

Figure 3-12: Hydrostatic imbalance results; diver roll

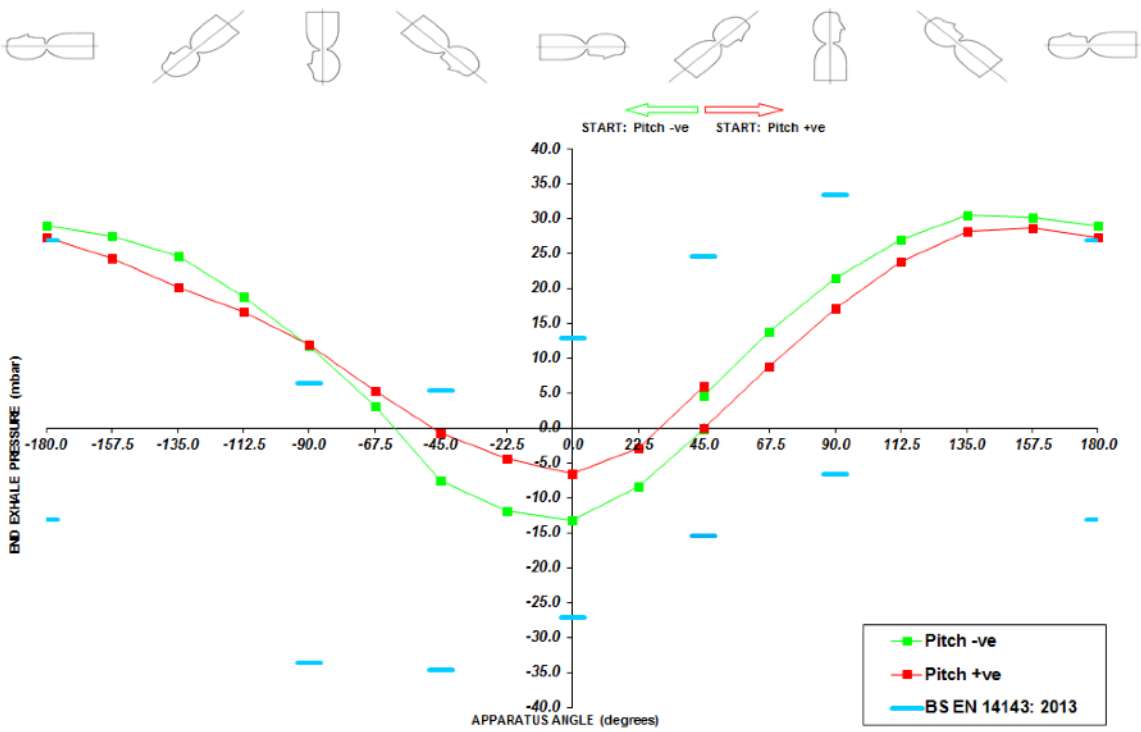

Figure 3-13: Hydrostatic imbalance results; diver pitch

ROLL ATTITUDE (degrees)	+ 45	0	- 45	- 90	± 180	+ 90
REQUIREMENT:	+15.1 to -24.9	+13.0 to -27.0	+15.1 to -24.9	+20.0 to -20.0	NA	+20.0 to -20.0
-ve direction	2.12	Start: -14.29 End: -11.69	-1.23	15.79	NA	19.52
+ve direction	-0.41	Start: -14.29 End: -11.09	2.53	19.57	NA	19.1
PITCH ATTITUDE (degrees)	+ 45	0	- 45	- 90	± 180	+ 90
REQUIREMENT:	+24.6 to -15.4	+13.0 to -27.0	+5.5 to -34.5	+6.5 to - 33.5	+27 to -13	+33.5 to -6.5
-ve direction	Start: - 0.16 End: 4.78	-13.15	-7.38	11.89	29.01	13.84
+ve direction	Start: 0.03 End: 5.98	-6.46	-0.68	12.08	27.32	17.22
PITCH with ADV closed						
-ve direction	Start: 0.74	-	-	4.68	-	-

Table 3-4: Hydrostatic imbalance results;
requirement and results in mbar, referenced to suprasternal notch

3.6 Resistance to temperature

3.6.1 Testing after storage

Following ≥ 3 h at + 70 °C and return to ambient temperature (23 °C), the apparatus was turned on. The diver displays were normal, easy to read and operational; the apparatus controlled the partial pressure of oxygen (PO_2) at 0.7 bar and functioned within specified limits during the 10 min ventilation period.

Following ≥ 3 h at - 30 °C and return to ambient temperature (19 °C), there was a momentary leak of gas (from the first stage regulator/cylinder pillar valve fitting) when the diluent supply was established; no leak from the diluent system occurred.

When the electronics were turned on, the diver displays were normal, easy to read and operational. The apparatus controlled the PO_2 at 0.7 bar and functioned within specified limits during the 10 min ventilation period.

3.6.2 Testing in pre-dive operation

Following ≥ 3 h at 55 °C, the apparatus did not leak gas from the HP and MP systems when the oxygen and diluent gas supplies were established.

Following ≥ 3 h at - 20 °C, there was a momentary leak of HP gas (from the first stage regulator/cylinder pillar valve fitting) when the oxygen supply was established; no leak from the HP or MP diluent systems occurred.