Annex to: QinetiQ/MPP0466
Dated: 17 August 2009

Unmanned evaluation of JJ-CCR

28 July 2009

1. Procedures

1.1 General

Two apparatus were evaluated; one apparatus had a rear-mounted counterlungs (RMC), the other had front-mounted counterlungs (FMC).

For all evaluation, the apparatus was supplied with oxygen and diluent gases (either air or trimix (11:65. *i.e.* 11% oxygen: 65% helium; balance nitrogen), from integral cylinders. All gases were supplied by the manufacturer.

The bite mouthpiece of each apparatus was fitted, in turn, directly to the pipework of the breathing machine and the whole apparatus was rigged in the vertical orientation. All evaluation was carried out in fresh water at a temperature of 4 ±1 ℃.

Prior to each simulated dive, the carbon dioxide (CO_2) absorbent canister was filled with soda lime (Molecular Products; 1.0 – 2.5 mm granular size) and the apparatus set up by the manufacturer.

This report covers the unmanned testing conducted by QinetiQ at Alverstoke using the hyperbaric breathing simulator and associated equipment within the 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 [1].

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's (Pa). Throughout the work carried out to produce this report it has been assumed that a pressure change of 100 kilo Pascals (kPa) = 1 bar = 10 metres (m) (assuming a density of seawater of 1.01972 at 4 ℃) and that the air pressure at sea level = 0 m = 101.3 kPa (one standard atmosphere).

The apparatus was evaluated for compliance with the requirements of BS EN 14143 for diving re-breathers [2]; elements of the Norwegian Petroleum Directorate/Department of Energy (NPD/DEn) guidelines for breathing apparatus [3] and with reference to STANAG 1410-UD Standard unmanned test procedures for underwater breathing apparatus [4].

1.2 Closed-circuit breathing performance

Breathing performance was assessed with the breathing simulator set at the nominal ventilation rates shown in Table 2-1.

BREATHING SIMULATOR VENTILATION SETTINGS (litres per minute)	***TIDAL VOLUME (litres) (± 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

To obtain 'optimised' data (consistent with a user manually controlling the volume of gas within the counterlungs to give optimal breathing performance), 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.

The inhale and exhale respiratory pressures were recorded throughout the breathing cycle and work of breathing and compliance were calculated.

The apparatus was evaluated under the following conditions of use:

- RMC apparatus
  Oxygen-in-nitrogen (air) diluent gas
  Optimised breathing circuit
  40 metres (m)
  LSSL Reference: 1109-01
- FMC apparatus
  Oxygen-in-nitrogen (air) diluent gas
  Optimised breathing circuit
  40 m
  LSSL Reference: 1109-02
- FMC apparatus
  Trimix (11:65) diluent gas
  Optimised breathing circuit
  60, 80 and 100 m
  LSSL Reference: 1109-04

No gas heating and humidification was employed.

1.3 Carbon dioxide absorbent canister endurance

Canister endurance was defined as the time that the CO_2 absorbent canister maintained the inspired partial pressure of carbon dioxide (PCO_2) below 0.5 kPa. To further assess the performance of the CO_2 absorbent canister the simulated dive was conducted until the inspired PCO_2 had reached 1.0 kPa.

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

Canister endurance evaluation was carried out with a CO_2 injection rate of 1.6 $l \cdot min^{-1}$ whilst ventilating at a rate of 40.0 $l \cdot min^{-1}$, under the following conditions of use:

- FMC apparatus
  Oxygen-in-nitrogen (air) diluent gas
  40 m dive profile:
  - Descent rate, 20 $m \cdot min^{-1}$
  - 40 minutes bottom time
  - Ascent rate, 15 $m \cdot min^{-1}$
  - Decompression stop at 15 m for 5 minutes
  - Remain at 9 m (until carbon dioxide breakthrough of 1.0 kPa was reached)

During the canister endurance evaluation, the exhaled gas from the breathing simulator was humidified and heated to 32 ± 4 °C); breath-by-breath temperature was monitored at the mouthpiece of the apparatus.

For each test the CO_2 injection flow rate was verified by real-time flow rate monitoring and weight-loss of the CO_2 supply cylinder.

1.4 Partial Pressure of Oxygen control

The apparatus was set to 0.7 bar PO_2 at the surface with an automatic switch to 1.2 bar PO_2 for use at the maximum depth and subsequent decompression.

To assess the performance of the PO_2 control, the FMC apparatus was evaluated with a simulated metabolic oxygen consumption rate of 1.78 $l \cdot min^{-1}$ whilst ventilating at a rate of 40.0 $l \cdot min^{-1}$, under the same conditions of use described in Paragraph 1.3.

The simulated oxygen consumption system was stopped when carbon dioxide was detected within the inhalation hose.

