Results from the testing of two Hollis Prism closed-circuit rebreathers

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55 pages

Customer Information	
Project title	Hollis Prism rebreather
Customer Organisation	Hollis Rebreathers LLC
Customer contact	Mr Nick Hollis
Contract number	QINETIQ/53438/0003v5a

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Record of changes

Issue	Date	Detail of changes
1.0	30 January 2019	First issue
1.1	1 February 2019	Corrected breathable volume results

1 Introduction

1.1 Apparatus received

This report presents brief procedures with tabular and/or graphical results from the testing of two Hollis Prism closed-circuit rebreathers. They were configured and identified within this report by the counterlung configuration, as follows:

- Apparatus serial number (S/N):1001.1810.1858
  Front-mounted counterlungs
  Sensor S/N: S1: 804688565; S2: 804688418; S3: 804688527 (expiry 08/19)

- Apparatus S/N 1001.1810.1859
  Rear-mounted counterlungs
  Sensor S/N: S1: 804688545; S2: 804688607; S3: 804688537 (expiry 08/19)
  Exhaust valve relief pressure: 0.55 psi unless otherwise stated

1.2 Oxygen sensors

During testing to determine the accuracy of the oxygen sensors, it became apparent that the original sets of sensors configured within the two apparatus were indicating signs of inaccuracy (*i.e.* drop off) at the higher partial pressure of oxygen (PO_2) readings.

Therefore, some tests were repeated with a new set of sensors configured within the front-mounted counterlung apparatus, as follows:

- Sensor S/N: S1:809750386; S2: 809750387; S3: 809750388 (expiry 01/20)

The results obtained during the tests described in section 11, with the original sensors configured as part of the front-mounted apparatus, are not included in this report.

1.3 Rear-mounted counterlung configuration

It was noted that the movement of the rear-mounted counterlungs during ventilation could be restricted by the position of the wing buoyancy compensator (WBC), particularly if inflated. It was also of concern that the function of the exhalation counterlung variable exhaust valve (VEV) could also be compromised.

Therefore, to ensure that any influence was kept to a minimum, the WBC was never inflated during testing.

1.4 BS EN 14143: 2013 requirements

All procedures were carried out in accordance with (*i.a.w.)*, and results compared to, the requirements of British Standard European Norm (BS EN) 14143: 2013 (unless otherwise stated); the relevant paragraphs were as follows (tests were not conducted in this order):

- Performance requirements
  Requirements: 5.6.1.1, 5.6.1.2, 5.6.1.3, 5.6.1.6
  Testing: 6.3.2, 6.3.5

- Hydrostatic imbalance
  Requirements: 5.6.1.4
  Testing: 6.4

- Maximum inspired partial pressure of carbon dioxide
  Requirement: 5.6.1.5
  Testing: 6.3.3

- Breathable volume
  Requirement: 5.6.2
  Testing: 6.5.1 (6.18 Practical performance, not applicable)

- Exhaust valve
  Requirement: 5.6.4
  Testing: 6.5.3

- Carbon dioxide absorbent canister
  Requirements: 5.6.6
  Testing: 6.6.1, 6.6.2

- Inhalation temperature
  Requirements: 5.6.7
  Testing: 6.3.4

- Ingress of water
  Requirements: 5.6.8
  Testing: 6.5.5

- Inspired partial pressure of oxygen/setpoint maintenance
  Requirements: 5.7.1, 5.7.2
  Testing: 6.7 (6.18 Practical performance, not applicable)

- Alphanumeric display for inspired partial pressure of oxygen
  Requirements: 5.7.3
  Testing: 6.10.2

- Resistance to temperature
  Requirements: 5.14
  Testing: 6.13
  Elements of BS EN 250: 2014 (paragraphs 5.12.2 and 6.12.4) were included in this test

Testing commenced 30 October 2018 using the hyperbaric chamber (with breathing simulator), Hydrostatic and Extreme Temperature Tank (HETT) (with breathing simulator) and associated equipment within the Diving and Hyperbaric Test Centre (DHTC) Life Support Systems Laboratory (LSSL). This laboratory is able to evaluate apparatus in a range of simulated environments and operational conditions; monitoring uses instrumentation and software that give results in real time.

A number of the tests were witnessed by Mr C Chapman, the manufacturer's representative, and Mr T G Anthony, a consultant for Société Générale de Surveillance (SGS).

QinetiQ at Haslar were tasked by Hollis Rebreathers LLC to undertake testing under Contract Number QINETIQ/53438/0003v5a.

Throughout this report table cells shaded in green means that a particular test complied with the requirements of BS EN 14143: 2013, whereas red shading means that a particular test did not comply with the requirements of BS EN 14143: 2013.

Three different units for pressure are used extensively in this report. It is common to use metres 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 millibar (mbar) or the Système International D'unités (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 metre (m) (assuming a density of seawater of 1.01972 at 4 ° Celsius (C)) and that the air pressure at sea level = 0 m = 101.3 kPa (one standard atmosphere). Simulator rates used during testing are quoted at ambient temperature pressure (ATP) and flow rates at standard temperature pressure dry (STPD).

2 Performance requirements

(*i.a.w.* paragraphs 5.6.1.1, 5.6.1.2, 5.6.1.3, 5.6.1.6; 6.3.2, 6.3.5)

2.1 General breathing performance

The full range of breathing performance evaluation was carried out with the apparatus configured with the Dive Surface Valve (DSV) and appropriate hoses. For comparison purposes, a single test was carried out with the apparatus configured with the Bail-out valve (BOV) and appropriate hoses; this was in the horizontal orientation, with front-mounted counter lungs and at a simulated depth of 40 m.

Both apparatus (front and rear mounted counterlungs) were configured within the hyperbaric chamber and evaluated under the following conditions:

- water temperature: 4 °C (± 1 °C)
- apparatus orientation: vertical and horizontal
- apparatus configuration: front- and rear-mounted counterlungs
- VEV: fully closed
- O_2 sensor S/N: 804688-565, -418, -527 (front-mounted)
  804688-545, -607, -537 (rear-mounted)
- breathing circuit: optimised and demand actuated
- simulated depths: 0 (surface), 40 and 100 m
- diluent supply gases: air (nominal oxygen (O_2) content: 20.9 %)
  trimix (9% O_2:65% helium (He):26% nitrogen (N_2)
- simulator settings: shown in Table 2-1

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

Table 2-1: Ventilation rates

To obtain ‘optimised’ data, breathing volume make-up and over pressure venting of the breathing circuit was performed manually, via quarter turn valves fitted externally to the breathing simulator. To obtain demand actuated data, gas was vented externally from the breathing circuit. This was at a nominal rate of 1.78 $l\cdot min^{-1}$ (ATP), thus causing the Diluent Demand Valve (DDV) to operate.

Inhale and exhale respiratory pressures were recorded throughout the breathing cycle and work of breathing was calculated.

No gas humidification or heating was employed during breathing performance evaluation.

All breathing performance testing was undertaken with a single carbon dioxide (CO_2) absorbent canister fill; this was with Molecular Products Sofnolime CO_2 absorbent (Lot: 2440918, Expiry: 09/2023, 797 Grade, 1.0 – 2.5 mm, Non Indicating).

The graphical results, plotted at Body Temperature and Pressure, Saturated (BTPS) for comparison with elements of BS EN 14143: 2013, are shown section 2.2; Figure 2-1 to Figure 2-24. The tabulated results are shown in section 2.3; Table 2-2 to Table 2-6.