2 Results

2.1 Breathing performance graphs

2.1.1 RMC apparatus; Oxygen-in-nitrogen (air) diluent gas: 40 metres

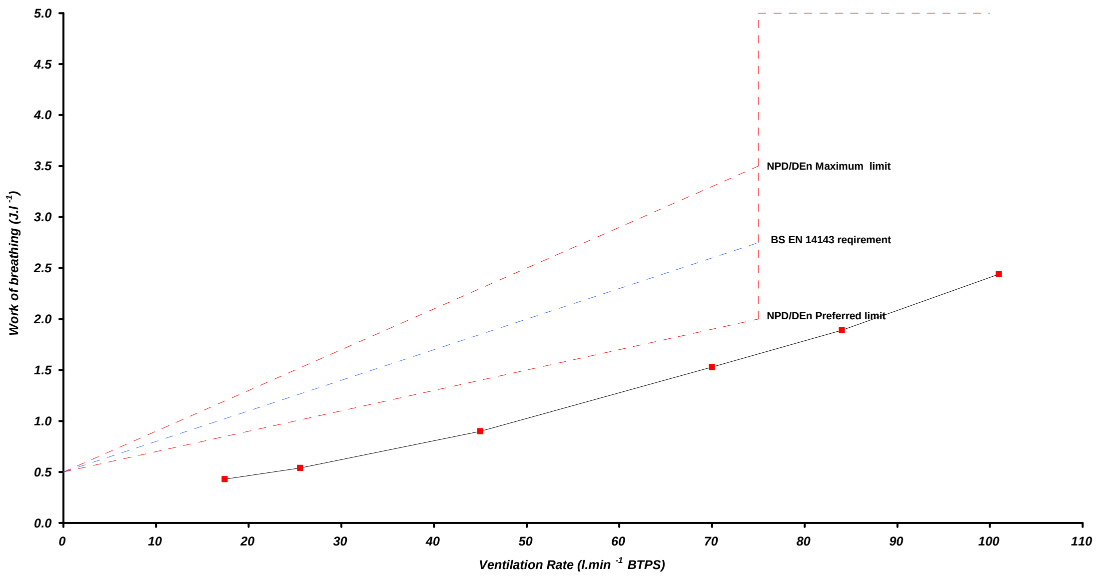

Figure 2-1: Work of breathing: BS EN 14143; NPD/DEn Guidelines

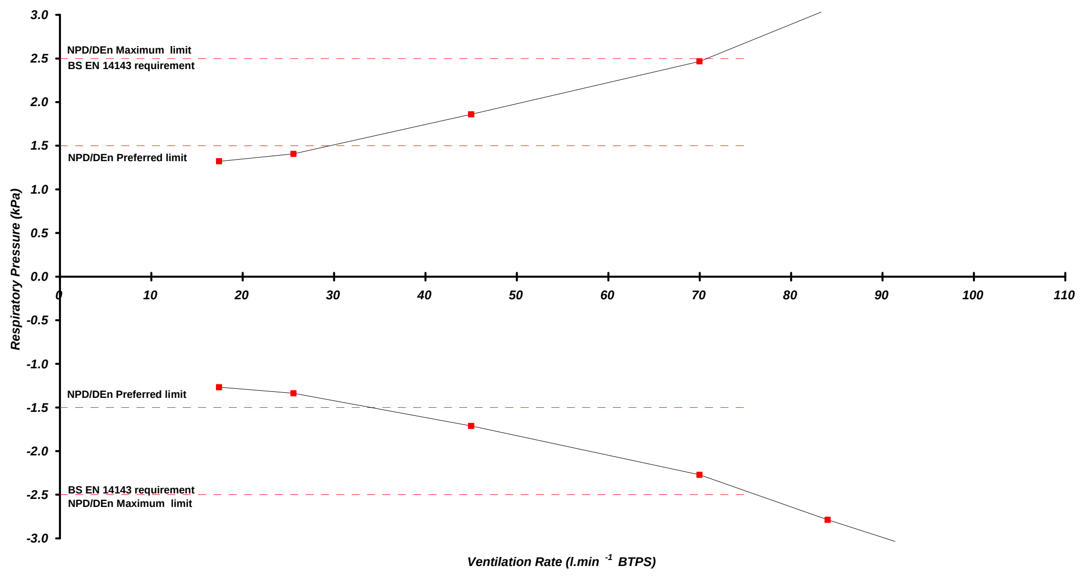

Figure 2-2: Peak-to-end respiratory pressures: BS EN 14143; NPD/DEn Guidelines

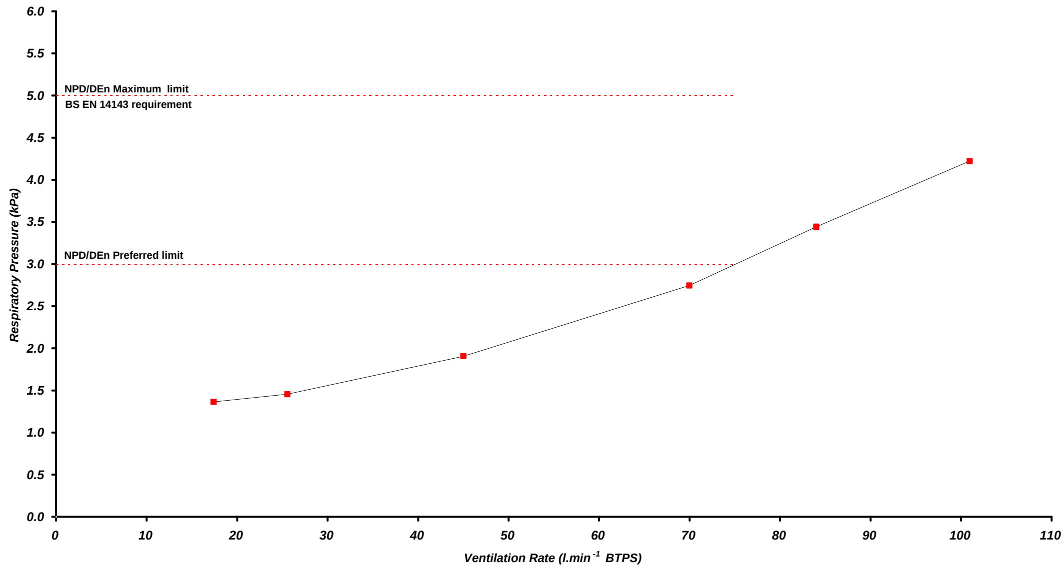

Figure 2-3: Peak-to-peak respiratory pressures: BS EN 14143; NPD/DEn Guidelines

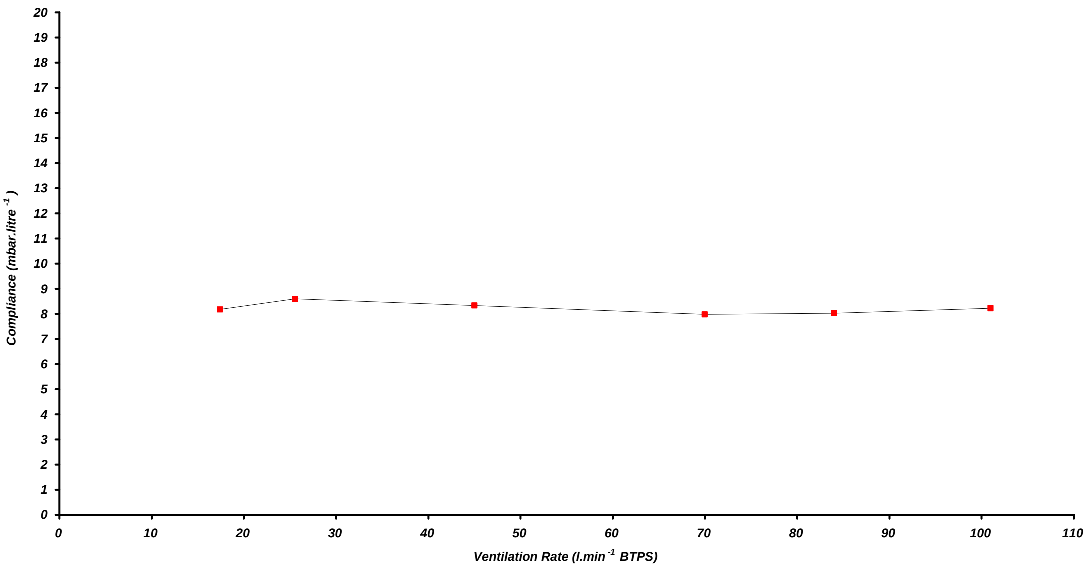

Figure 2-4: Compliance

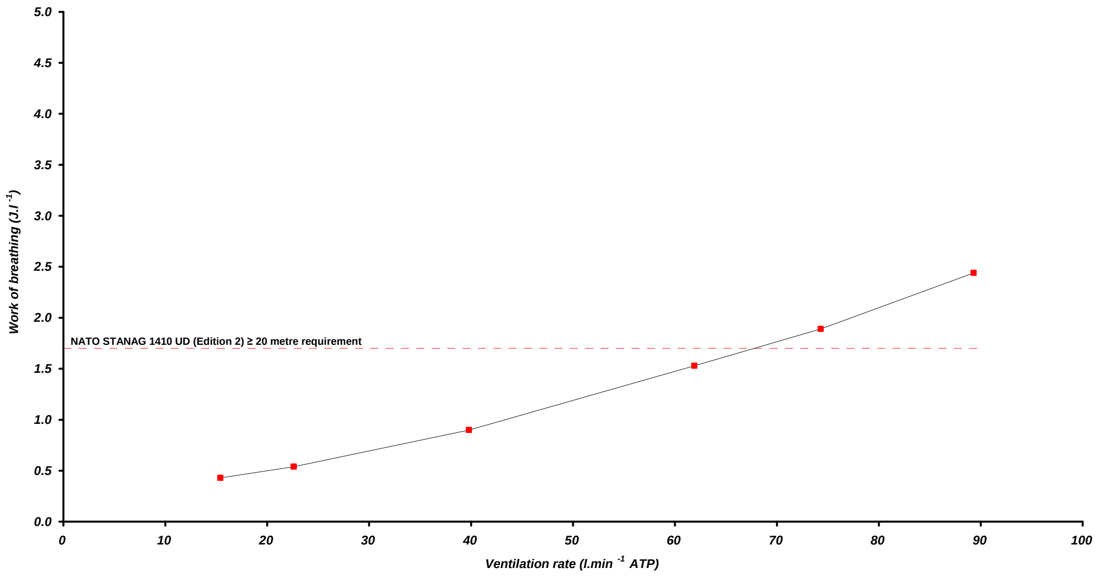

Figure 2-5: Work of breathing: NATO STANAG 1410 (UD) Edition 2