2.2 Graphical breathing performance results

2.2.1 Diluent supply gas, air; vertical orientation; front-mounted counterlungs

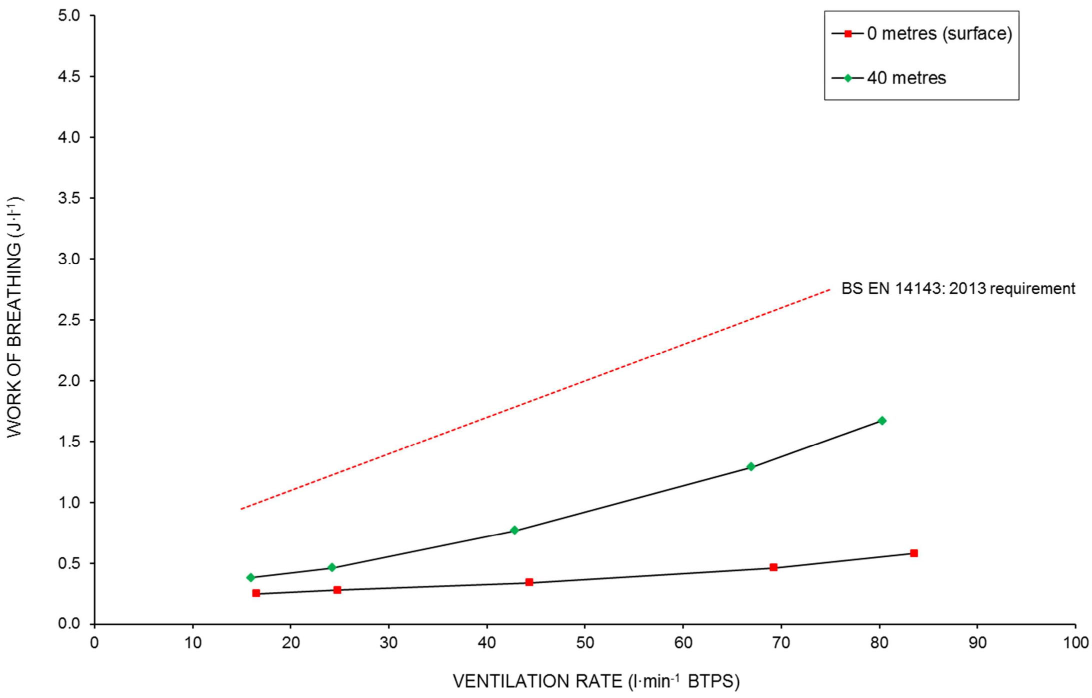

Figure 2-1: Work of breathing

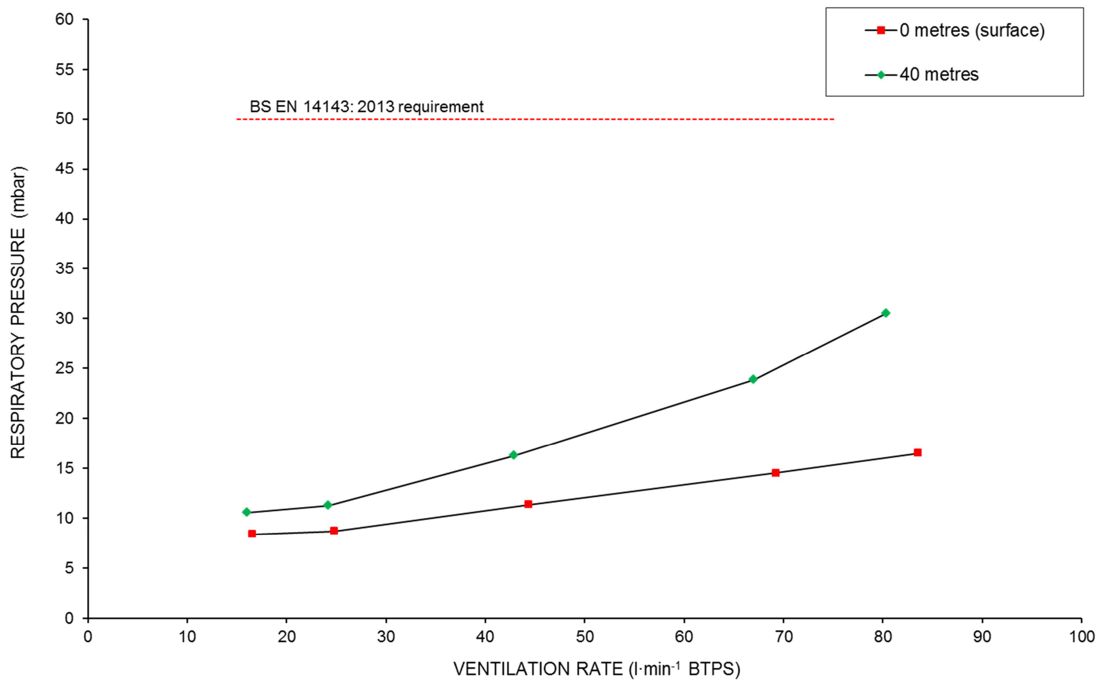

Figure 2-2: Peak-to-peak respiratory pressures

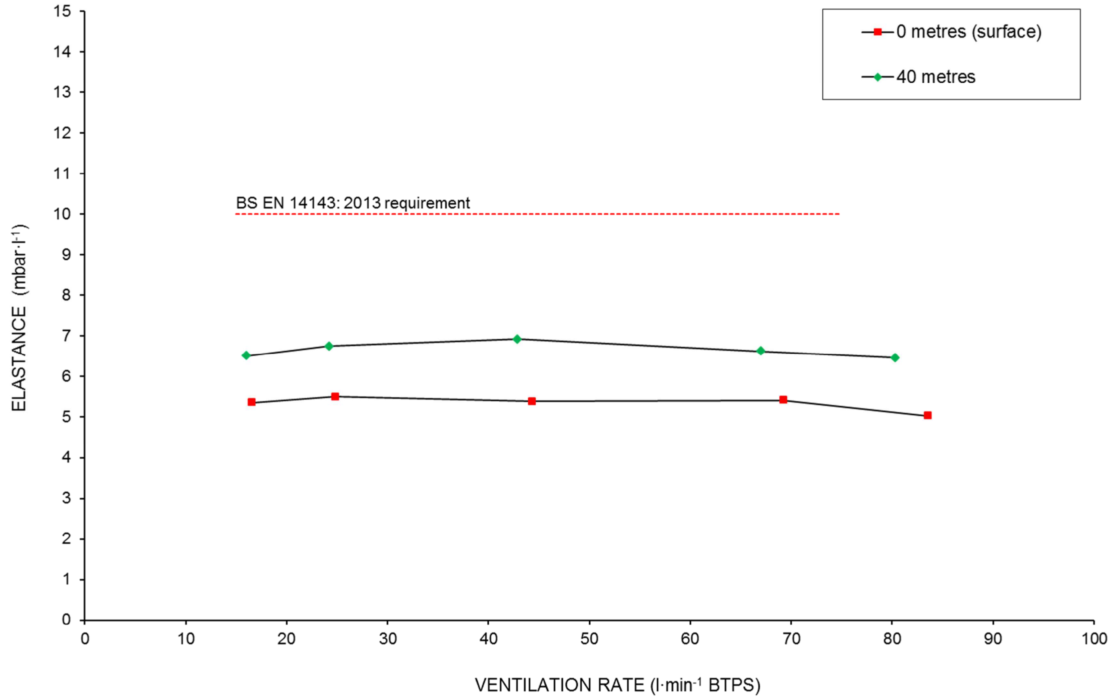

Figure 2-3: Elastance

2.2.2 Diluent supply gas, air; vertical orientation; rear-mounted counterlungs

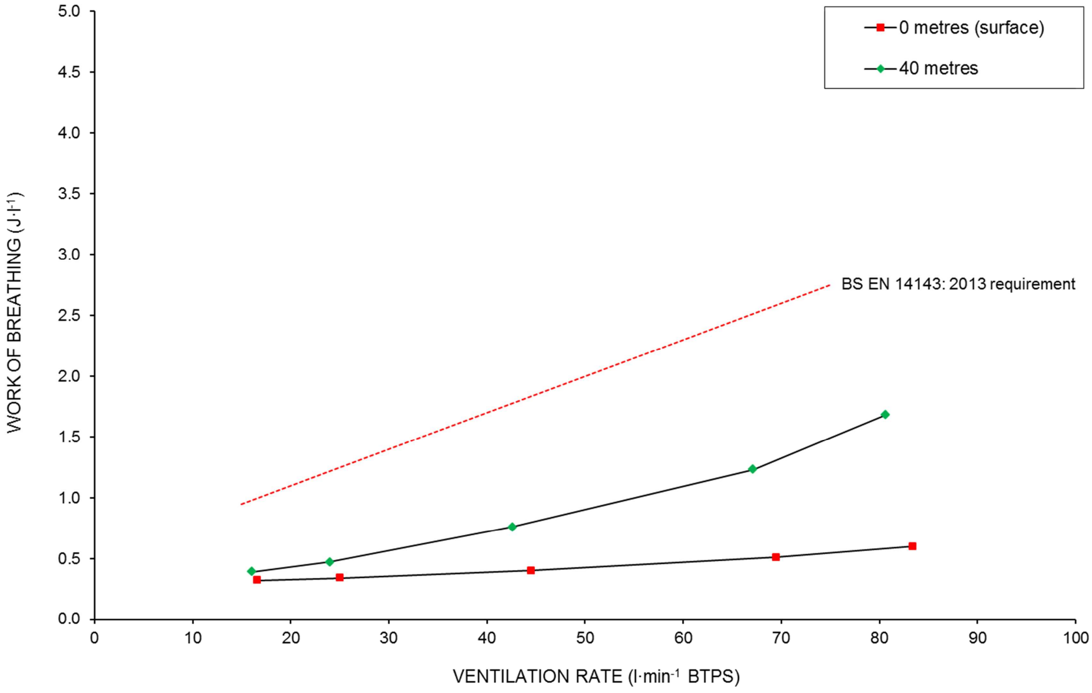

Figure 2-4: Work of breathing

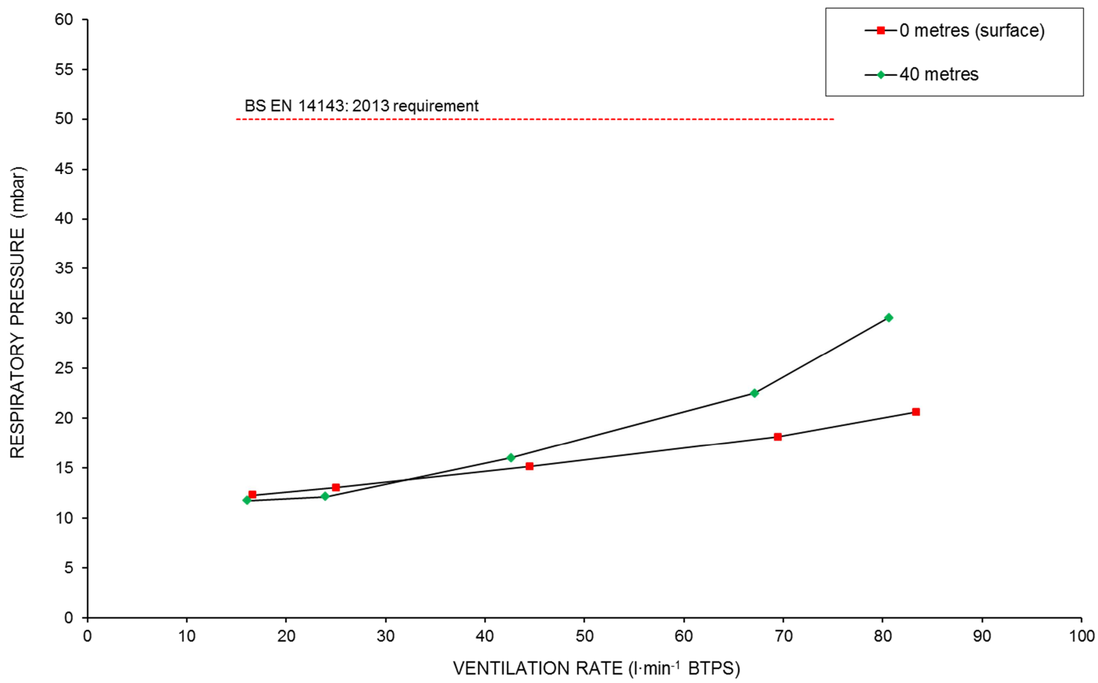

Figure 2-5: Peak-to-peak respiratory pressures

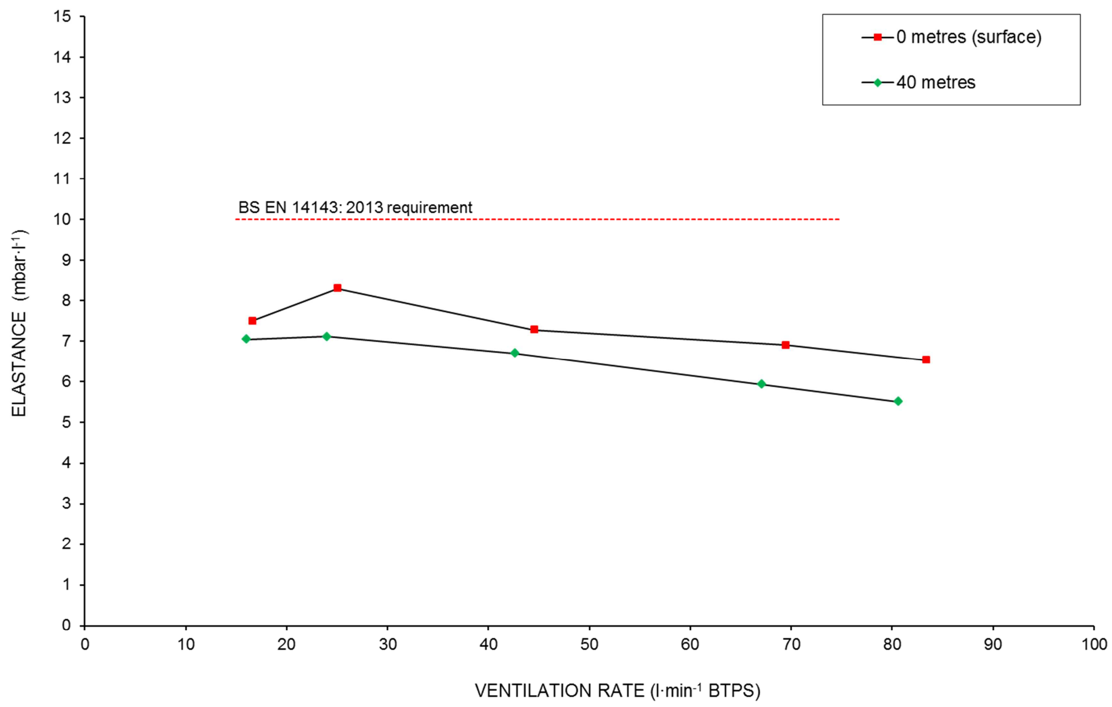

Figure 2-6: Elastance

2.2.3 Diluent supply gas, air; horizontal orientation; front-mounted counterlungs

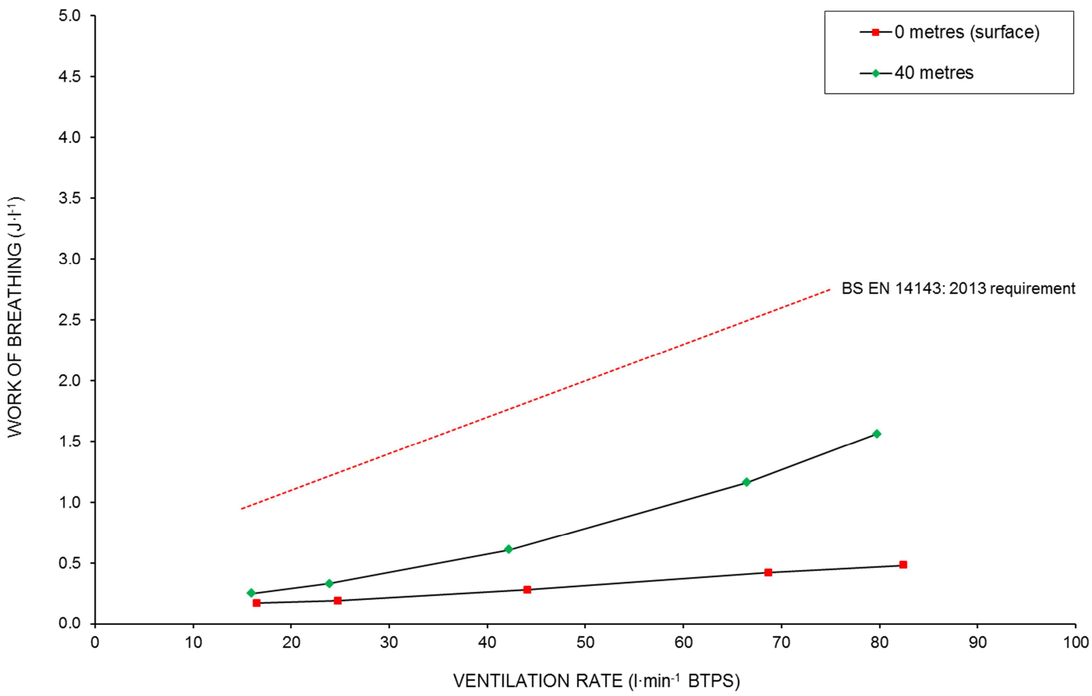

Figure 2-7: Work of breathing

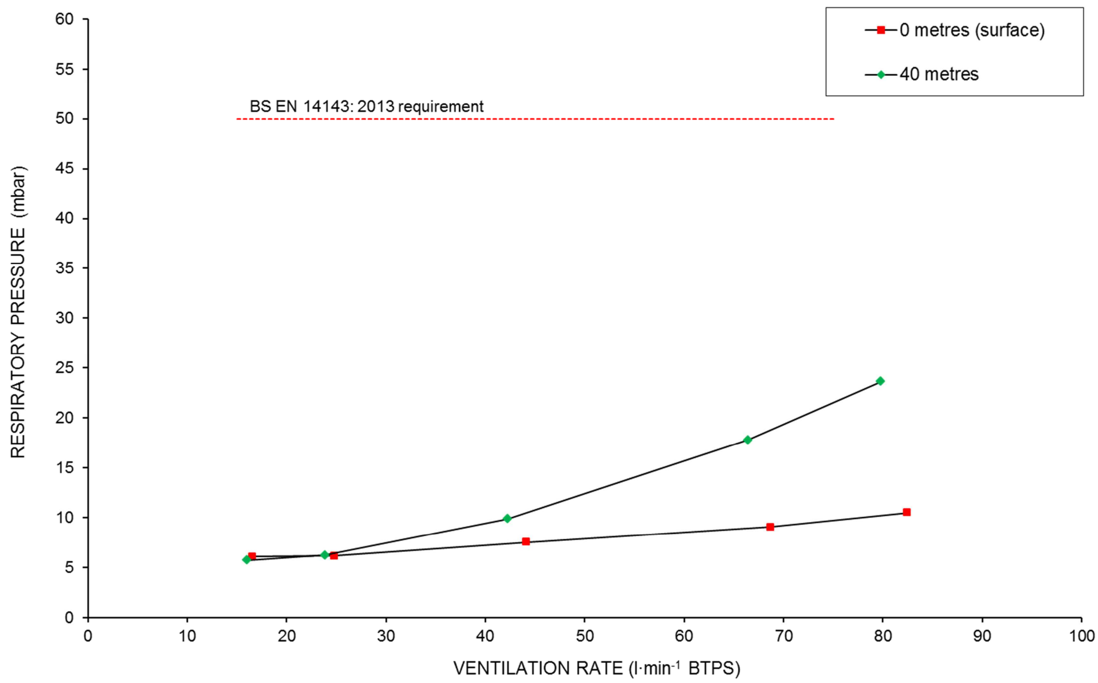

Figure 2-8: Peak-to-peak respiratory pressures

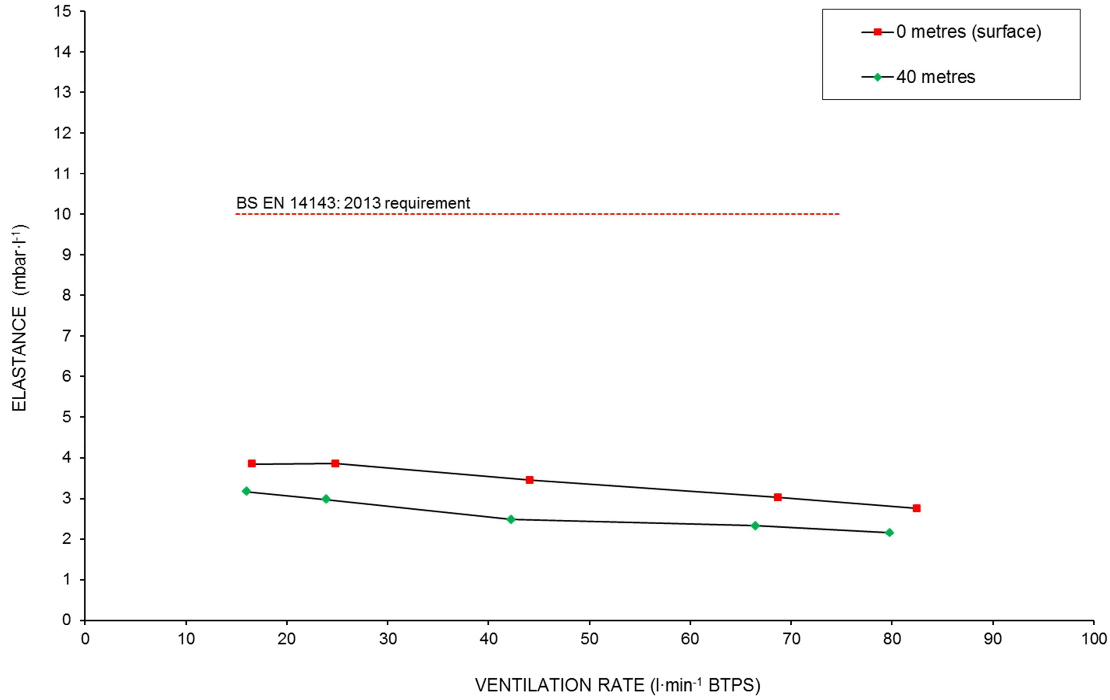

Figure 2-9: Elastance

2.2.4 Diluent supply gas, air; horizontal orientation; rear-mounted counterlungs

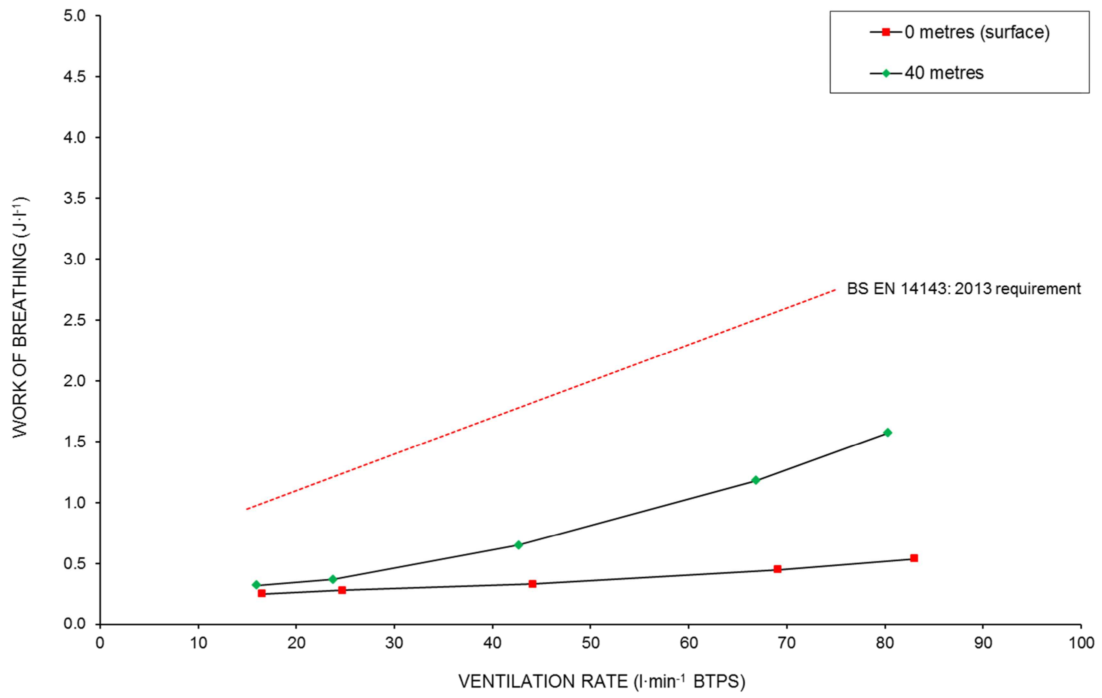

Figure 2-10: Work of breathing

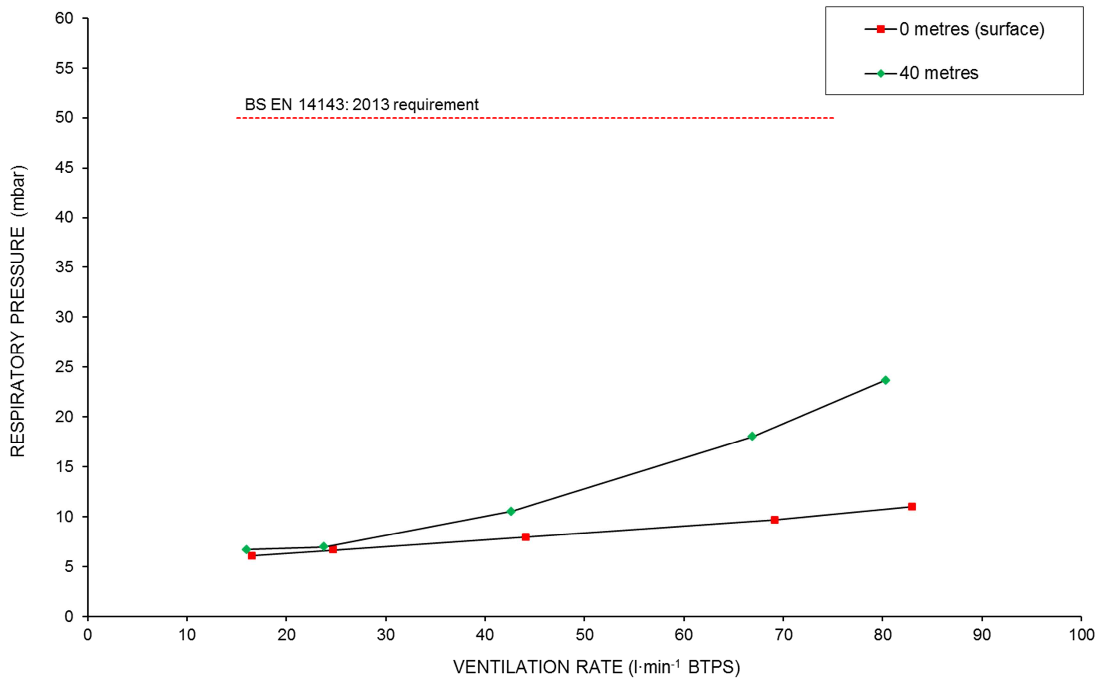

Figure 2-11: Peak-to-peak respiratory pressures

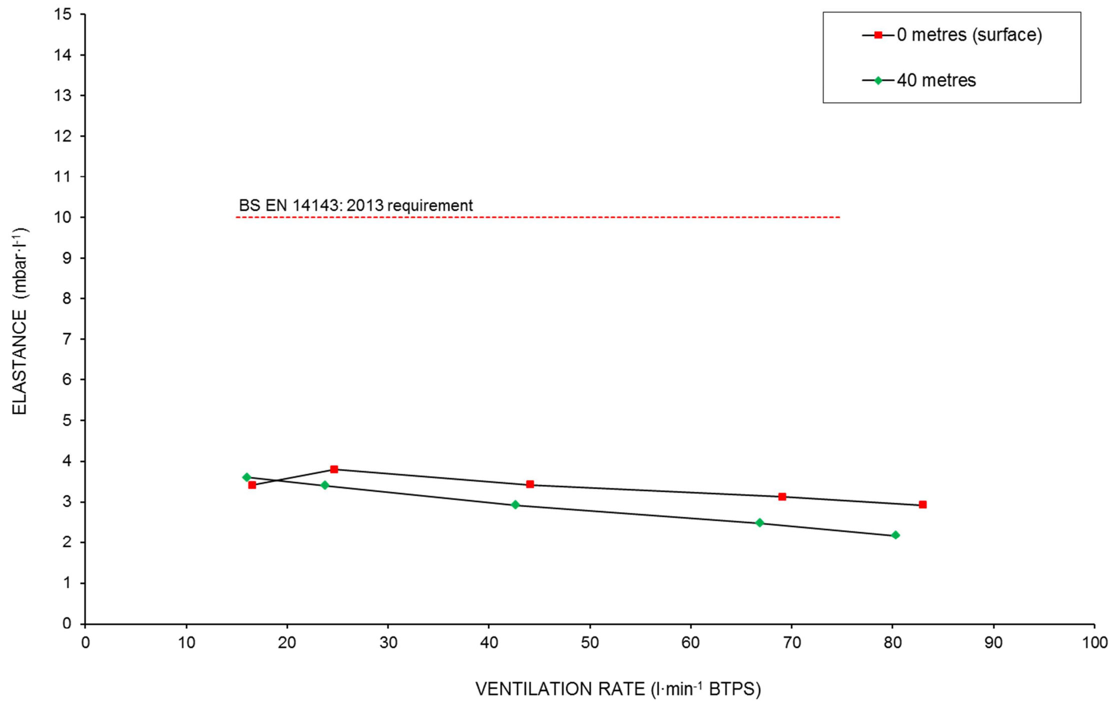

Figure 2-12: Elastance

2.2.5 Diluent supply gas, trimix; vertical orientation; front-mounted counterlungs

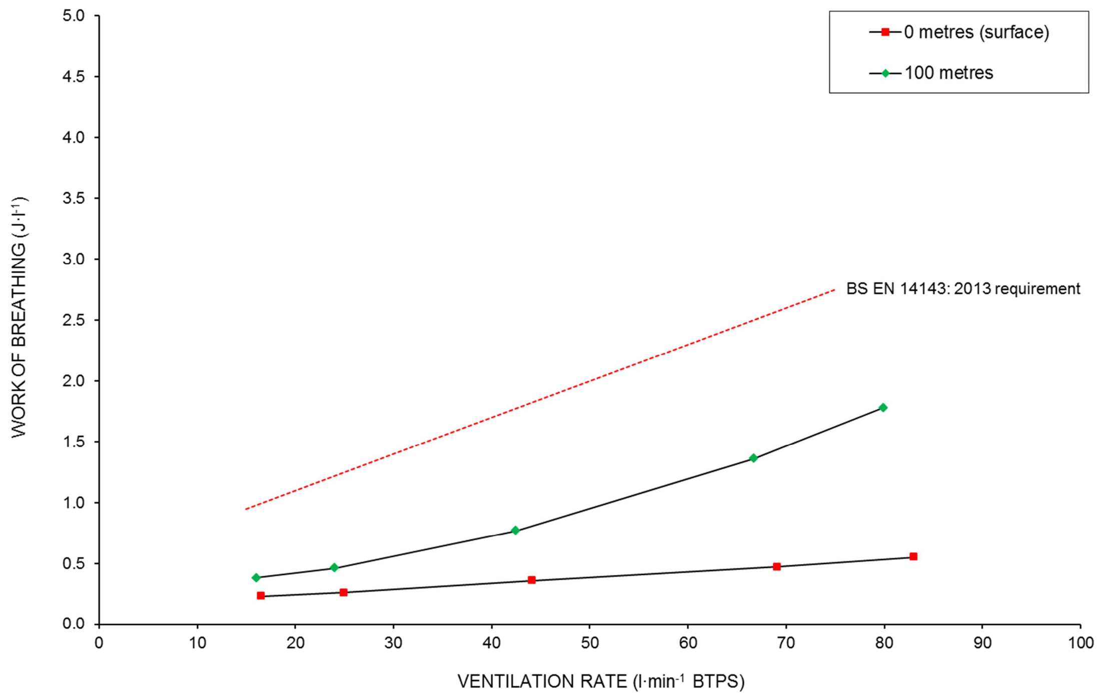

Figure 2-13: Work of breathing

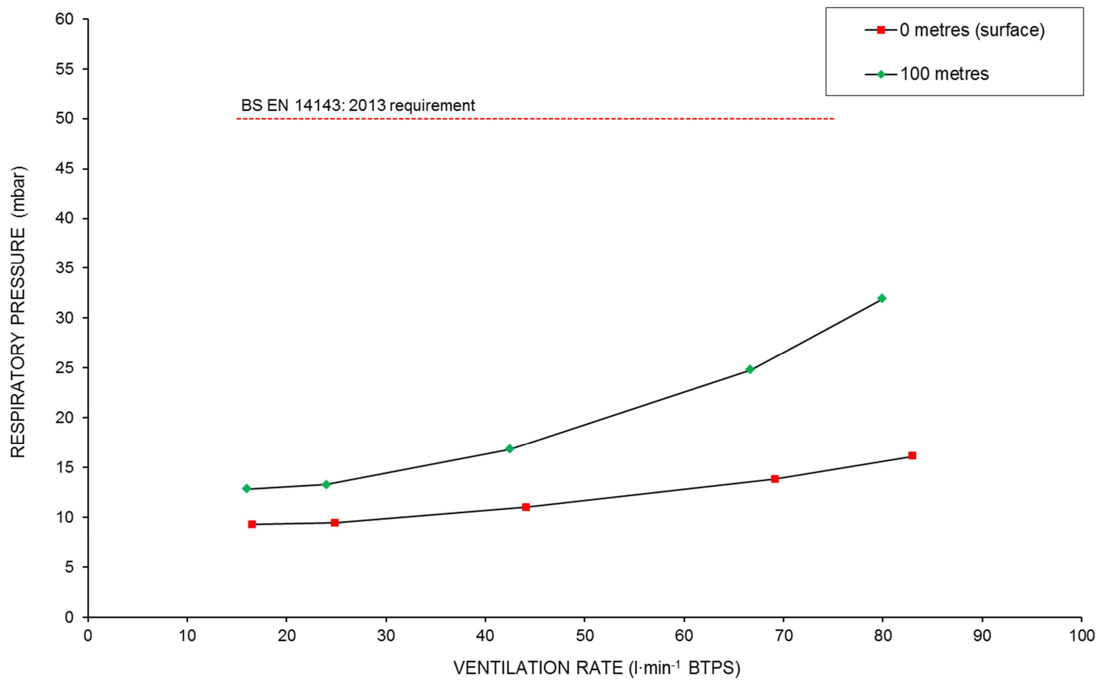

Figure 2-14: Peak-to-peak respiratory pressures

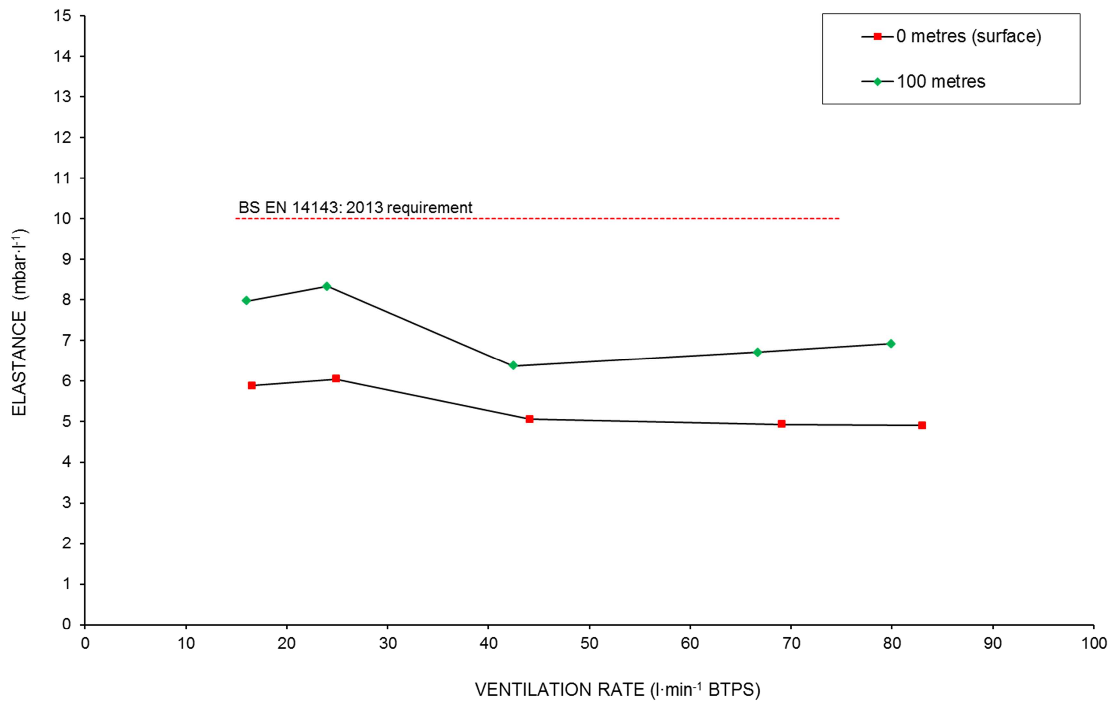

Figure 2-15: Elastance

2.2.6 Diluent supply gas, trimix; vertical orientation; rear-mounted counterlungs

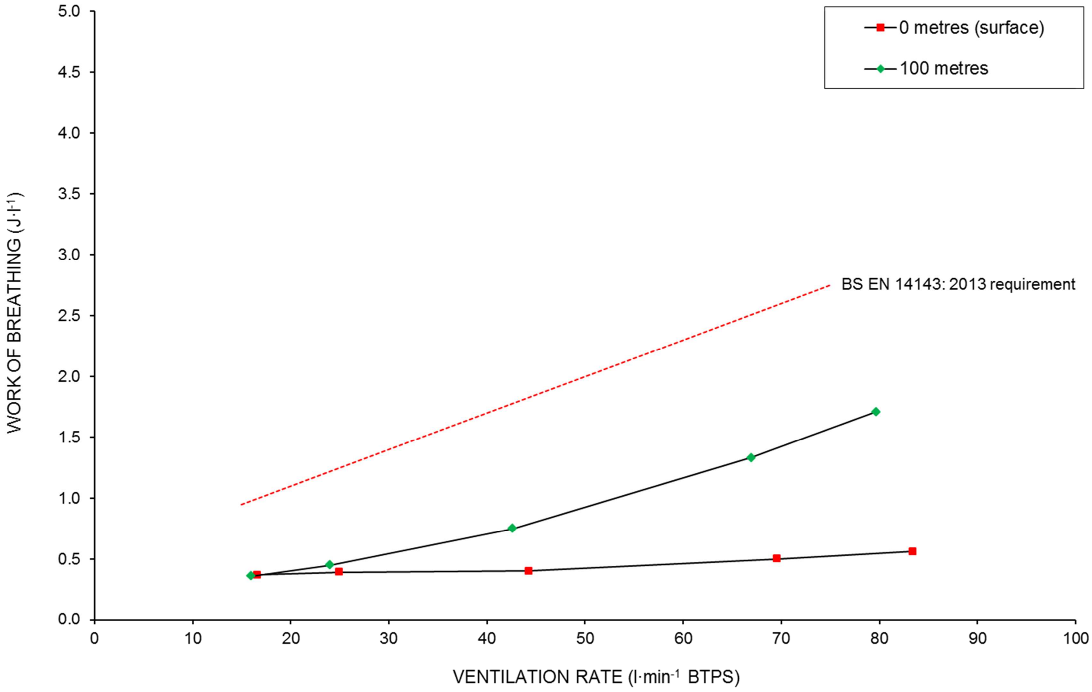

Figure 2-16: Work of breathing

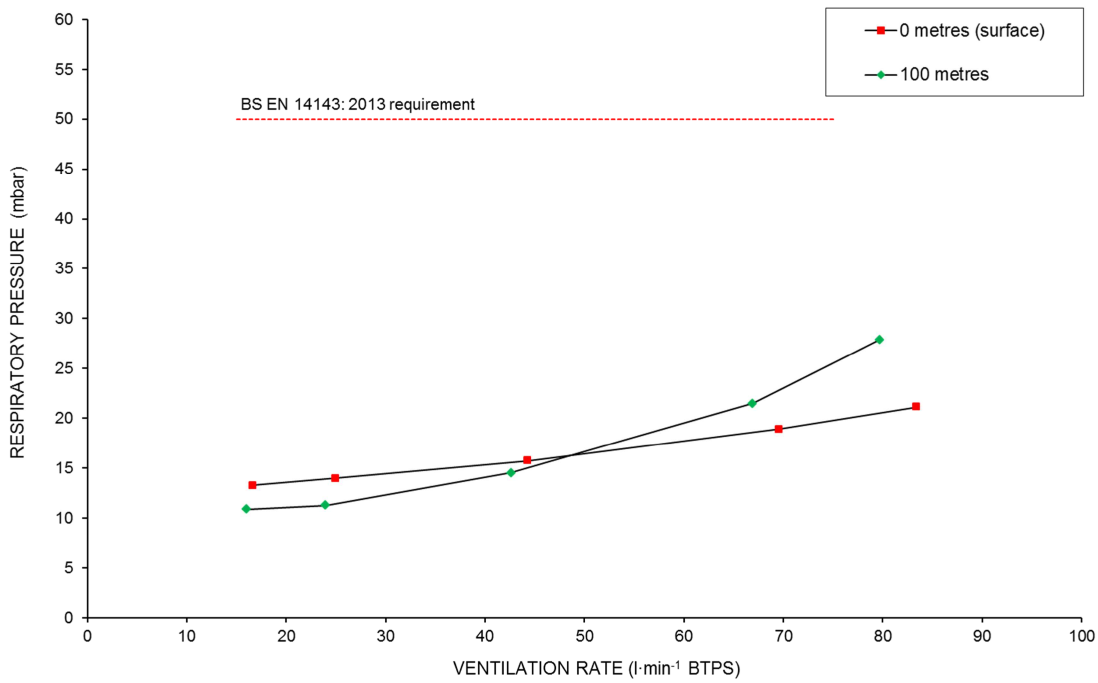

Figure 2-17: Peak-to-peak respiratory pressures

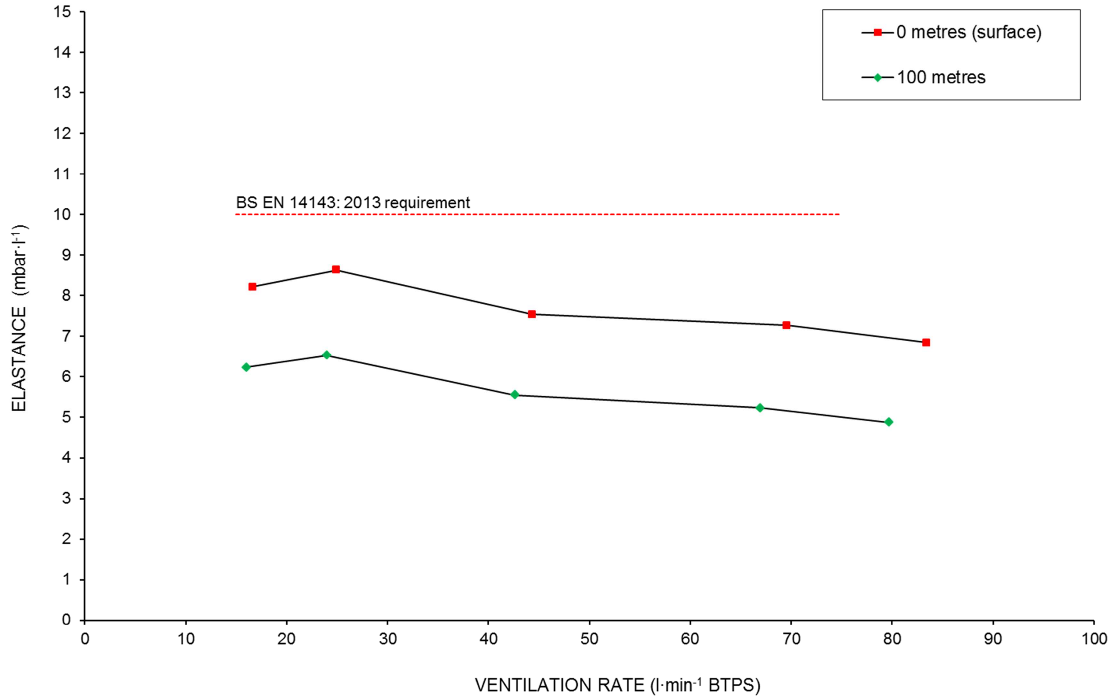

Figure 2-18: Elastance

2.2.7 Diluent supply gas, trimix; horizontal orientation; front-mounted counterlungs

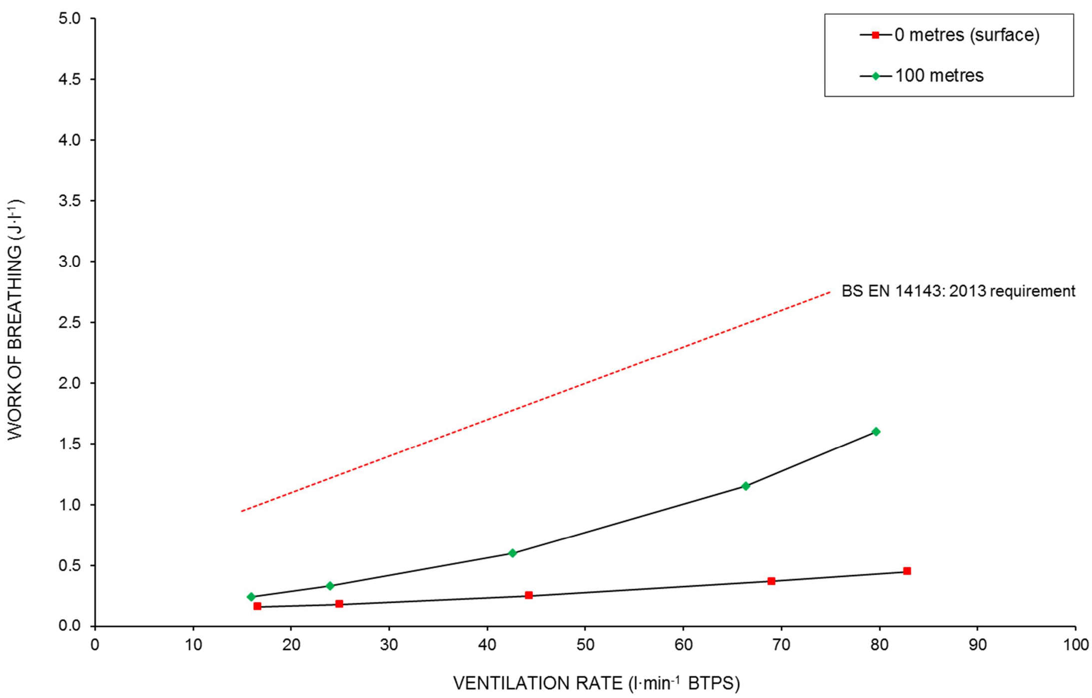

Figure 2-19: Work of breathing

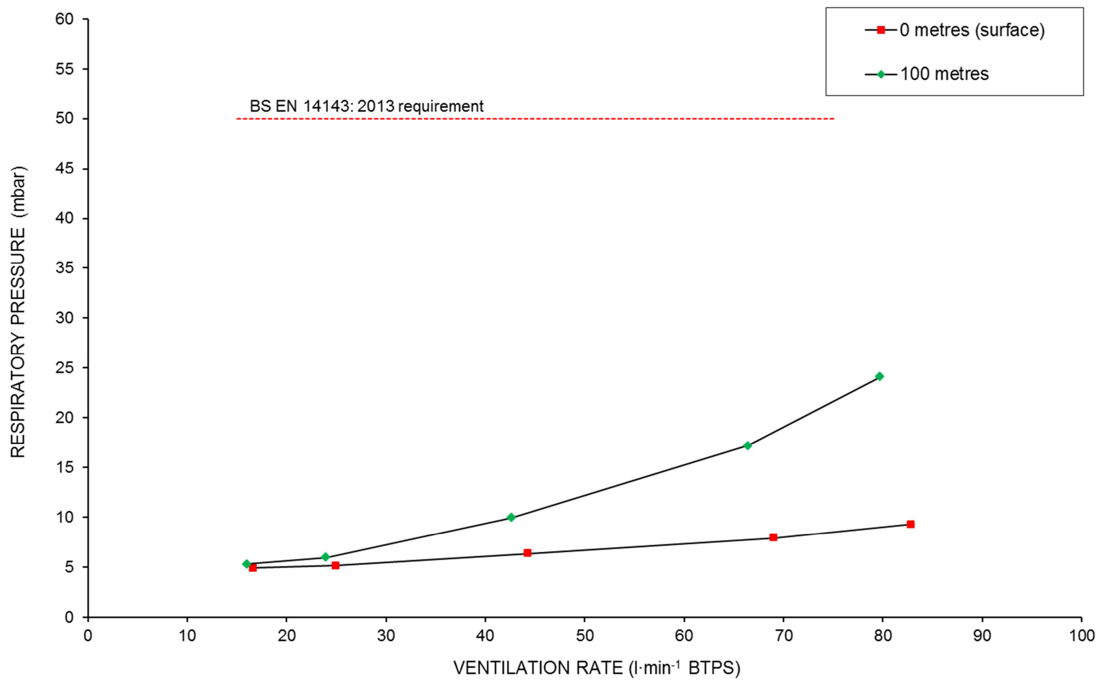

Figure 2-20: Peak-to-peak respiratory pressures

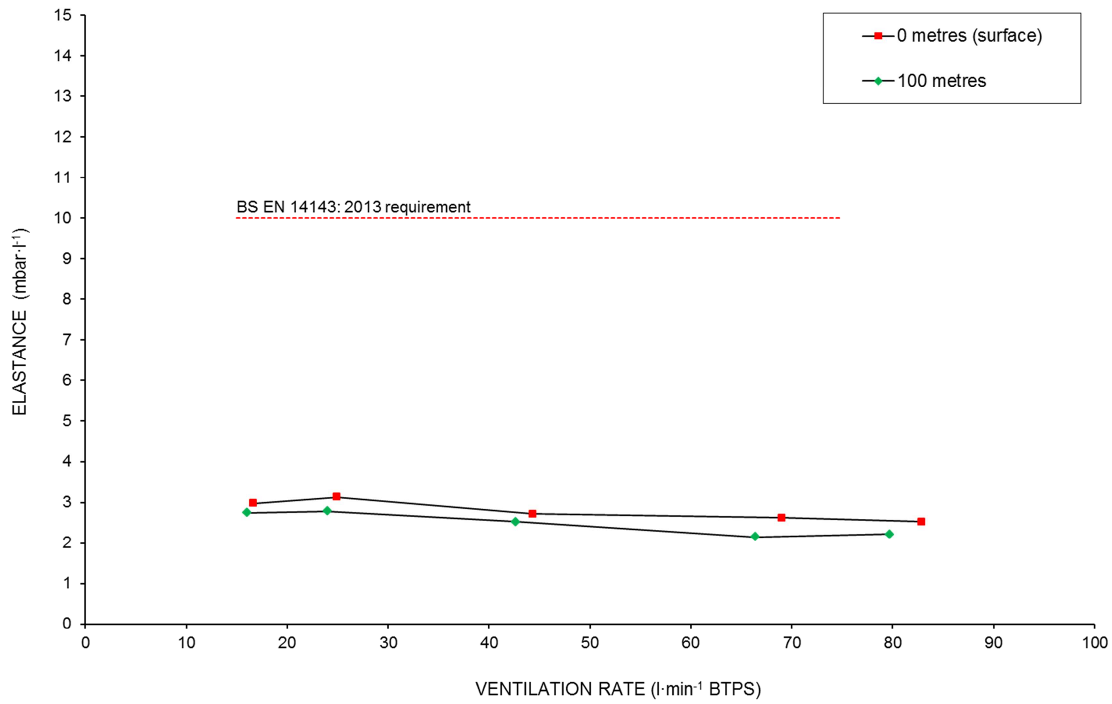

Figure 2-21: Elastance

QinetiQ Proprietary

2.2.8 Diluent supply gas, trimix; horizontal orientation; rear-mounted counterlungs

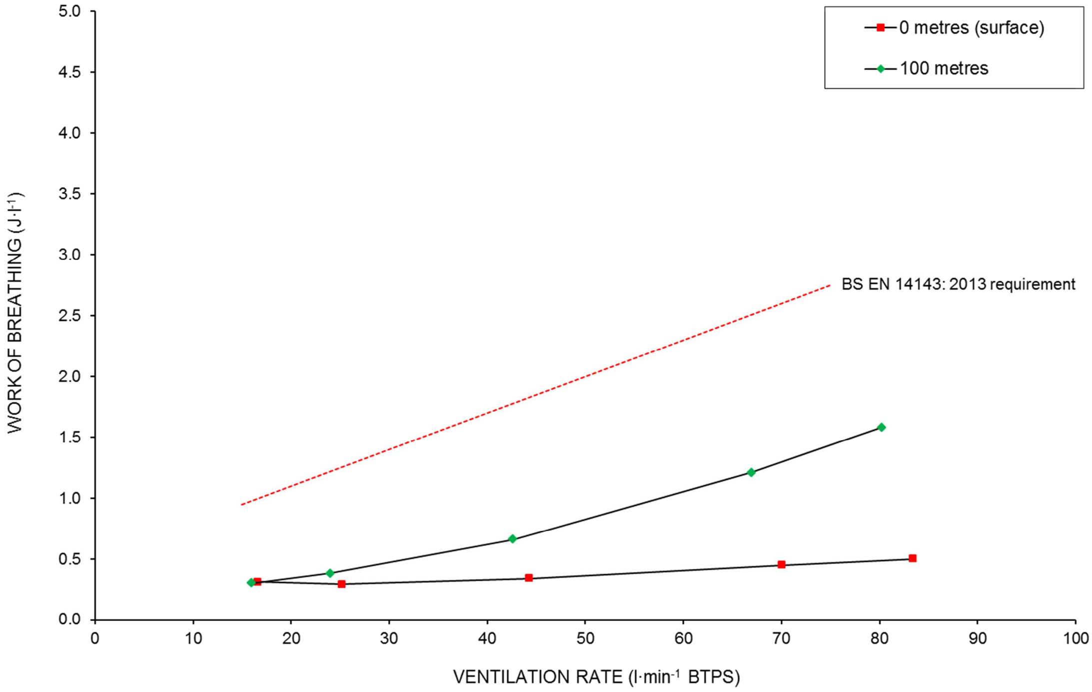

Figure 2-22: Work of breathing

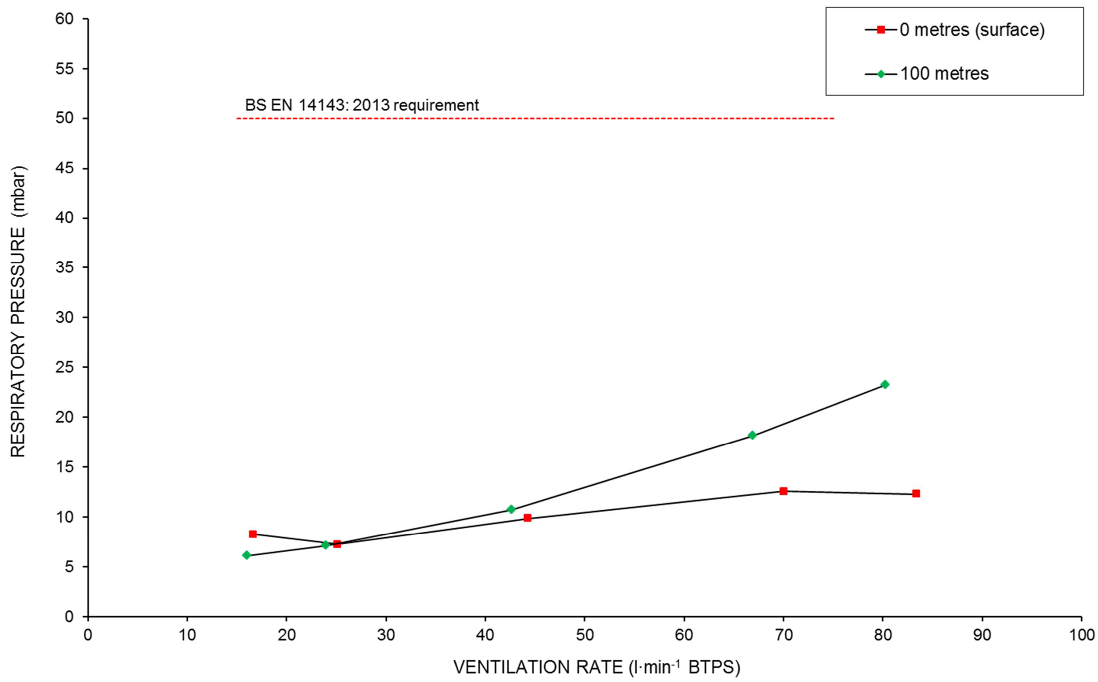

Figure 2-23: Peak-to-peak respiratory pressures

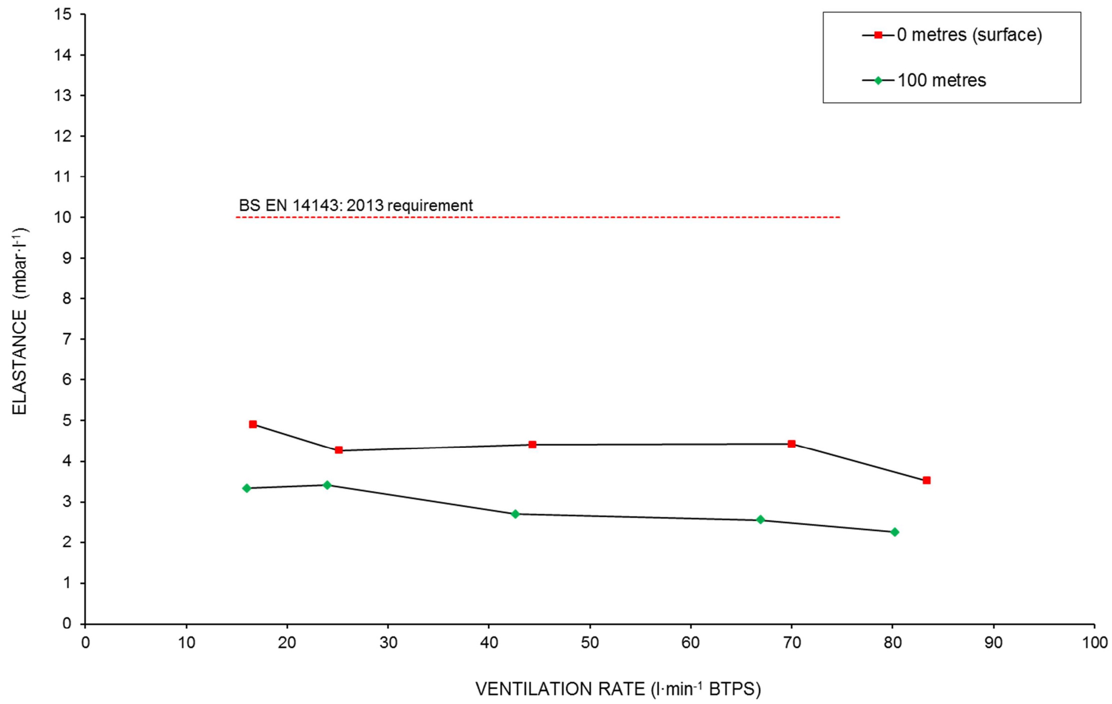

Figure 2-24: Elastance

2.3 Tabulated breathing performance results

2.3.1 Diluent supply gas: Air

APPARATUS ORIENTATION	COUNTERLUNG MOUNTED POSITION	SIMULATED DEPTH (m)	SIMULATOR SETTING (l·min^{-1} ATP)	VENTILATION RATE (l·min^{-1} BTPS)	WORK OF BREATHING (J/l)	PEAK-TO-PEAK RESPIRATORY PRESSURE (mbar)	ELASTANCE (mbar·l^{-1})
Vertical	Front	0	15.0	16.5	0.25	8.39	5.36
			22.5	24.8	0.28	8.68	5.51
			40.2	44.3	0.34	11.34	5.39
			62.8	69.2	0.46	14.51	5.42
			75.8	83.6	0.58	16.53	5.03
		40	15.0	16.0	0.38	10.58	6.51
			22.7	24.2	0.46	11.28	6.75
			40.2	42.9	0.77	16.29	6.93
			62.8	67.0	1.29	23.87	6.63
			75.3	80.3	1.67	30.51	6.46
	Rear	0	15.0	16.6	0.32	12.30	7.51
			22.6	25.0	0.34	13.05	8.30
			40.2	44.5	0.40	15.16	7.28
			62.7	69.5	0.51	18.10	6.91
			75.3	83.4	0.60	20.62	6.53
		40	15.0	16.1	0.39	11.73	7.05
			22.4	24.0	0.47	12.14	7.12
			39.8	42.6	0.76	16.02	6.71
			62.7	67.1	1.23	22.49	5.94
			75.3	80.6	1.68	30.10	5.52

Table 2-2: Vertical orientation; breathing performance results

APPARATUS ORIENTATION	COUNTERLUNG MOUNTED POSITION	SIMULATED DEPTH (m)	SIMULATOR SETTING ($l \cdot min^{-1}$ ATP)	VENTILATION RATE ($l \cdot min^{-1}$ BTPS)	WORK OF BREATHING (J/l)	PEAK-TO-PEAK RESPIRATORY PRESSURE (mbar)	ELASTANCE ($mbar \cdot l^{-1}$)
Horizontal	Front	0	15.0	16.5	0.17	6.08	3.84
			22.5	24.8	0.19	6.14	3.85
			40.0	44.1	0.28	7.53	3.45
			62.3	68.7	0.42	9.04	3.02
			74.8	82.5	0.48	10.48	2.76
		40	15.0	16.0	0.25	5.73	3.17
			22.4	23.9	0.33	6.21	2.98
			39.6	42.2	0.61	9.85	2.49
			62.3	66.4	1.16	17.80	2.33
			74.8	79.8	1.56	23.65	2.16
	Rear	0	15.0	16.5	0.25	6.08	3.41
			22.4	24.7	0.28	6.65	3.79
			40.0	44.1	0.33	7.94	3.42
			62.7	69.1	0.45	9.66	3.12
			75.3	83.0	0.54	11.00	2.92
		40	15.0	16.0	0.32	6.70	3.60
			22.3	23.8	0.37	6.97	3.40
			40.0	42.7	0.65	10.55	2.92
			62.7	66.9	1.18	17.99	2.48
			75.3	80.3	1.57	23.69	2.17
Bail-out valve							
Horizontal	Front	40	15.0	16.0	0.26	5.62	2.84
			22.6	24.1	0.34	6.01	3.14
			40.0	42.7	0.70	11.21	2.62
			62.8	67.0	1.39	21.03	2.50