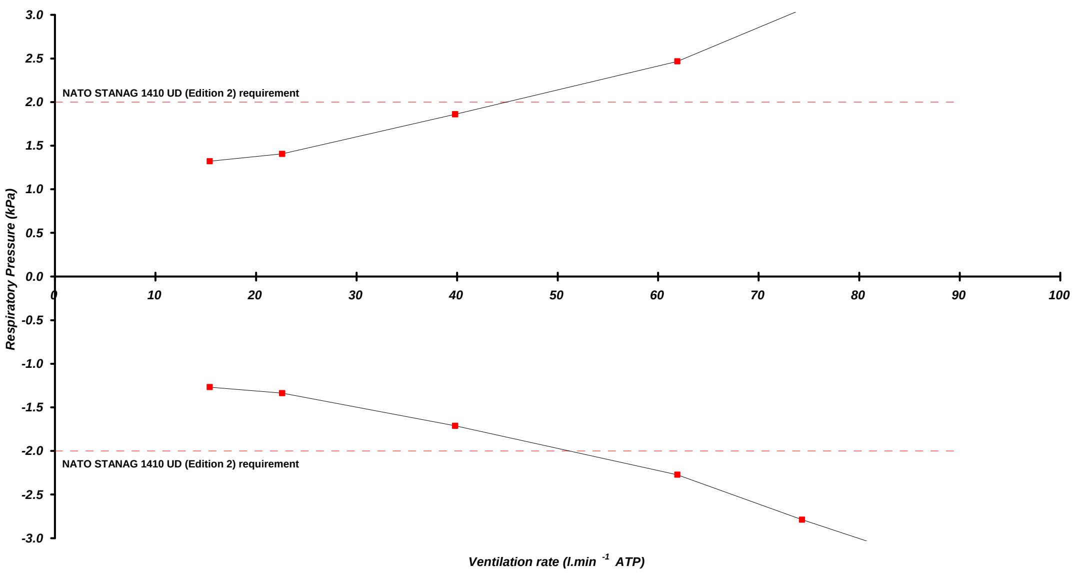

Figure 2-6: Peak-to-end respiratory pressures: NATO STANAG 1410 (UD) Edition 2

2.1.2 FMC apparatus; Oxygen-in-nitrogen (air) diluent gas: 40 metres

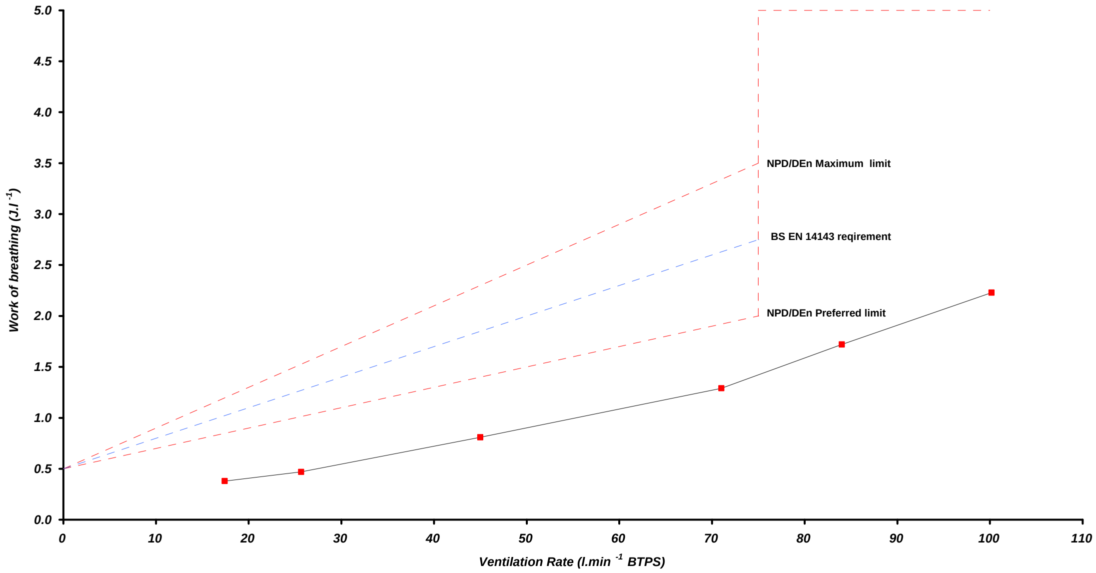

Figure 2-7: Work of breathing: BS EN 14143; NPD/DEn Guidelines

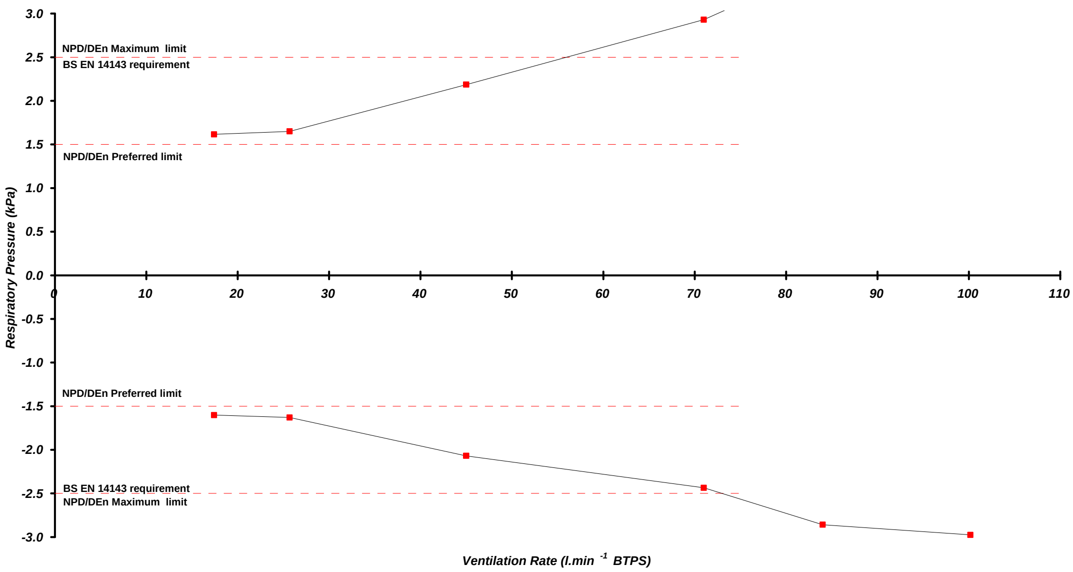

Figure 2-8: Peak-to-end respiratory pressures: BS EN 14143; NPD/DEn Guidelines

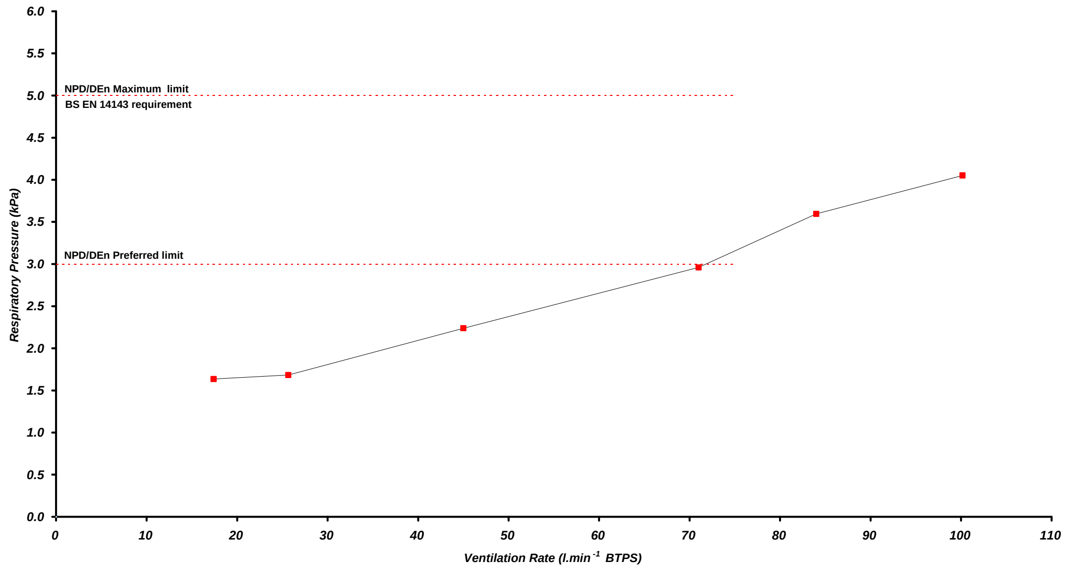

Figure 2-9: Peak-to-peak respiratory pressures: BS EN 14143; NPD/DEn Guidelines

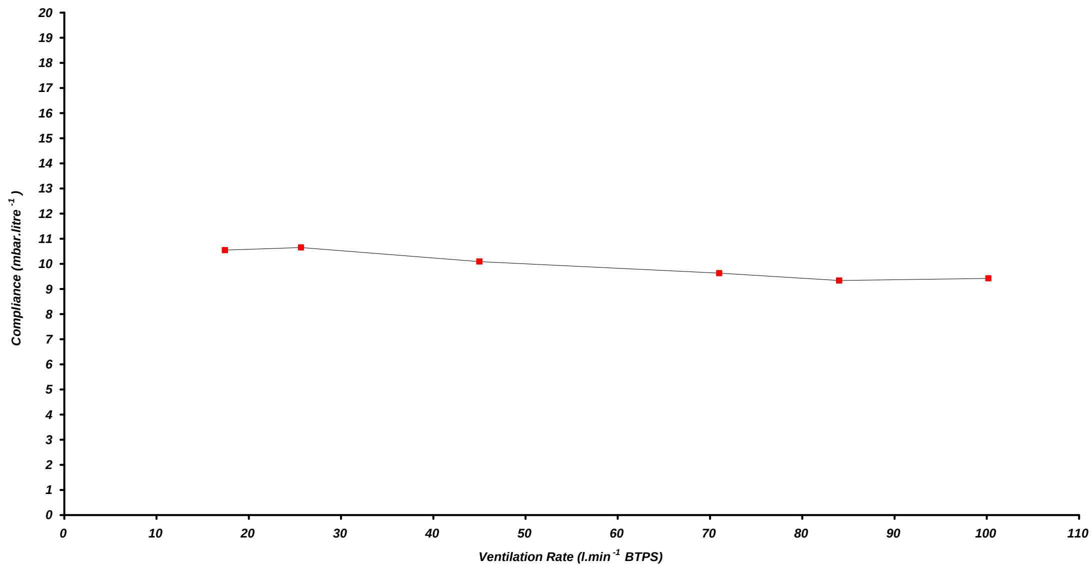

Figure 2-10: Compliance