			74.8	79.8	1.90	28.38	2.39

Table 2-3: Horizontal orientation; breathing performance results

2.3.2 Diluent supply gas: Trimix

APPARATUS ORIENTATION	COUNTERLUNG MOUNTED POSITION	SIMULATED DEPTH (m)	SIMULATOR SETTING (l·min^{-1} ATP)	VENTILATION RATE (l·min^{-1} BTPS)	WORK OF BREATHING (J/l)	PEAK-TO-PEAK RESPIRATORY PRESSURE (mbar)	ELASTANCE (mbar·l^{-1})
Vertical	Front	0	15.0	16.5	0.23	9.28	5.89
			22.6	24.9	0.26	9.45	6.05
			40.0	44.1	0.36	11.01	5.06
			62.7	69.1	0.47	13.81	4.94
			75.3	83.0	0.55	16.14	4.91
		100	15.1	16.0	0.38	12.85	7.97
			22.6	24.0	0.46	13.28	8.33
			40.0	42.5	0.77	16.84	6.38
			62.8	66.7	1.36	24.79	6.71
			75.3	80.0	1.78	31.91	6.93
	Rear	0	15.0	16.6	0.37	13.27	8.21
			22.5	24.9	0.39	13.99	8.63
			40.0	44.3	0.40	15.72	7.55
			62.8	69.6	0.50	18.90	7.27
			75.3	83.4	0.56	21.13	6.85
		100	15.0	16.0	0.36	10.87	6.23
			22.5	24.0	0.45	11.27	6.53
			40.0	42.6	0.75	14.51	5.55
			62.8	66.9	1.33	21.49	5.24
			74.8	79.7	1.71	27.90	4.88

Table 2-4: Vertical orientation; breathing performance results

APPARATUS ORIENTATION	COUNTERLUNG MOUNTED POSITION	SIMULATED DEPTH (m)	SIMULATOR SETTING (l·min^{-1} ATP)	VENTILATION RATE (l·min^{-1} BTPS)	WORK OF BREATHING (J/l)	PEAK-TO-PEAK RESPIRATORY PRESSURE (mbar)	ELASTANCE (mbar·l^{-1})
Horizontal	Front	0	15.0	16.6	0.16	4.90	2.98
			22.5	24.9	0.18	5.15	3.13
			40.0	44.3	0.25	6.36	2.72
			62.3	69.0	0.37	7.91	2.62
			74.8	82.9	0.45	9.27	2.53
		100	15.0	16.0	0.24	5.30	2.75
			22.5	24.0	0.33	5.94	2.78
			40.0	42.6	0.60	9.95	2.52
			62.3	66.4	1.15	17.17	2.15
			74.8	79.7	1.60	24.10	2.22
	Rear	0	15.0	16.6	0.31	8.25	4.91
			22.7	25.1	0.29	7.23	4.26
			40.0	44.3	0.34	9.86	4.41
			63.2	70.0	0.45	12.58	4.43
			75.3	83.4	0.50	12.28	3.51
		100	15.0	16.0	0.30	6.10	3.33
			22.5	24.0	0.38	7.11	3.41
			40.0	42.6	0.66	10.73	2.70
			62.8	66.9	1.21	18.15	2.55
			75.3	80.2	1.58	23.23	2.26

Table 2-5: Horizontal orientation; breathing performance results

2.4 Demand-actuated breathing circuit

The demand actuated data was acquired under the conditions of use described in paragraph 2.1. This was at the single breathing simulator setting of 40.0 l·min^{-1} (ATP), at each maximum simulated depth, with gas vented externally from the breathing circuit at a nominal rate of 1.78 l·min^{-1} (ATP).