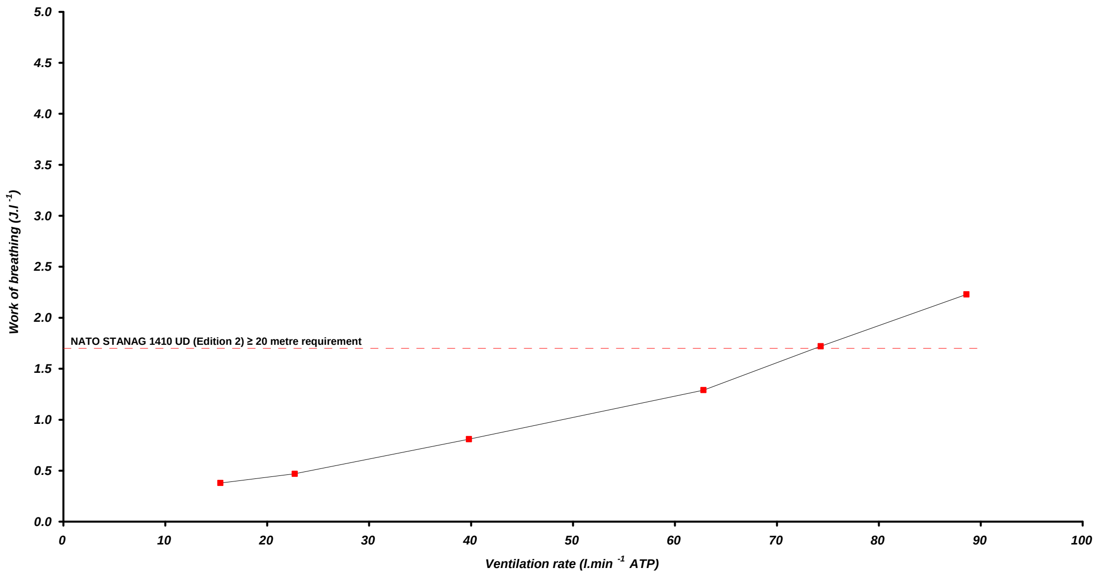

Figure 2-11 Work of breathing: NATO STANAG 1410 (UD) Edition 2

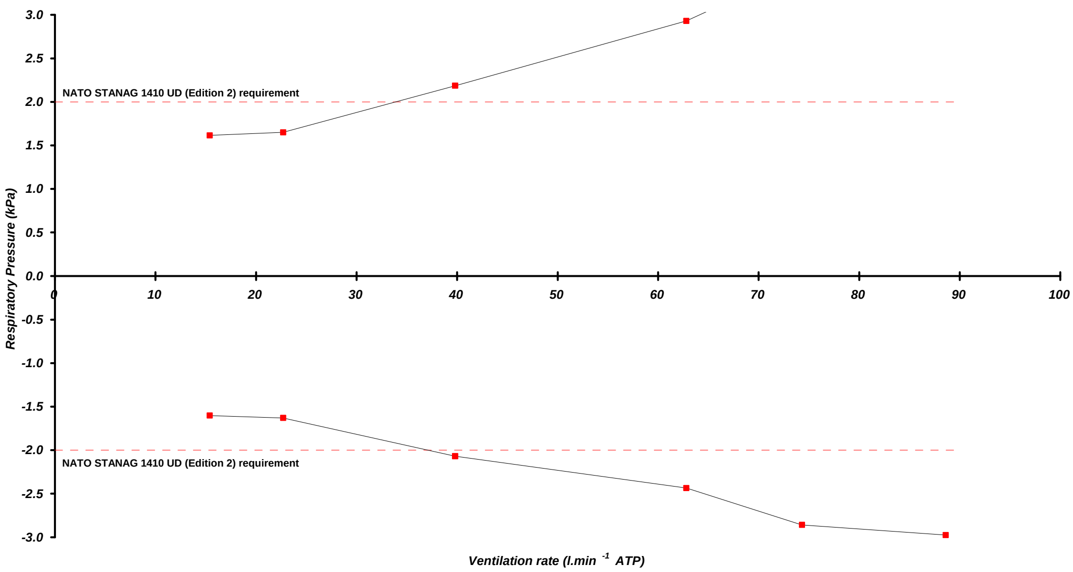

Figure 2-12: Peak-to-end respiratory pressures: NATO STANAG 1410 (UD) Edition 2

2.1.3 FMC apparatus; Trimix (11:65) diluent gas: 60, 80, 100 metres

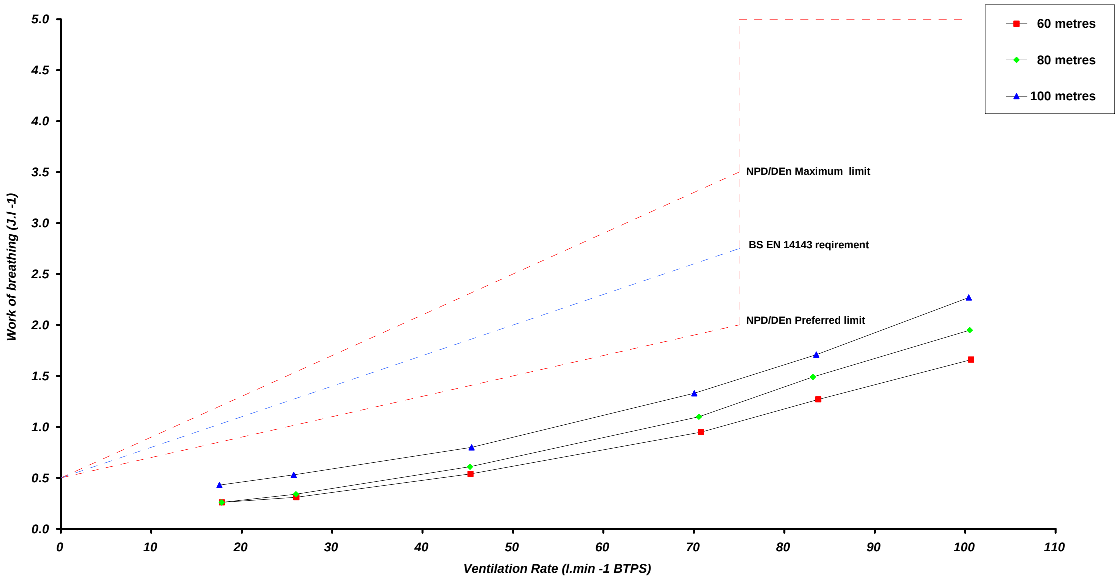

Figure 2-7: Work of breathing: BS EN 14143; NPD/DEn Guidelines

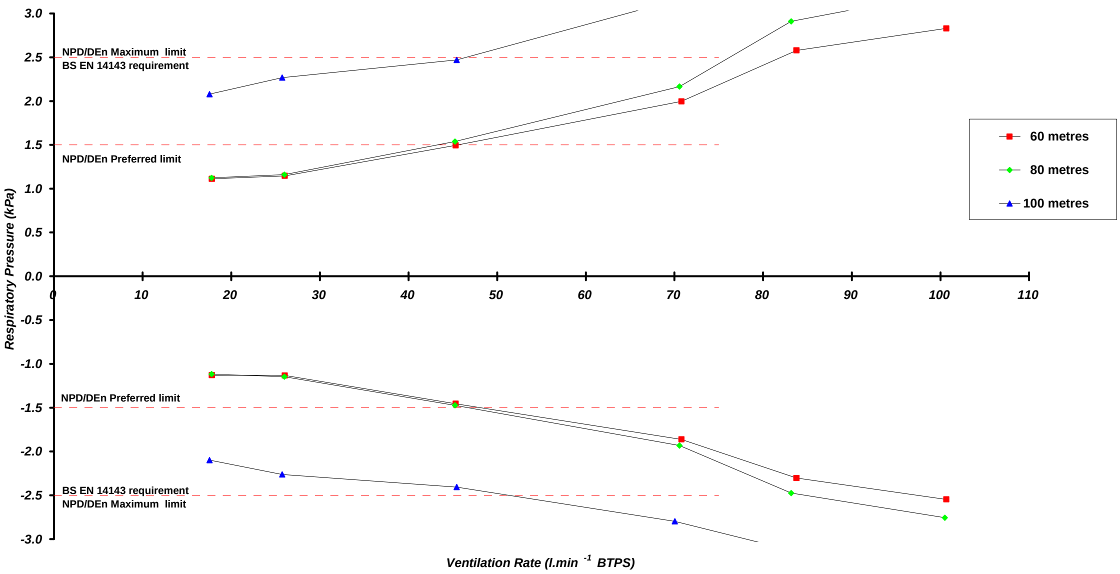

Figure 2-8: Peak-to-end respiratory pressures: BS EN 14143; NPD/DEn Guidelines

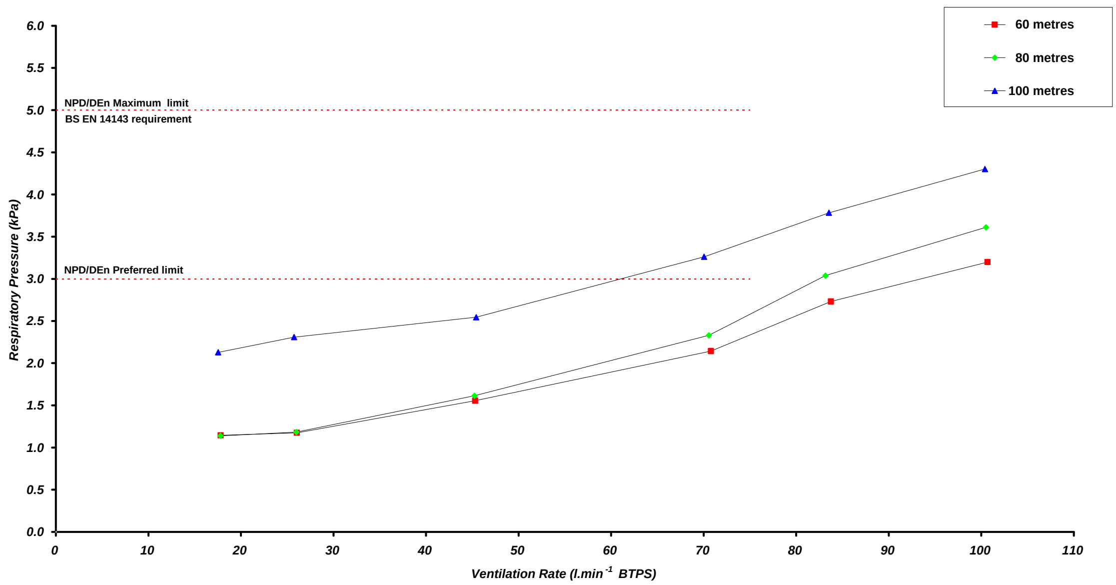

Figure 2-9: Peak-to-peak respiratory pressures: BS EN 14143; NPD/DEn Guidelines