DILUENT SUPPLY GAS MIX	APPARATUS ORIENTATION	COUNTERLUNG MOUNTED POSITION	SIMULATOR SETTING (ATP)	VENTILATION RATE (BTPS)	PEAK-TO-PEAK RESPIRATORY PRESSURE (mbar)
BS EN 14143: 2013 requirement: < 60 mbar					
Air	Vertical	Front	40.2	42.9	22.8
		Rear	40.0	42.8	24.4
	Horizontal	Front	40.0	42.7	22.6
		Rear	40.0	42.7	10.2
Trimix	Vertical	Front	40.2	42.7	30.5
		Rear	40.0	42.6	24.2
	Horizontal	Front	40.0	42.6	22.0
		Rear	40.2	42.8	10.6
Bail-out valve					
Air	Horizontal	Front	40.0	42.7	27.6

Table 2-6: Demand-actuated results

3 Hydrostatic imbalance

(*i.a.w.* paragraphs 5.6.1.4; 6.4)

3.1 General

The apparatus was set up on a rotatable mannequin within the HETT and tested under the following conditions of use:

- water temperature: 17 °C
- configuration: front- and rear- mounted counterlungs
  DSV mouthpiece and hoses
  VEV fully closed
  O_2 sensor S/N 804688-565, -418, -527 (front)
  O_2 sensor S/N 804688-545, -607, -537 (rear)
- diluent supply gas: air
- simulated depth: nominal 0.35 m to lung centroid (+ 90 °)
- simulator setting: 62.5 $l \cdot min^{-1}$ (ATP)
- roll orientation: 0, 45, 90, -90, -45 °
- pitch orientation: 45, 0, -45, -90, 180, 90 °

Each of the pitch and roll tests, with captured data referenced to lung centroid, were carried out with the apparatus rotated, from the start position, in the following directions:

- pitch positive (diver head back)
- pitch negative (diver head forwards)
- roll positive (diver left downwards)
- roll negative (diver right downwards)

3.2 Hydrostatic imbalance results graphical and tabular results

3.2.1 Front-mounted counterlungs

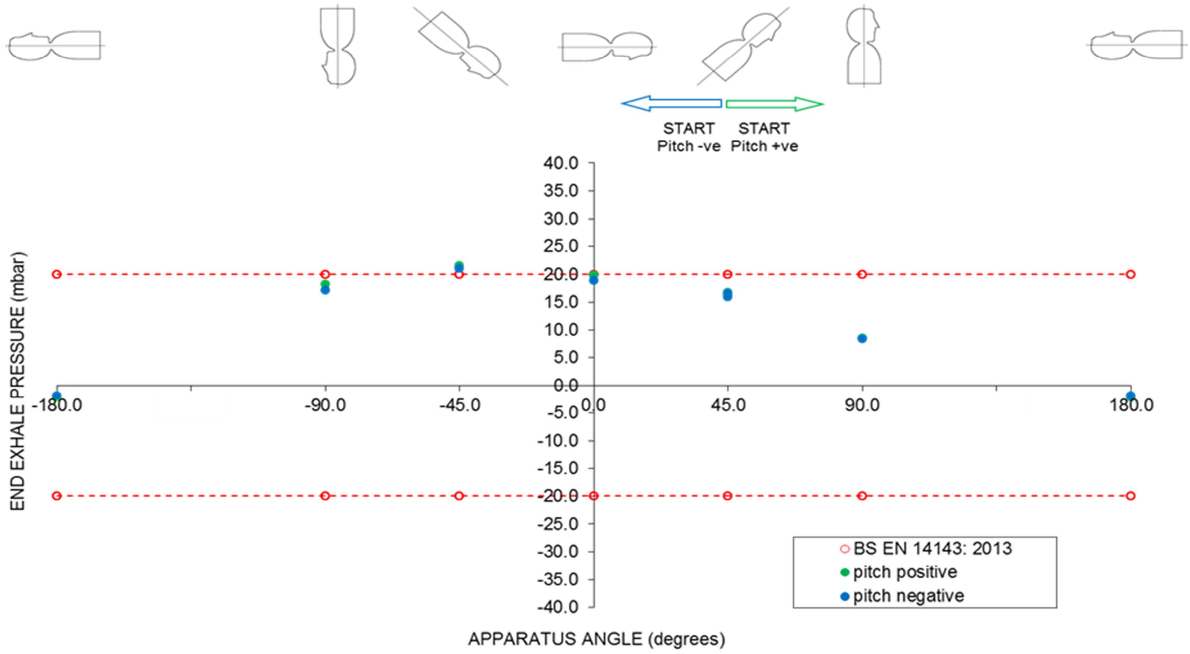

Figure 3-1: Front-mounted counterlungs: pitch results

APPARATUS ORIENTATION (°) DIRECTION OF ROTATION		PRESSURE AT START INHALE (mbar)
BS EN 14143: 2013 requirement: ± 20 mbar		
pitch positive (roll 0)	+45	16.8
	+90	8.5
	+180	-2.1
	-90	18.2
	-45	21.5
	0	19.8
(repeat)	+45	16.3
pitch negative (roll 0)	+45	16.6
	0	18.9
	-45	21.0
	-90	17.2
	+180	-1.9
	+90	8.3
(repeat)	+45	15.9

Table 3-1: Front-mounted counterlungs: pitch results

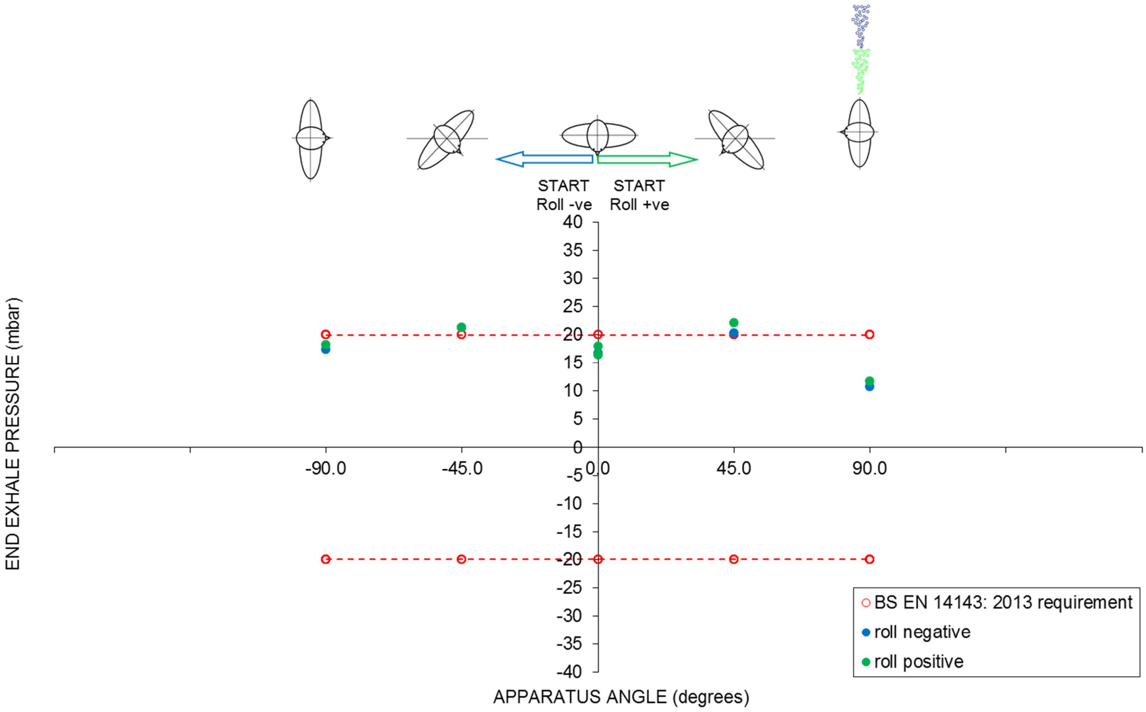

Figure 3-2: Front-mounted counterlungs: roll results

APPARATUS ORIENTATION (°) DIRECTION OF ROTATION BS EN 14143: 2013 requirement: ± 20 mbar		PRESSURE AT START INHALE (mbar)
roll positive (pitch 0)	0	16.4
	+45	22.1
	+90	11.7 large bubbles each breath
	-90	18.3
	-45	21.3
(repeat)	0	18.0
roll negative (pitch 0)	0	16.7
	-45	21.3
	-90	17.4
	+90	10.7 large bubbles each breath
	+45	20.3
(repeat)	0	16.7

Table 3-2: Front-mounted counterlungs: roll results

2.2 Hydrostatic imbalance results graphical and tabular results

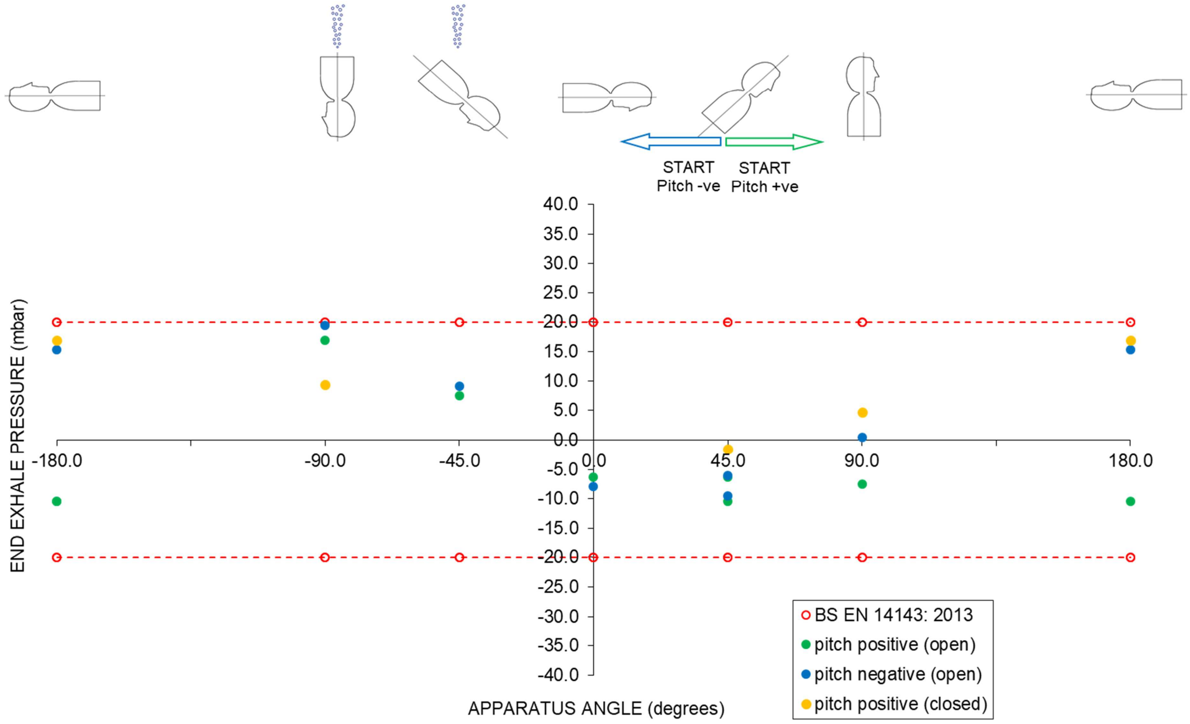

Figure 2-1: Back-mounted counter-lungs: pitch results

APPARATUS ORIENTATION (°) DIRECTION OF ROTATION		PRESSURE AT START INHALE (mbar)	
BS EN 14143: 2013 requirement: ± 20 mbar		Open shut-off	Closed shut-off
pitch positive (roll 0)	+45	-10.4	-1.54
	+90	-7.5	4.69
	+180	-10.5	16.93
	-90	16.9	9.32*
	-45	7.5	ND
	0	-6.4	ND
(repeat)	+45	-6.3	ND
pitch negative (roll 0)	+45	-9.5	ND
	0	-7.9	ND
	-45	9.1	ND
	-90	19.4	ND
	+180	15.4	ND
	+90	0.4	ND
(repeat)	+45	-6.1	ND

ND Not Done

* Measurement taken from first breath, rapidly became impossible to breath

Table 2-1: Back-mounted counter-lungs: pitch results

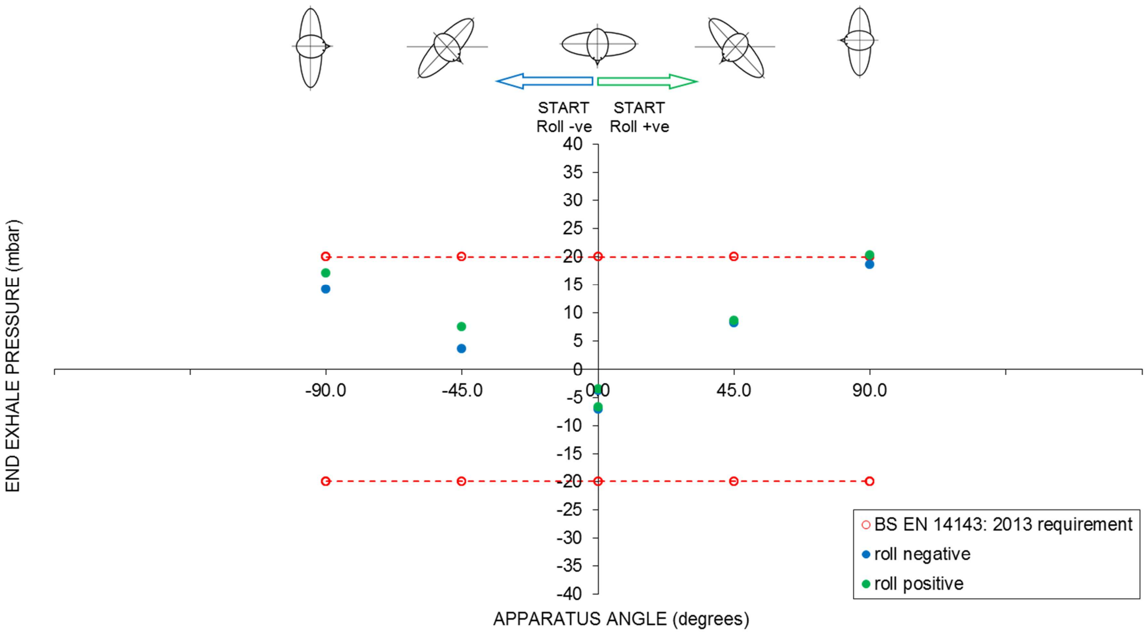

Figure 3-4: Rear-mounted counterlungs: roll results

APPARATUS ORIENTATION (°) DIRECTION OF ROTATION		PRESSURE AT START INHALE (mbar)
BS EN 14143: 2013 requirement: ± 20 mbar		
roll positive (pitch 0)	0	-6.7
	+45	8.7
	+90	20.3
	-90	17.1
	-45	7.5
(repeat)	0	-3.6
roll negative (pitch 0)	0	-7.2
	-45	3.7
	-90	14.2
	+90	18.7
	+45	8.3
(repeat)	0	-3.8

Table 3-4: Rear-mounted counterlungs: roll results

4 Maximum inspired partial pressure of carbon dioxide

(*i.a.w.* paragraphs 5.6.1.5; 6.3.3)

4.1 General

The apparatus was configured within the hyperbaric chamber and the volume-weighted average inspired partial pressure of carbon dioxide ($VWAICO_2$) evaluated under the following conditions:

- water temperature: 4 °C (± 1 °C)
- apparatus orientation: vertical
- apparatus configuration: front-mounted counterlungs
  DSV and BOV mouthpiece and hoses
  VEV fully closed
  O_2 sensor S/N 804688-565, -418, -527
- simulated depth: 40 m
- diluent supply gas: air
- simulator settings: 15.0 and 75.0 $l \cdot min^{-1}$ (ATP)

4.2 $VWAICO_2$ tabulated results

The $VWAICO_2$ results are shown in Table 4-1.

SIMULATOR SETTING ($l \cdot min^{-1}$ ATP)	DSV MOUTHPIECE	BOV MOUTHPIECE
	BS EN 14143: 2013 requirement: ≤ 20 mbar	
15	4.6	5.9
75	3.3	5.8

Table 4-1: $VWAICO_2$ results

5 Breathable volume

(*i.a.w.* paragraphs 5.6.2; 6.5.1)

5.1 General

Each apparatus was configured within the HETT and evaluated under the following conditions:

- water temperature: 19 °C
- apparatus orientation: vertical
- apparatus configuration: front- and rear-mounted counterlungs
  DSV mouthpiece and hoses
  VEV fully closed
  O_2 sensor S/N 804688-565, -418, -527 (front)
  O_2 sensor S/N 804688-545, -607, -537 (rear)
- simulated depth: 0 m (surface at mouthpiece)
- diluent supply gas: air

5.2 Breathable volume results

The breathable volume results are shown in Table 5-1.

VOLUME DISPLACEMENT	FRONT-MOUNTED COUNTERLUNGS	REAR-MOUNTED COUNTERLUNGS	
		0.55 psi spring	0.36 psi spring
	(mbar)		
Start pressure	BS EN 14143: 2013 requirement: 25 mbar or at valve relief		
	6	25	16
Withdraw 4.5 litre	BS EN 14143: 2013 requirement: ≥ - 25 mbar		
	-12	-8	-11
Inject 4.5 litre	BS EN 14143: 2013 requirement: ≤ + 25 mbar		
	6	25	16

Table 5-1: Breathable volume results

6 Exhaust valve

(*i.a.w.* paragraphs 5.6.4; 6.5.3)

6.1 Maximum pressure within the breathing circuit

To determine the maximum pressure within the breathing circuit and function of the VEVs, each apparatus was tested as a complete unit under the following conditions:

- Surface, in air at a temperature of 19 °C
- VEV fully clockwise
- Front-mounted counterlungs
  - external 150 $l{\cdot}min^{-1}$ diluent (air) injection
  - additional operation of manual oxygen injection
- Rear-mounted counterlungs
  - external 150 $l{\cdot}min^{-1}$ diluent (air) injection
  - additional operation of manual oxygen injection
  - additional operation of manual diluent (air) injection
    the WBC held away from VEV to ensure an unrestricted flow

6.2 Leak test

For this test, the VEV was removed from the counterlung of the front-mounted apparatus and tested as an independent unit. The VEV of the rear-mounted apparatus could not be removed and was tested configured with the counterlung and breathing hoses.

6.3 Exhaust valve results

The results of the maximum pressure within the breathing circuit tests are presented in Table 6-1.

DILUENT (AIR) INJECTION	FRONT-MOUNTED (mbar)	REAR-MOUNTED
	BS EN 14143: 2013 requirement: ≤ 40 mbar	
Relief valve setting		0.55 psi
Valve lift	22	40
150 l·min^{-1}	38	44
150 l·min^{-1} and O_2	38	45
150 l·min^{-1} and diluent (air)	NA	50
150 l·min^{-1} and O_2 and diluent (air)	NA	50
Relief valve setting		0.36 psi
Valve lift	NA	23
150 l·min^{-1}	NA	28
150 l·min^{-1} and O_2	NA	29
150 l·min^{-1} and diluent (air)	NA	40
150 l·min^{-1} and O_2 and diluent (air)	NA	41

Table 6-1: Breathing circuit maximum pressure

It was noted that when the automatic diluent valve of the front-mounted apparatus was activated, the additional flow increased the pressure within the breathing circuit to 63 mbar.

7 Carbon dioxide absorbent canister

(*i.a.w.* paragraphs 5.6.6; 6.6.1, 6.6.2)

7.1 General

For each endurance test, the CO_2 absorbent canister was filled with fresh soda lime from the same batch as described in paragraph 2.1.1; individual fill weights are shown in Table 7-1.

The apparatus was configured within the hyperbaric chamber and evaluated under the following general conditions:

- water temperature: 4 °C (± 1 °C)
- apparatus orientation: vertical
- apparatus configuration: front-mounted counterlungs
DSV mouthpiece and hoses
VEV fully closed
O_2 sensor S/N 804688-565, -418, -527
- exhale gas heating: 32 °C (± 4 °C)
- descent rate: 20.0 $m \cdot min^{-1}$
- ascent rate: *i.a.w.* Shearwater Dive Computer display

7.2 Simulated dive profiles

7.2.1 Diluent supply gas: trimix

The three 100 m simulated dive profiles had the following specific conditions:

- LSSL Reference Number: 201812-11
  - diluent supply gas: trimix
  - simulator setting: constant 40.0 $l \cdot min^{-1}$ (ATP)
CO_2 injection rate: constant 1.6 $l \cdot min^{-1}$ (STPD)
  - PO_2 setpoints: 1.2 bar; return to 0.7 bar at 9 m
  - bottom time: 20 min
  - intended profile duration: 180 min
  - decompression stops *i.a.w.* Shearwater Dive Computer display
remain at 6 m until $PCO_2 \geq 10$ mbar

NOTE: PO_2 remained at a nominal 1.6 bar at 100 m (following descent) and > 0.7 bar at ≤ 9 m (following ascent). Both affected the Shearwater Dive Computer calculation for decompression.