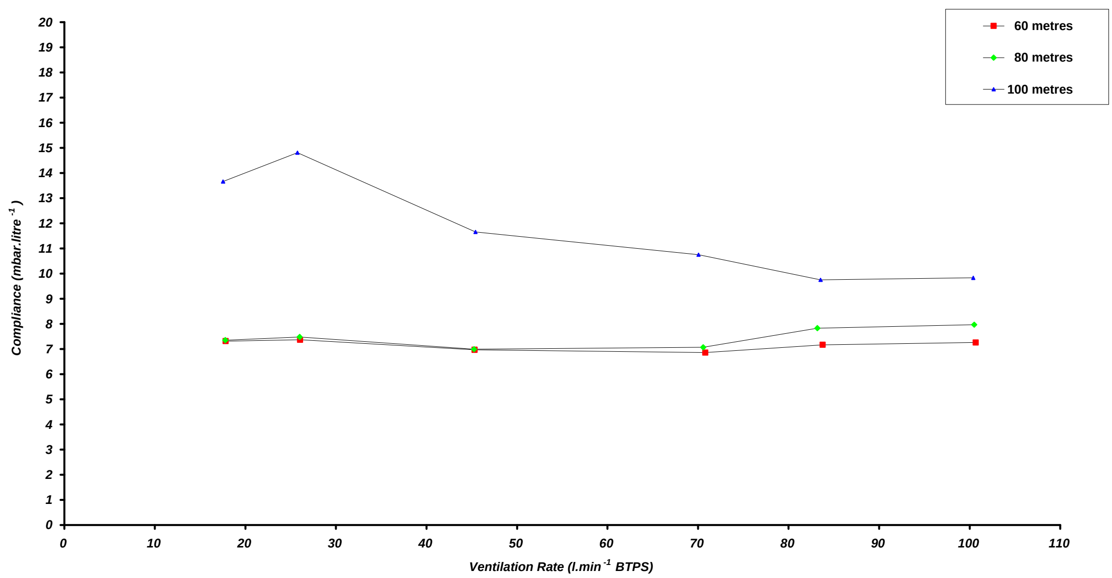

Figure 2-10: Compliance

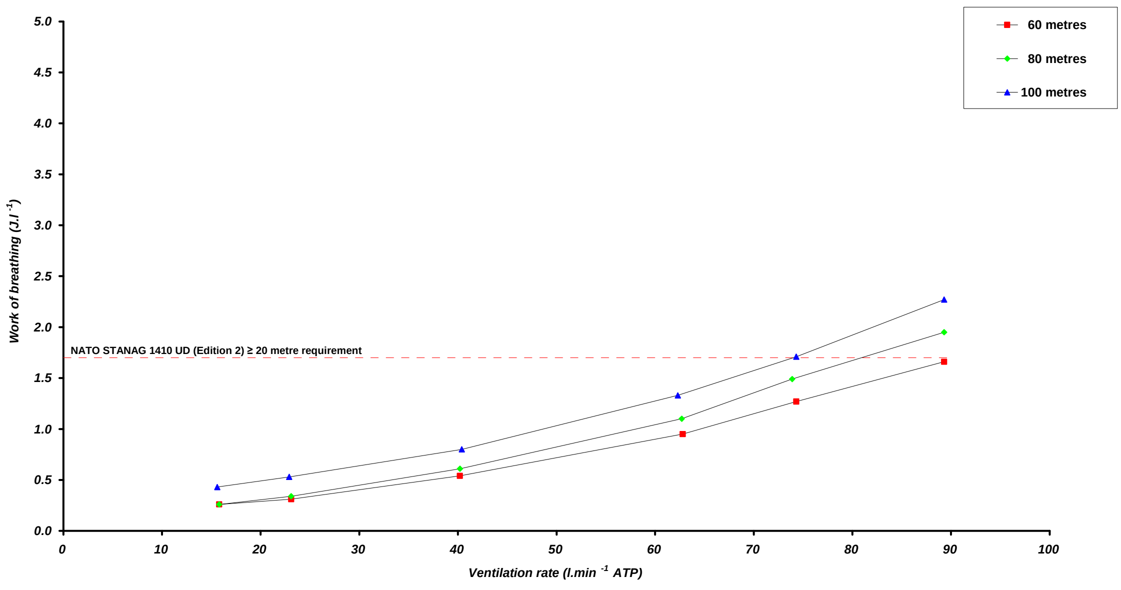

Figure 2-11 Work of breathing: NATO STANAG 1410 (UD) Edition 2

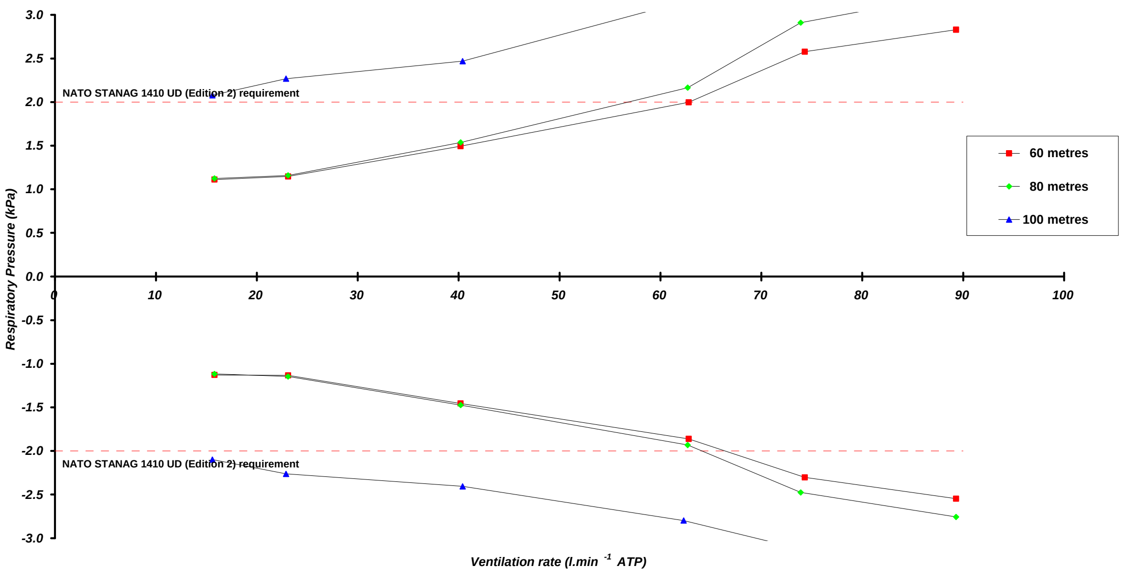

Figure 2-12: Peak-to-end respiratory pressures: NATO STANAG 1410 (UD) Edition 2

2.2 Breathing performance; tabulated values

VENTILATION RATE (ATP) (l·min^{-1})	***VENTILATION RATE (BTPS) (l·min^{-1})***	***WORK OF BREATHING (J/l)***	***INHALE RESPIRATORY PRESSURE (kPa)***	***EXHALE RESPIRATORY PRESSURE (kPa)***	***PEAK-TO-PEAK RESPIRATORY PRESSURE (kPa)***
15.4	17.4	0.43	-1.27	1.32	1.36