- LSSL Reference Numbers: 201812-12 and 201812-14
  - diluent supply gas: trimix
  - simulator setting: constant 40.0 $l \cdot min^{-1}$ (ATP)
CO_2 injection rate: constant 1.6 $l \cdot min^{-1}$ (STPD)
  - PO_2 setpoints: 1.2 bar; return to 0.7 bar at 9 m
  - bottom time: 20 min
  - intended profile duration: 180 min
  - decompression *i.a.w.* Shearwater Dive Computer display
remain at 6 m until $PCO_2 \geq 10$ mbar

NOTE: PO_2 manually reduced to a nominal 1.2 bar at 100 m and 0.7 bar at 9 m.

7.2.2 Diluent supply gas: air

The three 40 m simulated dive profiles had the following specific conditions:

- LSSL Reference Number: 201812-15
  - diluent supply gas: air
  - simulator setting: constant 40.0 l·min^{-1} (ATP)
    CO_2 injection rate: constant 1.6 l·min^{-1} (STPD)
  - PO_2 setpoints: 1.2 bar; return to 0.7 bar at 9 m
  - bottom time: 88 min
  - intended profile duration: 180 min
  - decompression *i.a.w.* Shearwater Dive Computer display remain at 6 m until $PCO_2 \geq 10$ mbar

NOTE: PO_2 manually reduced to a nominal 1.2 bar at 40 m (following descent) and 0.7 bar at 9 m (following ascent).

- LSSL Reference Number: 201812-16 and 17
  - diluent supply gas: air
  - simulator setting: constant 40.0 l·min^{-1} (ATP)
    CO_2 injection rate: constant 1.6 l·min^{-1} (STPD)
  - PO_2 setpoints: 1.3 bar constant (return to 0.7 bar at 3 m)
  - bottom time: 95 min
  - intended profile duration: 180 min
  - decompression *i.a.w.* Shearwater Dive Computer display remain at 6 m until $PCO_2 \geq 10$ mbar

NOTE: PO_2 manually reduced to a nominal 1.3 bar at 40 m (following descent).

7.3 Constant simulated depth

The three endurance tests at a constant simulated depth of 6 m had the following specific conditions:

- LSSL Reference Numbers: 201812-18, 19 and 20
  - diluent supply gas: air
  - simulator setting: 40.0 l·min^{-1} (ATP)
    CO_2 injection rate: 1.6 l·min^{-1} (STPD)
  - 5 min period at 90 min: 75.0 l·min^{-1} (ATP)
    CO_2 injection rate: 3.0 l·min^{-1} (STPD)
  - PO_2 setpoint: 0.7 bar

7.4 CO_2 absorbent canister endurance tabulated results

The tabulated results of endurance tests are presented in Table 7-1.

LSSL REFERENCE NUMBER	TEST PARAMETERS	SODA LIME WEIGHT (g)	BREAKTHROUGH 5 mbar (min)	BREAKTHROUGH 10 mbar (min)	5 to 10 mbar: ≥ 10 min (min)
201812-11	100 m profile	2682.5	231	245	14
201812-12		2668.3	215	233	18
201812-14		2666.0	219	236	17
201812-15	40 m profile	2666.5	190	216	26
201812-16		2671.1	205	224	19
201812-17		2685.2	197	221	24
201812-18	6 m constant	2691.4	190	209	19
201812-19		2666.3	204	222	18
201812-20		2694.2	202	216	14