22.6	25.5	0.54	-1.34	1.41	1.45
39.8	45.0	0.90	-1.71	1.86	1.91
61.9	70.0	1.53	-2.27	2.47	2.75
74.3	84.0	1.89	-2.79	3.06	3.44
89.3	101.0	2.44	-3.36	3.33	4.22

Table 2-1: RMC apparatus; Oxygen-in-nitrogen (air) diluent gas: 40 metres

VENTILATION RATE (ATP) (l·min^{-1})	***VENTILATION RATE (BTPS) (l·min^{-1})***	***WORK OF BREATHING (J/l)***	***INHALE RESPIRATORY PRESSURE (kPa)***	***EXHALE RESPIRATORY PRESSURE (kPa)***	***PEAK-TO-PEAK RESPIRATORY PRESSURE (kPa)***
15.4	17.4	0.38	-1.60	1.61	1.63
22.7	25.7	0.47	-1.63	1.65	1.68
39.8	45.0	0.81	-2.07	2.19	2.24
62.8	71.0	1.29	-2.44	2.93	2.96
74.3	84.0	1.72	-2.86	3.54	3.60
88.6	100.2	2.23	-2.97	3.90	4.05

Table 2-2: FMC apparatus; Oxygen-in-nitrogen (air) diluent gas: 40 metres

VENTILATION RATE (ATP) (l·min^{-1})	***VENTILATION RATE (BTPS) (l·min^{-1})***	***WORK OF BREATHING (J/l)***	***INHALE RESPIRATORY PRESSURE (kPa)***	***EXHALE RESPIRATORY PRESSURE (kPa)***	***PEAK-TO-PEAK RESPIRATORY PRESSURE (kPa)***
60 metres					
15.8	17.8	0.26	-1.13	1.11	1.14
23.1	26.0	0.31	-1.13	1.15	1.18
40.2	45.3	0.54	-1.46	1.50	1.56
62.8	70.8	0.95	-1.86	2.00	2.14
74.3	83.8	1.27	-2.30	2.58	2.73
89.3	100.7	1.66	-2.55	2.83	3.20
80 metres					
15.8	17.8	0.26	-1.12	1.12	1.14
23.1	26.0	0.34	-1.15	1.16	1.18
40.2	45.2	0.61	-1.47	1.54	1.61
62.7	70.6	1.10	-1.93	2.17	2.33
73.9	83.2	1.49	-2.48	2.91	3.04
89.3	100.5	1.95	-2.76	3.24	3.61
100 metres					
15.6	17.5	0.43	-2.10	2.08	2.13
22.9	25.7	0.53	-2.26	2.27	2.31
40.4	45.4	0.80	-2.41	2.47	2.55
62.3	70.0	1.33	-2.80	3.15	3.26
74.3	83.5	1.71	-3.14	3.57	3.78
89.3	100.4	2.27	-3.34	3.91	4.30

Table 2-3: FMC apparatus; Trimix (11:65) diluent gas

2.3 Carbon dioxide absorbent canister endurance

The carbon dioxide absorbent canister maintained the inspired PCO_2 below 0.5 kPa for 152 minutes; and reached 1.0 kPa in 168 minutes.

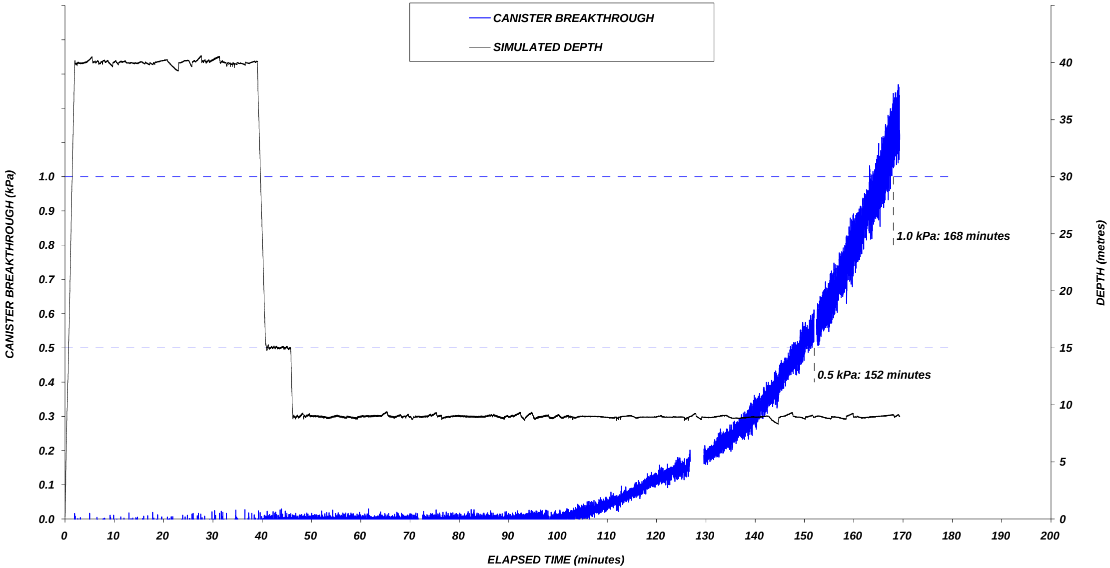

Figure 2-13: Absorbent canister duration