Table 7-1: Endurance test results

7.5 CO_2 absorbent canister endurance graphical results

7.5.1 100 m simulated dive profiles

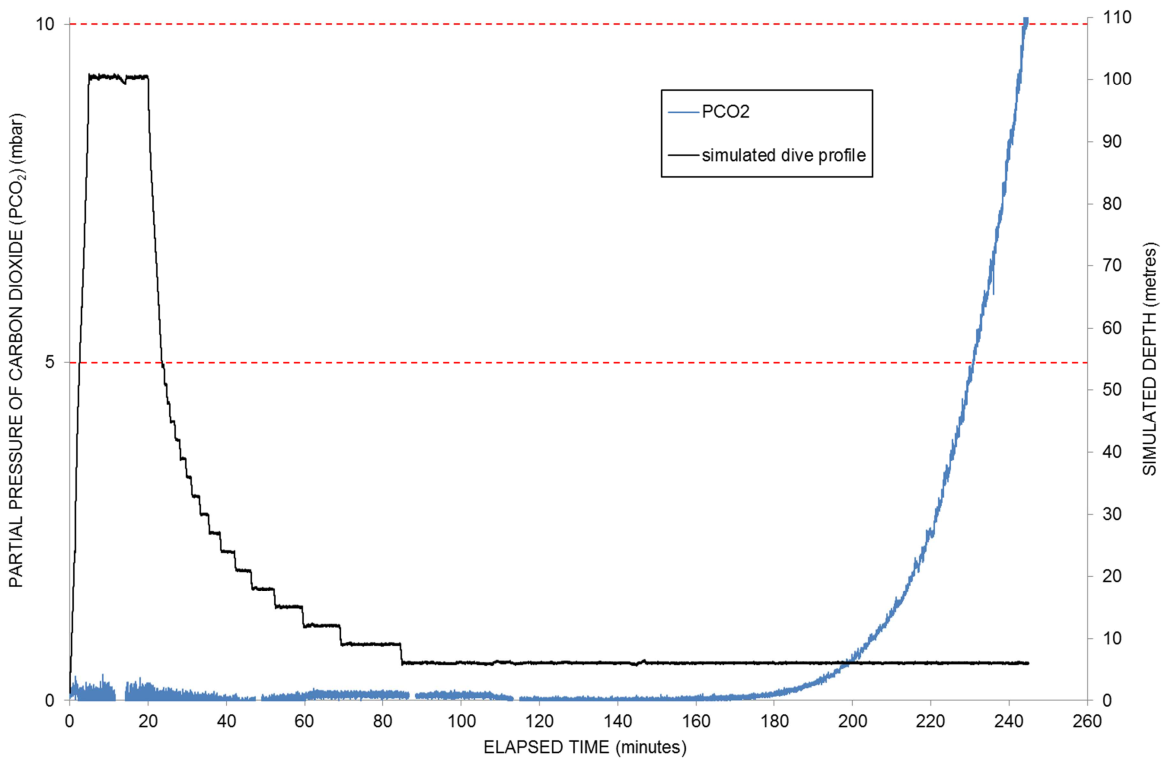

Figure 7-1: LSSL Reference: 201812-11

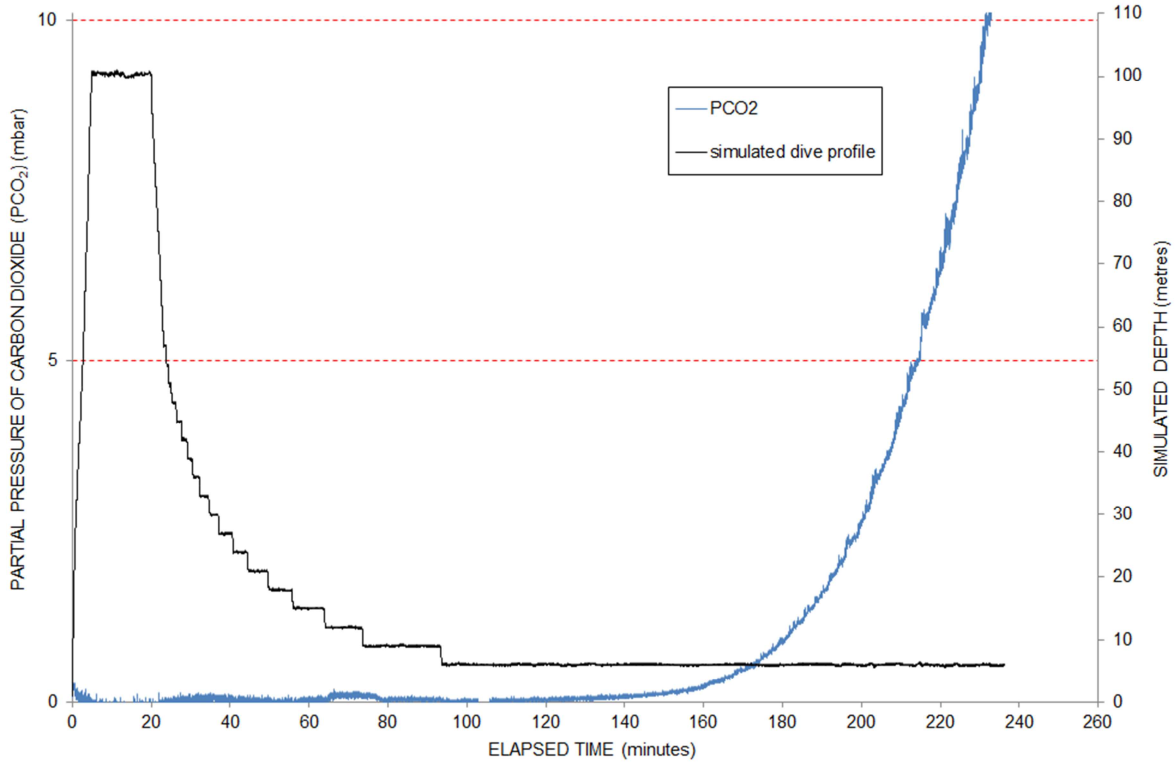

Figure 7-2: LSSL Reference: 201812-12

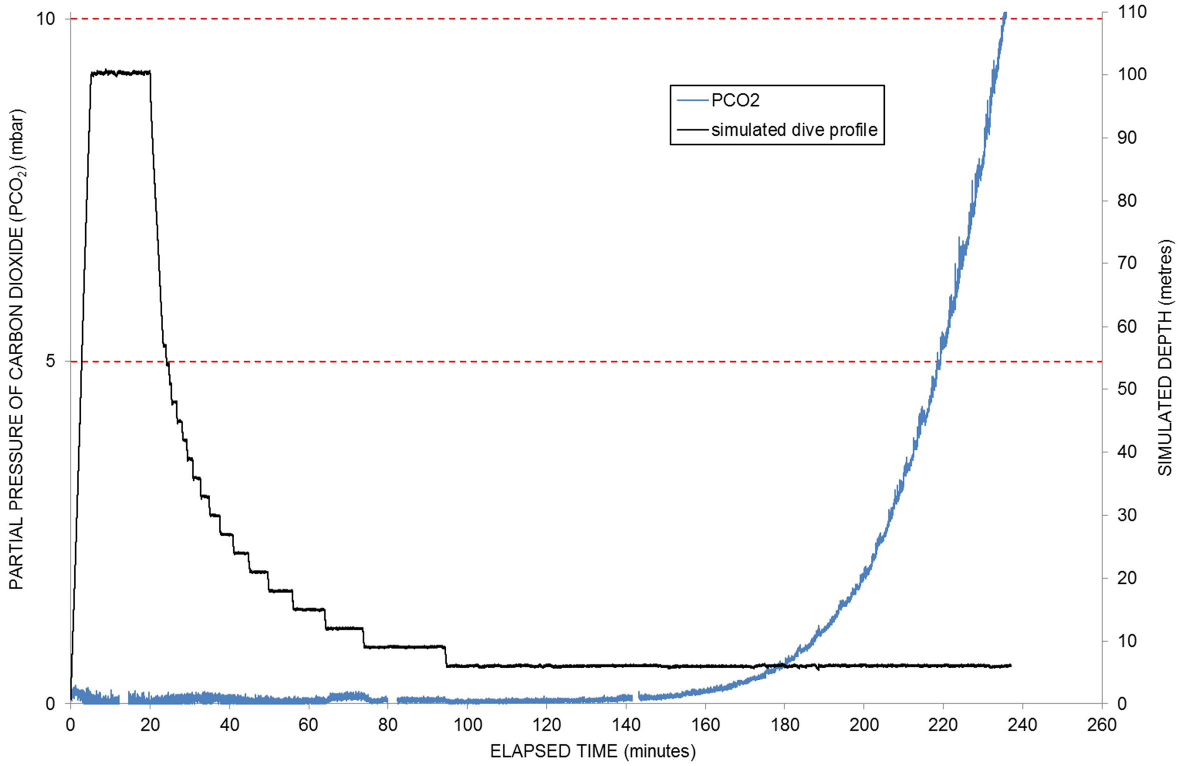

Figure 7-3: LSSL Reference: 201812-14

7.5.2 40 m simulated dive profiles

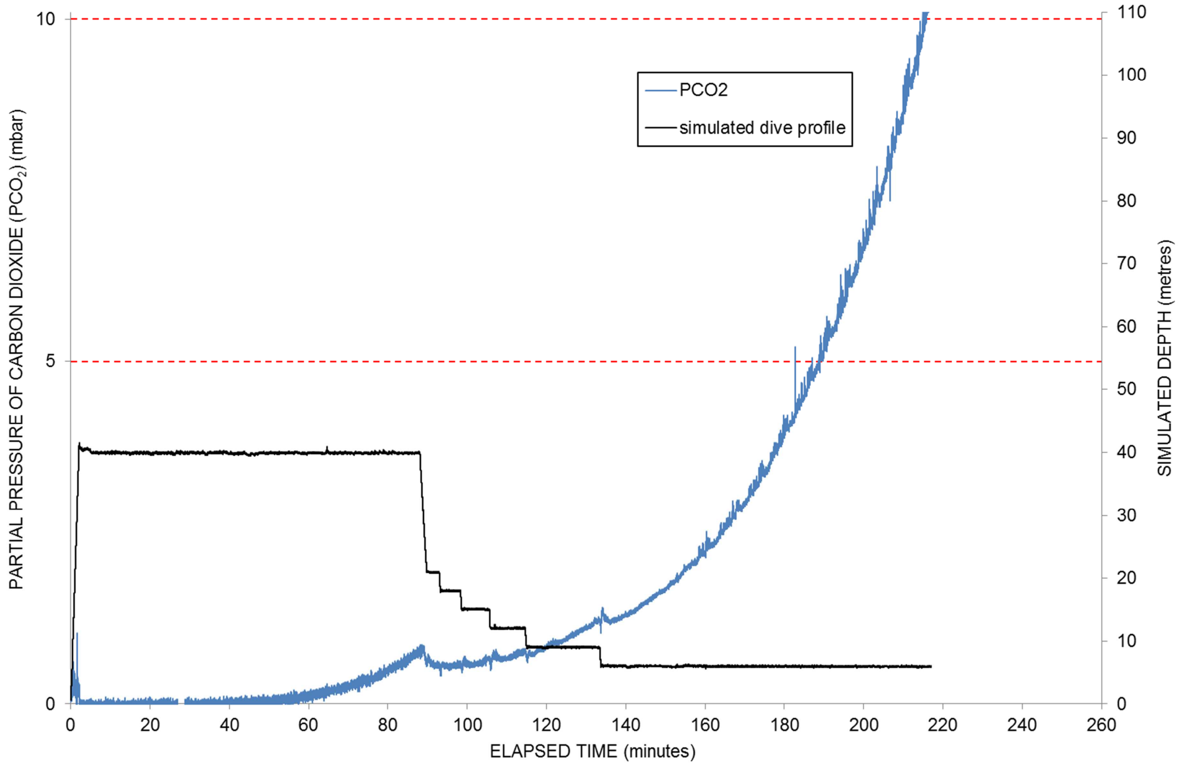

Figure 7-4: LSSL Reference: 201812-15

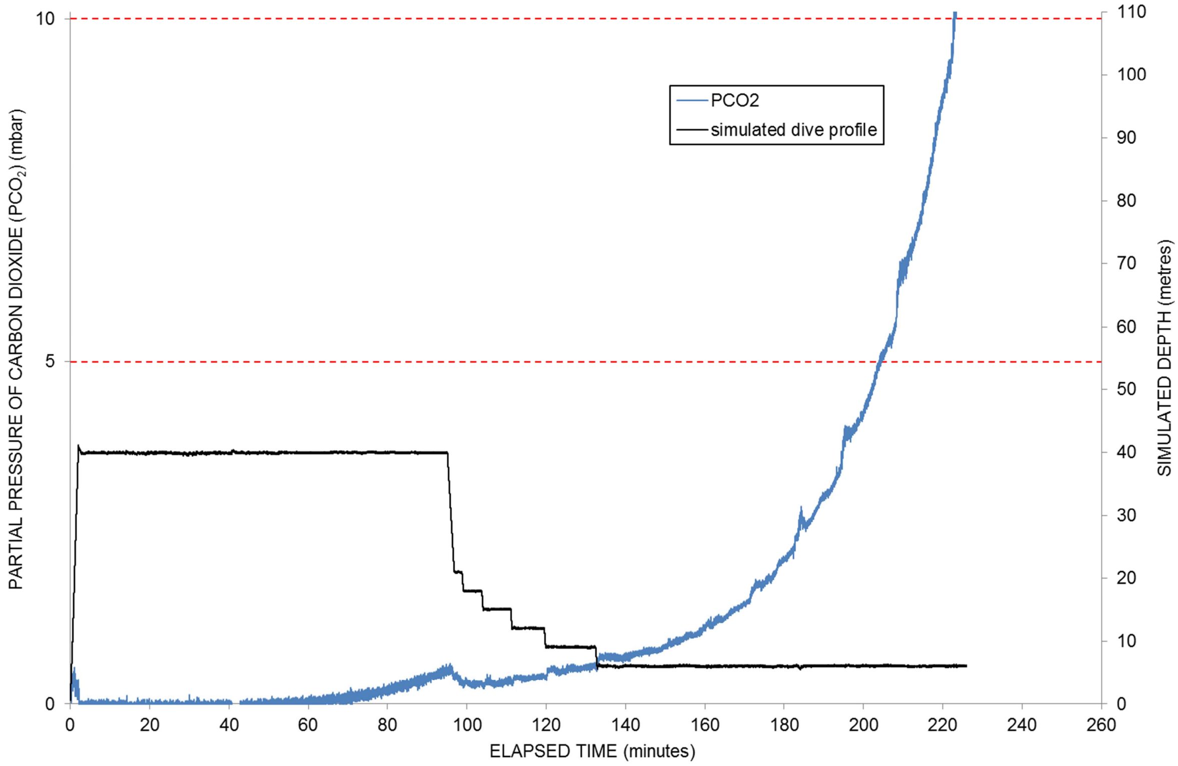

Figure 7-5: LSSL Reference: 201812-16

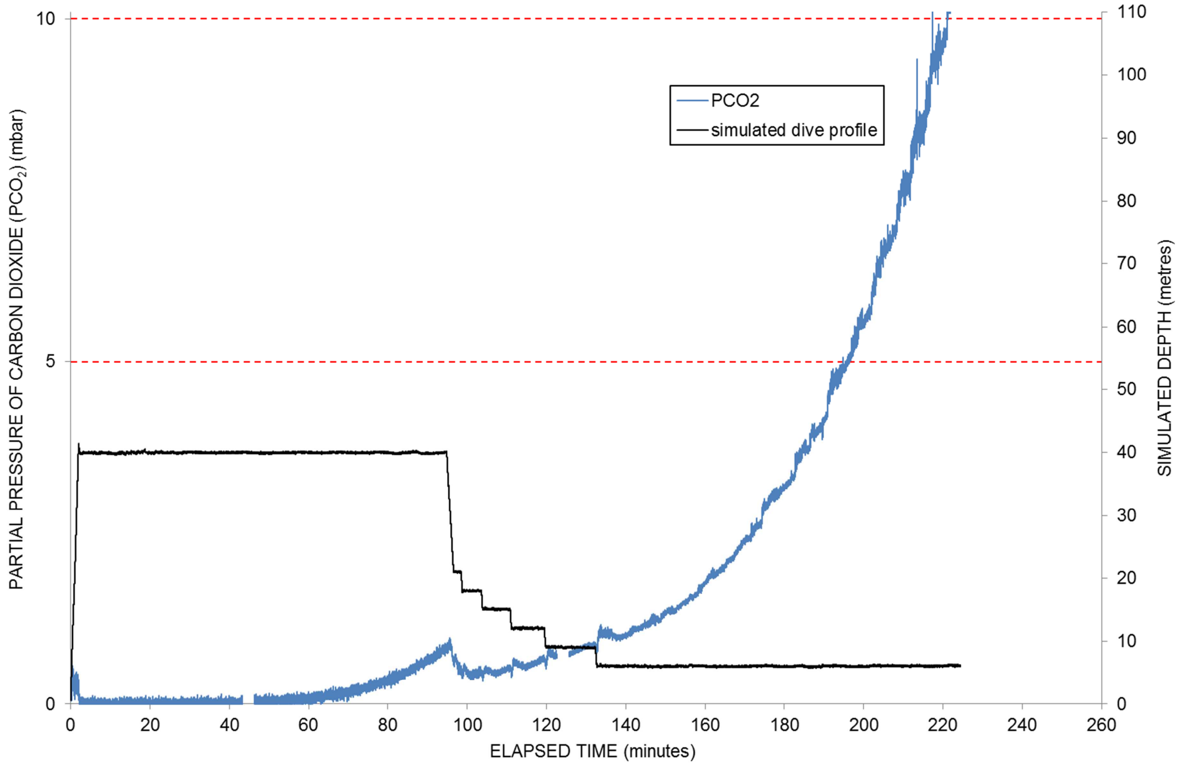

Figure 7-6: LSSL Reference: 201812-17

7.5.3 6 m constant simulated depth

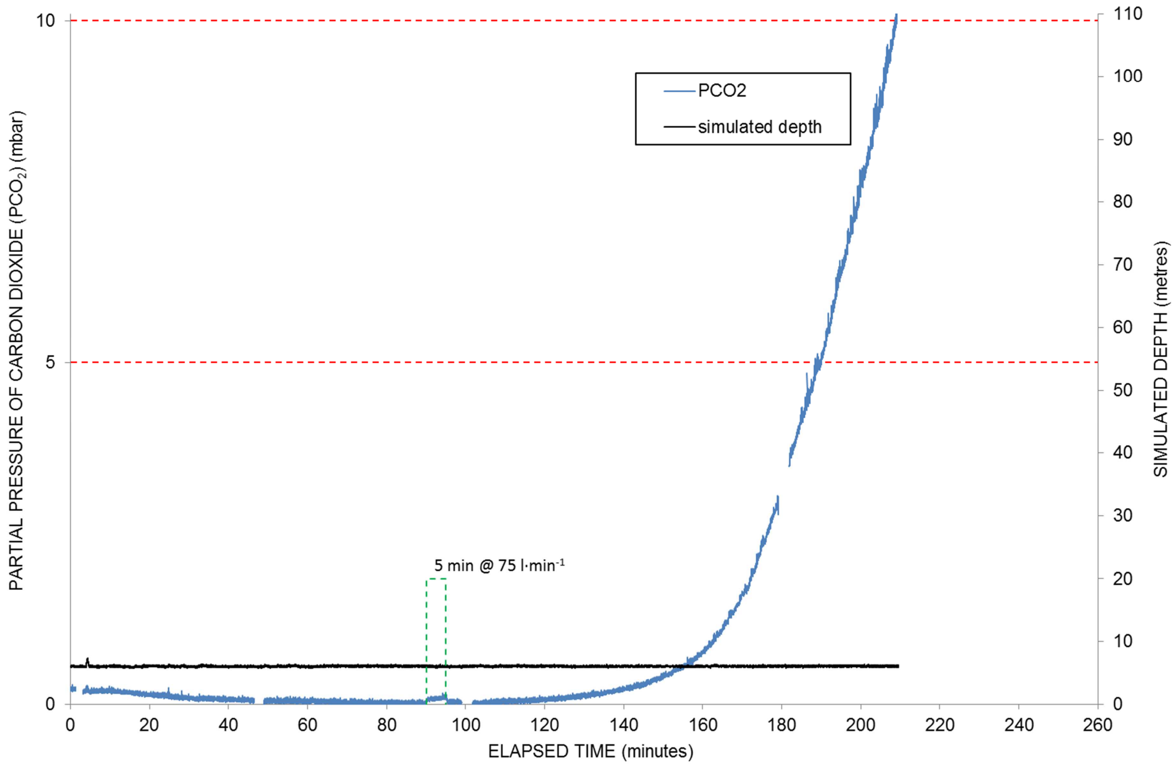

Figure 7-7: LSSL Reference: 201812-18

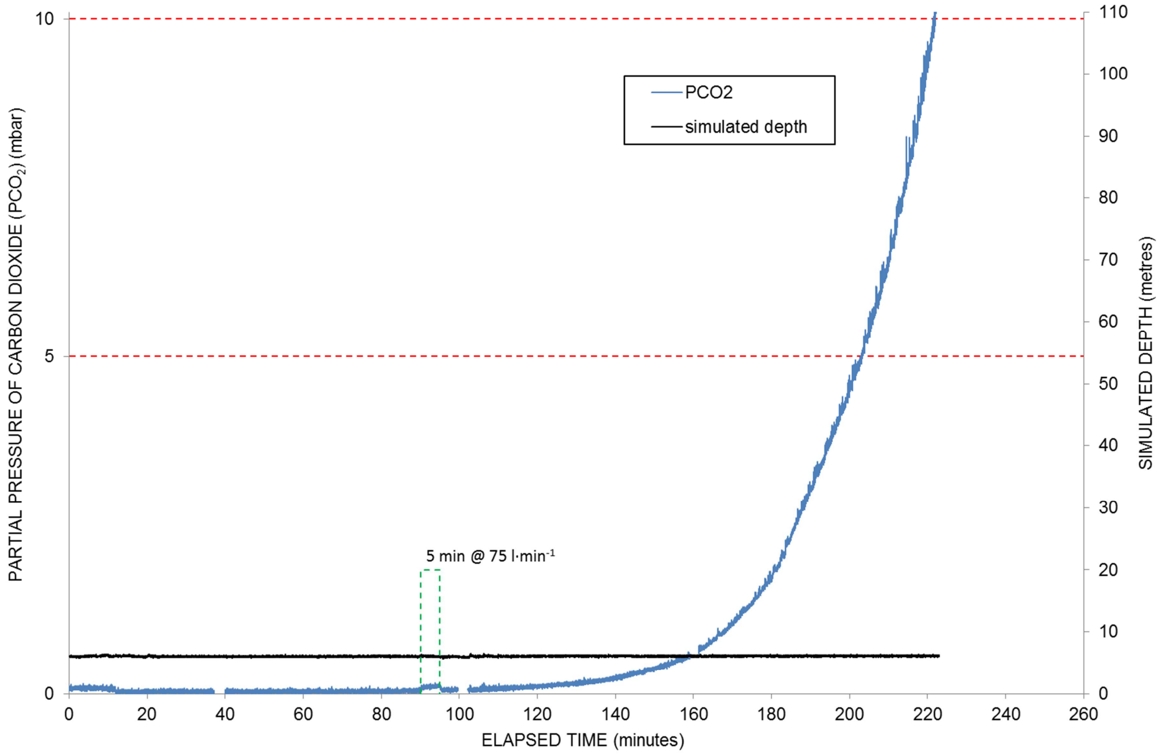

Figure 7-8: LSSL Reference: 201812-19

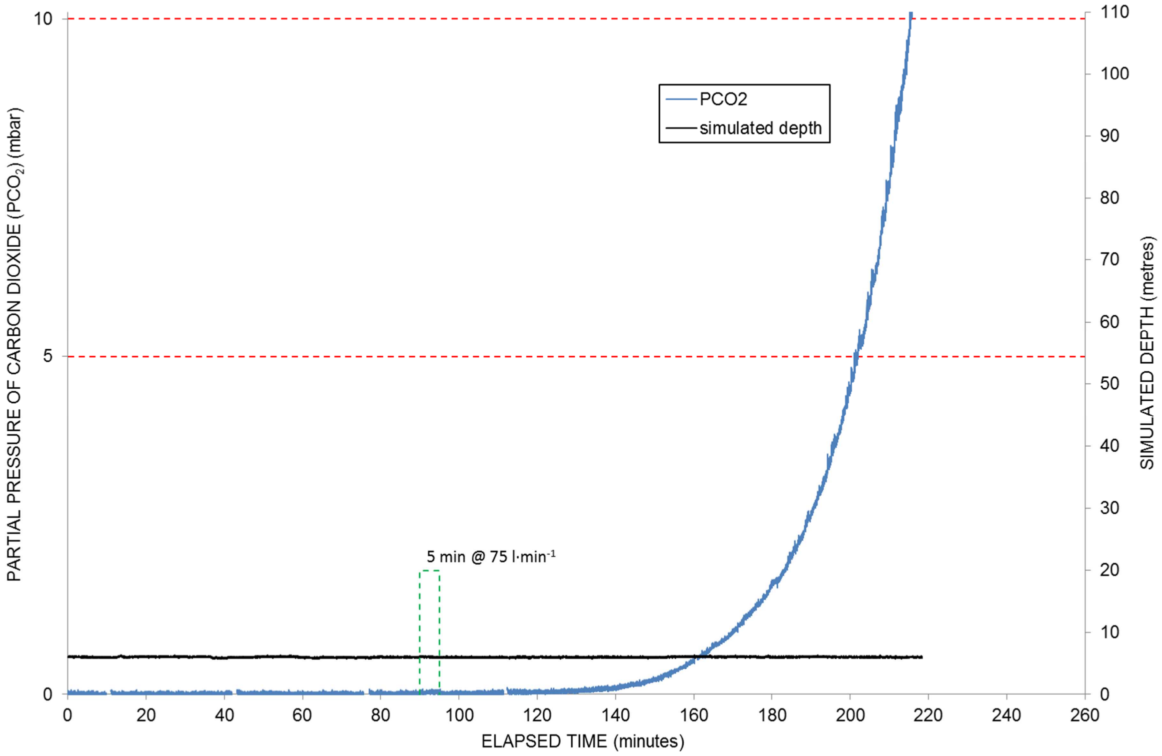

Figure 7-9: LSSL Reference: 201812-20

8 Inhalation temperature

(*i.a.w.* paragraphs 5.6.7; 6.3.4)

8.1 General

The apparatus was configured within the hyperbaric chamber and evaluated under the following conditions:

- water temperature: 34 °C (± 2 °C)
- apparatus orientation: vertical
- apparatus configuration: front-mounted counterlungs
  DSV mouthpiece and hoses
  VEV fully closed
  O_2 sensor S/N 804688-565, -418, -527
- simulated depth: surface
- diluent supply gas: air
- exhale gas temperature: 32 °C (± 4 °C)
- simulator setting: 40.0 $l \cdot min^{-1}$ (ATP)
- CO_2 injection: 1.60 $l \cdot min^{-1}$ (STPD)

8.2 The inspired inhalation gas temperature graphical result

The graphical result is presented in Figure 8-1.

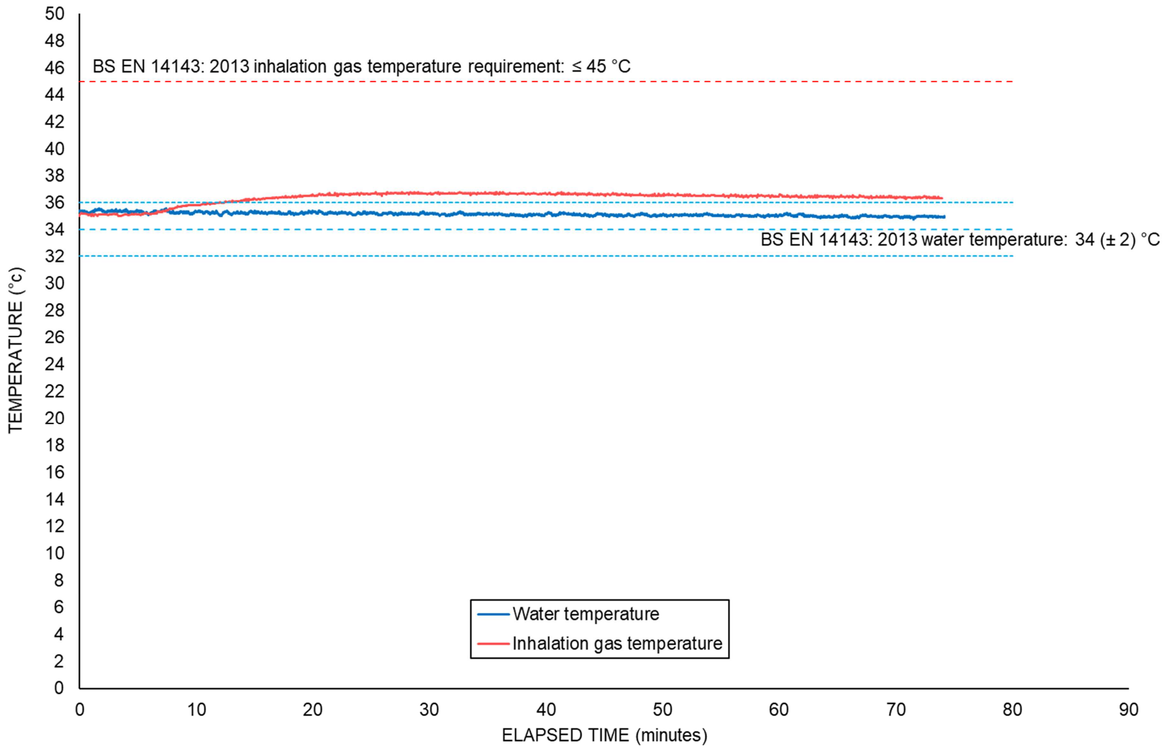

Figure 8-1: Inhalation gas temperature result

9 Ingress of water

(*i.a.w.* paragraphs 5.6.8; 6.5.5)

9.1 General

Both apparatus were set up, in turn, on a rotatable mannequin within the HETT and tested under the following conditions of use:

- water temperature: 19 °C
- configuration: front- and rear-mounted counterlungs
  DSV mouthpiece and hoses
  VEV fully closed
  O_2 sensor S/N 804688-565, -418, -527 (front)
  O_2 sensor S/N 804688-545, -607, -537 (rear)
- diluent supply gas: air
- simulated depth: nominal 0.35 m to lung centroid (+ 90 °)
- roll orientation: 0, 45, 90, -90, -45 °
- simulator setting: $62.5\ l{\cdot}min^{-1}$ (ATP)
  3 min at each attitude

9.2 Results

Following each test, no water was detected within the breathing circuits of either apparatus.

10 Inspired partial pressure of oxygen/setpoint maintenance

(*i.a.w.* paragraphs 5.7.1, 5.7.2; 6.7)

10.1 General

BS EN 14143: 2013 requires PO_2 control to be carried out at manufacturer's recommended maximum depths and at the surface. However, to ensure stable simulated oxygen consumption flows, PO_2 control was carried out at the maximum depths and 3 m, not 0 m (surface).

The apparatus was configured within the hyperbaric chamber and evaluated under the following general conditions:

- water temperature: 4 °C (± 1 °C)
- apparatus orientation: vertical
- apparatus configuration: front-mounted counterlungs
  DSV mouthpiece and hoses
  VEV fully closed
  O_2 sensor S/N 804688-565, -418, -527
- exhale gas heating: 32 °C (± 4 °C)
- descent rate: 30 m·min^{-1}
- ascent rate: 20 m·min^{-1}
- simulator settings: 40.0 l·min^{-1} (ATP);
  simulated metabolic oxygen consumption, 1.78 l·min^{-1} (STPD)
  with periods of 15.0 l·min^{-1} (ATP), 0.67 l·min^{-1} (STPD)
  75.0 l·min^{-1} (ATP), 3.33 l·min^{-1} (STPD)

10.2 Simulated depth, 40 m

A single simulated dive profile to 40 m was carried out under the following specific conditions of use:

- PO_2 setpoints: 0.7 bar at the surface
  switch to 1.3 bar at 39 m (on descent)
  switch to 0.7 bar at 3 m (on ascent)
- diluent supply gas: air

10.3 Simulated depth, 100 m

A single simulated dive profile to 100 m was carried out under the following specific conditions of use:

- PO_2 setpoints: 0.7 bar at the surface
  switch to 1.2 bar at 90 m (on descent)
  switch to 0.7 bar at 3 m (on ascent)
- diluent supply gas: trimix

10.4 PO_2 control graphical results

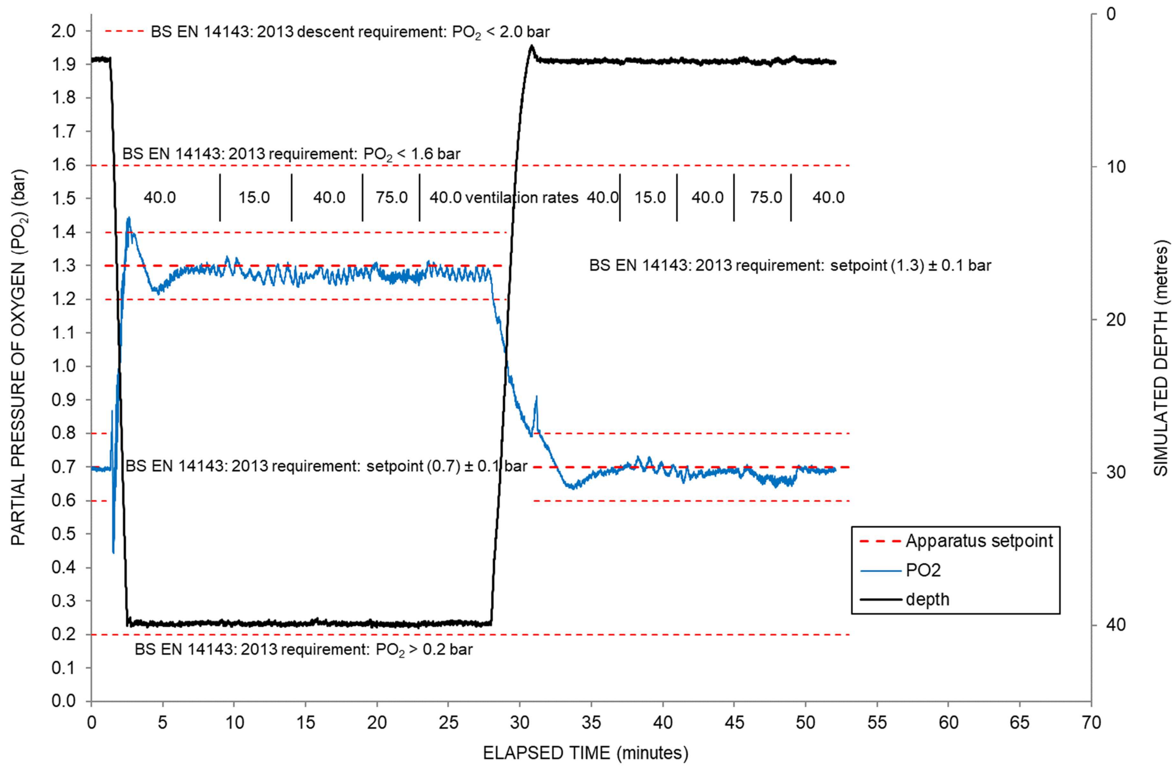

Figure 10-1: Simulated depth, 40 m; diluent supply gas, air

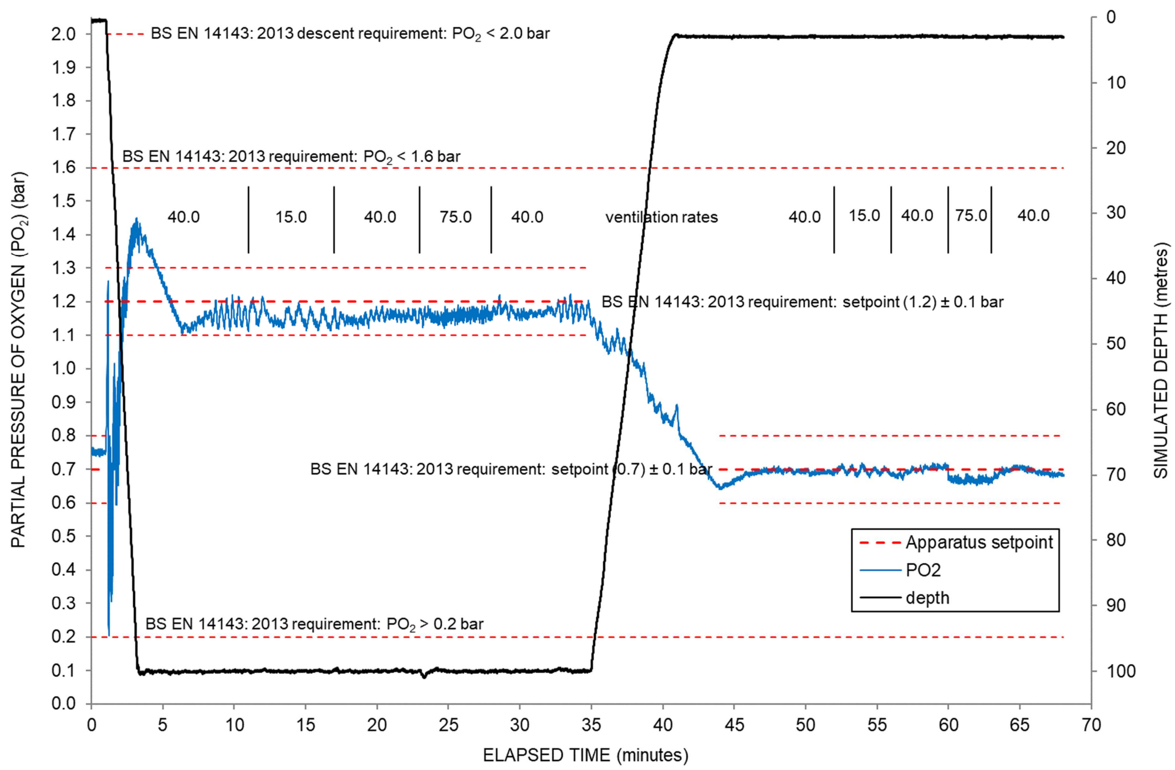

Figure 10-2: Simulated depth, 100 m; diluent supply gas, trimix

11 Alphanumeric display for inspired partial pressure of oxygen

(*i.a.w.* paragraphs 5.7.3; 6.10.2)

11.1 PO_2 in the range 0.1 to 2.0 bar, 0.2 bar steps

The apparatus was configured within the hyperbaric chamber and evaluated under the following conditions:

• air temperature:	19 °C
• apparatus orientation:	vertical
• apparatus configuration:	front- and rear-mounted counterlungs DSV mouthpiece and hoses VEV fully closed O_2 sensor S/N 804688-565, -418, -527 (front) O_2 sensor S/N 804688-545, -607, -537 (rear)
• diluent supply gases:	100 % N_2 (in place of air) 71 % He:29 % N_2 (in place of trimix)
• oxygen supply:	integral supply isolated external manual injection
• simulated depth:	20 m
• simulator setting:	40.0 $l \cdot min^{-1}$ (ATP)

At a steady simulated depth of 20 m, from a starting breathing circuit gas composition of 100 % N_2, oxygen was added to achieve steady, nominal, PO_2 readings of 0.1 bar to 2.0 bar, in 0.2 bar steps.

11.2 Constant PO_2 of 0.2 and 2.0 bar

11.2.1 General

The apparatus was configured within the hyperbaric chamber and evaluated under the following general conditions:

• air temperature:	19 °C
• apparatus orientation:	vertical
• apparatus configuration:	rear-mounted counterlungs DSV mouthpiece and hoses VEV fully closed O_2 sensor S/N 804688-565, -418, -527 (front) O_2 sensor S/N 809750-386, -387, -388 (front) O_2 sensor S/N 804688-545, -607, -537 (rear)
• oxygen supply:	integral supply isolated external manual injection
• constant PO_2:	0.2 bar (from the surface) 2.0 bar (from 10 m)
• simulator setting:	40.0 $l \cdot min^{-1}$ (ATP)
• descent rate:	30.0 $m \cdot min^{-1}$
• ascent rate:	20.0 $m \cdot min^{-1}$

11.2.2 44 m (1.1 times maximum stated depth) simulated dive profile

Two 44 m simulated dive profiles (with constant PO_2 of 0.2 and 2.0 bar) had the following specific conditions:

- diluent supply gas: 100 % N_2 (in place of air)
- bottom time: 143 min (1.5 times maximum bottom time)
- decompression stops: as CO_2 absorbent canister tests (see 7.2.2)
  2 min at each stop

11.2.3 110 m (1.1 times maximum stated depth) simulated dive profile

Two 110 m simulated dive profiles (with constant PO_2 of 0.2 and 2.0 bar) had the following specific conditions:

- diluent supply gas: 71 % He:29 % N_2 (in place of trimix)
- bottom time: 30 min (1.5 times maximum bottom time)
- decompression stops: as CO_2 absorbent canister tests (see 7.2.1)
  2 min at each stop

11.3 Alphanumeric displayed PO_2 accuracy results

11.3.1 PO_2 in the range 0.1 to 2.0 bar, 0.2 bar steps

The results of the tests using the rear-mounted counterlung apparatus with the original sensors are presented in Table 11-1.

SIMULATED DEPTH (m)	LABORATORY CALCULATED PO_2 (bar)	APPARATUS DISPLAYED PO_2 (bar) S1	S2	S3
Diluent supply gas: 100 % N_2 (in place of air)				
20 m	BS EN 14143: 2013 0.1 – 0.4 bar requirement: ±0.03			
	0.10	0.11	0.10	0.11
	0.29	0.29	0.28	0.29
	BS EN 14143: 2013 0.4 – 2.0 bar requirement: ± 0.06			
	0.48	0.49	0.48	0.49
	0.69	0.70	0.70	0.70
	0.89	0.91	0.90	0.91
	1.10	1.11	1.10	1.11
	1.29	1.34	1.33	1.34
	1.50	1.55	1.54	1.54
	1.71	1.75	1.74	1.74
	1.91	1.95	1.93	1.94
	2.01	2.05	2.03	2.03
Diluent supply gas: 71 % He:29 % N_2 (in place of trimix)				
20 m	BS EN 14143: 2013 0.1 – 0.4 bar requirement: ±0.03			
	0.10	0.10	0.11	0.11
	0.30	0.31	0.31	0.31
	BS EN 14143: 2013 0.4 – 2.0 bar requirement: ± 0.06			
	0.50	0.52	0.52	0.52
	0.70	0.72	0.72	0.72
	0.90	0.94	0.93	0.94
	1.09	1.13	1.12	1.13
	1.29	1.33	1.32	1.33
	1.50	1.54	1.53	1.53
	1.70	1.74	1.73	1.73
	1.89	1.93	1.92	1.92
	1.99	2.03	2.02	2.02

Table 11-1: PO_2 0.1 to 2.0 bar, 0.2 bar steps

11.3.2 Constant PO_2 of 0.2 bar

The results of the tests using the rear-mounted counterlung apparatus with the original sensors are presented in Table 11-2.

SIMULATED DEPTH (m)	LABORATORY CALCULATED PO_2 (bar)	APPARATUS DISPLAYED PO_2 (bar) S1	S2	S3
	BS EN 14143: 2013 0.1 – 0.4 bar requirement: ±0.03			
0	0.20	0.21	0.20	0.21
10	during descent	0.37	0.37	0.37
20		0.38	0.38	0.38
30		0.33	0.32	0.33
40		0.31	0.30	0.31
44 (+3 min)	0.20	0.21	0.20	0.21
44 (+140 min)	0.20	0.21	0.21	0.21
21	0.20	0.21	0.21	0.21
18	0.19	0.20	0.19	0.19
15	0.20	0.21	0.20	0.21
12	0.20	0.21	0.21	0.21
9	0.19	0.21	0.20	0.20
6	0.19	0.21	0.20	0.20
0	0.20	0.21	0.21	0.21

Table 11-2: 44 m dive profile; diluent supply gas, 100 % N_2 (in place of air)

The results of the tests using the front-mounted counterlung apparatus with the new sensors are presented in Table 11-3.

SIMULATED DEPTH (m)	LABORATORY CALCULATED PO_2 (bar)	APPARATUS DISPLAYED PO_2 S1 (bar)	S2	S3
	BS EN 14143: 2013 0.1 – 0.4 bar requirement: ±0.03			
0	0.20	0.20	0.19	0.20
10	during descent	0.35	0.36	0.35
20		0.28	0.29	0.30
30		0.27	0.28	0.28
40		0.26	0.27	0.27
50		0.25	0.25	0.26
60		0.24	0.24	0.24
70		0.24	0.24	0.24
80		0.23	0.23	0.23
90		0.23	0.23	0.23
100		0.22	0.22	0.23
110 (+ 3 min)	0.21	0.21	0.20	0.21
110 (+ 29 min)	0.21	0.21	0.20	0.21
57	0.21	0.21	0.21	0.21
54	0.20	0.21	0.20	0.21
51	0.19	0.20	0.19	0.20
48	0.22	0.22	0.22	0.22
45	0.20	0.21	0.20	0.21
42	0.19	0.20	0.19	0.20
39	0.21	0.21	0.20	0.21
36	0.19	0.20	0.19	0.20
33	0.20	0.21	0.20	0.21
30	0.21	0.21	0.21	0.21
27	0.21	0.21	0.21	0.21
24	0.21	0.21	0.21	0.21
21	0.20	0.20	0.20	0.20
18	0.20	0.21	0.20	0.21
15	0.19	0.20	0.19	0.20
12	0.20	0.20	0.20	0.20

Table 11-3: 110 m dive profile; 71 % He: 29 % N_2 (in place of trimix)

11.3.3 Constant PO_2 of 2.0 bar

The results of the tests using the front-mounted counterlung apparatus with the new sensors are presented in Table 11-4.

SIMULATED DEPTH (m)	LABORATORY CALCULATED PO_2 (bar)	APPARATUS DISPLAYED PO_2 (bar)		
		S1	S2	S3
	BS EN 14143: 2013 0.4 – 2.0 bar requirement: ± 0.06			
10	2.00	1.95	1.95	1.96
20 - 40	during descent	0.25 (max)	0.25 (max)	0.25 (max)
44 (+3 min)	2.01	1.98	1.97	1.99
44 (+140 min)	2.00	1.97	1.95	1.98
21	2.00	1.98	1.96	1.99
18	2.03	2.00	1.99	2.01
15	2.02	2.00	1.98	2.01
12	1.99	1.97	1.95	1.97

Table 11-4: 44 m dive profile; diluent supply gas, 100 % N_2 (in place of air)

The results of the tests using the front-mounted counterlung apparatus with the new sensors are presented in Table 11-5.

SIMULATED DEPTH (m)	LABORATORY CALCULATED PO_2 (bar)	APPARATUS DISPLAYED PO_2 S1 (bar)	S2	S3
	BS EN 14143: 2013 0.4 – 2.0 bar requirement: ± 0.06			
10	1.99	2.01	2.01	2.02
30 - 100	during descent	0.25 (max)	0.25 (max)	0.25 (max)
110 (+ 3 min)	1.99	2.02	2.01	2.04
110 (+ 29 min)	2.00	2.05	2.04	2.06
57	2.00	2.05	2.05	2.06
54	2.02	2.07	2.07	2.08
51	2.01	2.05	2.05	2.07
48	2.02	2.07	2.07	2.08
45	2.00	2.05	2.05	2.05
42	2.01	2.06	2.05	2.07
39	1.99	2.03	2.02	2.04
36	2.01	2.05	2.05	2.07
33	1.98	2.02	2.02	2.03
30	2.02	2.06	2.06	2.08
27	2.01	2.05	2.05	2.07
24	2.00	2.03	2.03	2.05
21	1.98	2.02	2.02	2.03
18	1.99	2.03	2.02	2.04
15	1.99	2.03	2.02	2.04
12	2.01	2.04	2.03	2.05

Table 11-5: 110 m dive profile; 71 % He: 29 % N_2 (in place of trimix)

12 Resistance to temperature

(*i.a.w.* paragraphs 5.14; 6.13)

12.1 General

To establish a performance baseline prior to storage (as described in paragraphs 12.2 and 12.3), both apparatus were, in turn, configured within the hyperbaric chamber and each tested under the following conditions:

- air temperature: 19 °C
- configurations: front- and rear- mounted counterlungs
  DSV mouthpieces and hoses
  VEVs fully closed
  O_2 sensor S/N 804688-565, -418, -527 (front)
  O_2 sensor S/N 804688-545, -607, -537 (rear)
- diluent supply gas: air
- simulated depth: 10 m
- simulator setting: 40.0 $l \cdot min^{-1}$ (ATP)
  simulated metabolic oxygen consumption, 1.78 $l \cdot min^{-1}$ (STPD)
- test duration: 10 min

12.2 Pre-dive operation

Both apparatus (powered down with gas cylinders closed) were placed within an Environmental Cabinet and subjected to the following storage conditions:

- storage temperatures: 55 and - 20 °C
- duration: ≥ 3 hours (hr)
  function tests at 55 and - 20 °C

12.3 Storage

Both apparatus (powered down with gas cylinders closed) were placed within an Environmental Cabinet and subjected to the following storage conditions:

- storage temperatures: 70 and - 30 °C
- duration: ≥ 3 hr
  return to laboratory temperature ≥ 3 hr

Each apparatus was then, in turn, reconfigured within the hyperbaric chamber and tested under the conditions described in paragraph 12.1.

12.4 Resistance to temperature results

12.4.1 Pre-dive operation (*i.a.w.* BS EN 14143: 2013)

When the integral gas cylinders of both apparatus were opened, following ≥ 3 hr exposure to 55 °C, no leakage or gas release was observed.

However, on establishing gas following ≥ 3 hr exposure to - 20 °C, leakage was observed from:

- Front-mounted counterlung apparatus:
  - Oxygen first stage regulator body

- Rear-mounted counterlung apparatus:
  - Diluent manual injector, when hose/connectors moved

12.4.2 Pre-dive operation (*i.a.w.* BS EN 14143: 2013 and BS EN 250: 2014)

The Pre-dive operation test with exposure to - 20 °C was repeated, with the following results:

- Front-mounted counterlung apparatus:
  - No leaks detected

- Rear-mounted counterlung apparatus:
  - Oxygen manual injector button; leak ceased when immersed in water at a temperature of 4 °C for ≥ 30 seconds (s)
  - Oxygen injection heard (exact source unknown); leak ceased when immersed in water at a temperature > 4 °C

The Pre-dive operation test with exposure to - 20 °C was once again repeated, with the following results:

- Front-mounted counterlung apparatus:
  - Oxygen first stage regulator body; leak ceased when immersed in water at a temperature of 4 °C for ≥ 45 s

- Rear-mounted counterlung apparatus:
  - Oxygen manual injector blank leak; did not cease when immersed in 4 °C water for ≥ 2 min
  - Oxygen first stage regulator O ring did not seat within pillar valve of cylinder (cylinder valve had to be closed). Seal established when immersed in water at a temperature of 4 °C for ≥ 1 min

12.4.3 Storage

The results of the tests pre- and post-conditioning PO_2 control tests, shown in Figure 12-1, showed no discernible difference in performance.

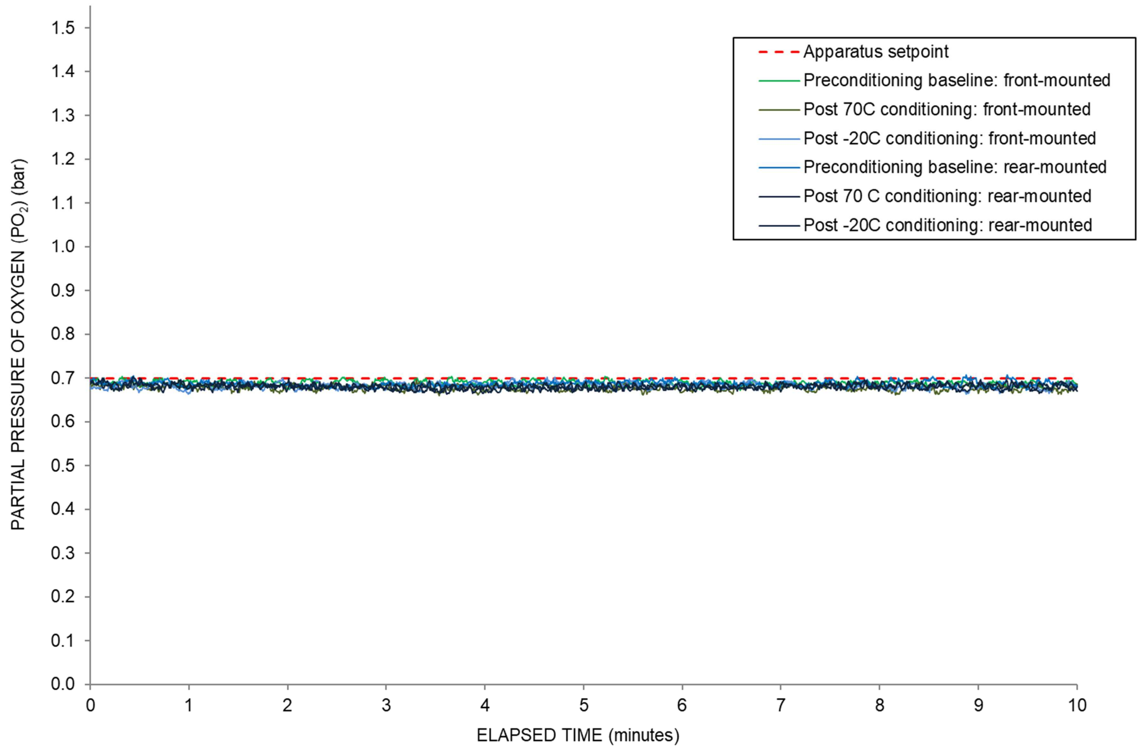

Figure 12-1: Pre- and post-conditioning PO_2 control results

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