

Unmanned evaluation of JJ-CCR

13 October 2009

1. Procedures

1.1 General

For all evaluation, the apparatus (with rear-mounted counterlungs) was supplied with oxygen and an oxygen-in-nitrogen diluent (*i.e.* air, with an oxygen content of 20.9%) gases from integral cylinders. All gases were supplied by the manufacturer.

The bite mouthpiece of the apparatus was fitted 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 °C.

Prior to each simulated dive, the carbon dioxide (CO₂) absorbent canister (either axial or radial) was filled with soda lime (Molecular Products Sofnolime 1.0 – 2.5 mm granules. Lot, 100039. Expiry Date, March 2014) 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.

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 °C) 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; elements of the Norwegian Petroleum Directorate/Department of Energy (NPD/DEN) guidelines for breathing apparatus and with reference to STANAG 1410-UD Standard unmanned test procedures for underwater breathing apparatus.

1.2 Closed-circuit breathing performance

Breathing performance of the apparatus configured with the radial CO₂ absorbent canister (LSSL reference: 1709-02) was assessed at 40 m 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.

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

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

1.3 Carbon dioxide absorbent canister endurance

Canister endurance was defined as the time that the CO₂ absorbent canister maintained the inspired partial pressure of carbon dioxide (PCO₂) below 0.5 kPa. To further assess the performance of the axial and radial CO₂ absorbent canisters, the simulated dive profiles (LSSL references: 1709-01 and 1709-03) were conducted until the inspired PCO₂ had reached 1.0 kPa.

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.

Canister endurance evaluation was carried out with a CO₂ injection rate of 1.6 l·min⁻¹ (STPD) whilst ventilating at a rate of 40.0 l·min⁻¹, under the following conditions of use:

- 40 m dive profile
- Descent rate, 20 m·min⁻¹
- Ascent rate, 15 m·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 CO₂ injection flow rate was verified by real-time flow rate monitoring and post-dive gravimetric analysis of the soda lime.

NOTE: The weight of soda lime used to fill the axial CO₂ absorbent canister (LSSL reference: 1709-01) was not recorded; the expected weight of soda lime was subsequently calculated from the results of the CO₂ absorbent canister gravimetric analysis (LSSL reference: 1709-03).

1.4 Partial Pressure of Oxygen control

The apparatus was set to 0.7 bar PO₂ at the surface with an automatic switch to 1.2 bar PO₂ (at 35 m) for use at the maximum depth and subsequent decompression.

NOTE: Whilst carrying out the radial CO₂ absorbent canister endurance test (LSSL reference: 1709-03), the control electronics did not switch over from low to high setpoint (*i.e.* 0.7 to 1.2 bar), therefore the PO₂ evaluation was conducted with a continuous setpoint of 0.7 bar.

To assess the performance of the PO₂ control, the apparatus was evaluated with a simulated metabolic oxygen consumption rate of 1.78 l·min⁻¹ (STPD) whilst ventilating at a rate of 40.0 l·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 Radial canister; 40 metres (LSSL reference 1709-02)

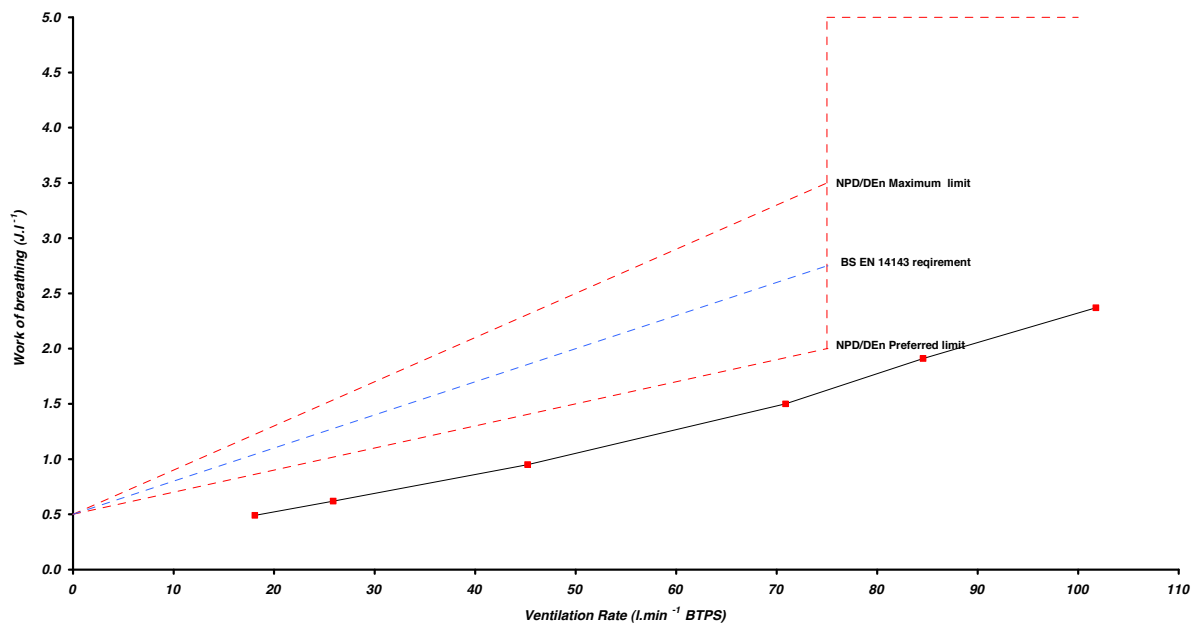


Figure 2-1: Work of breathing: BS EN 14143; NPD/Den Guidelines

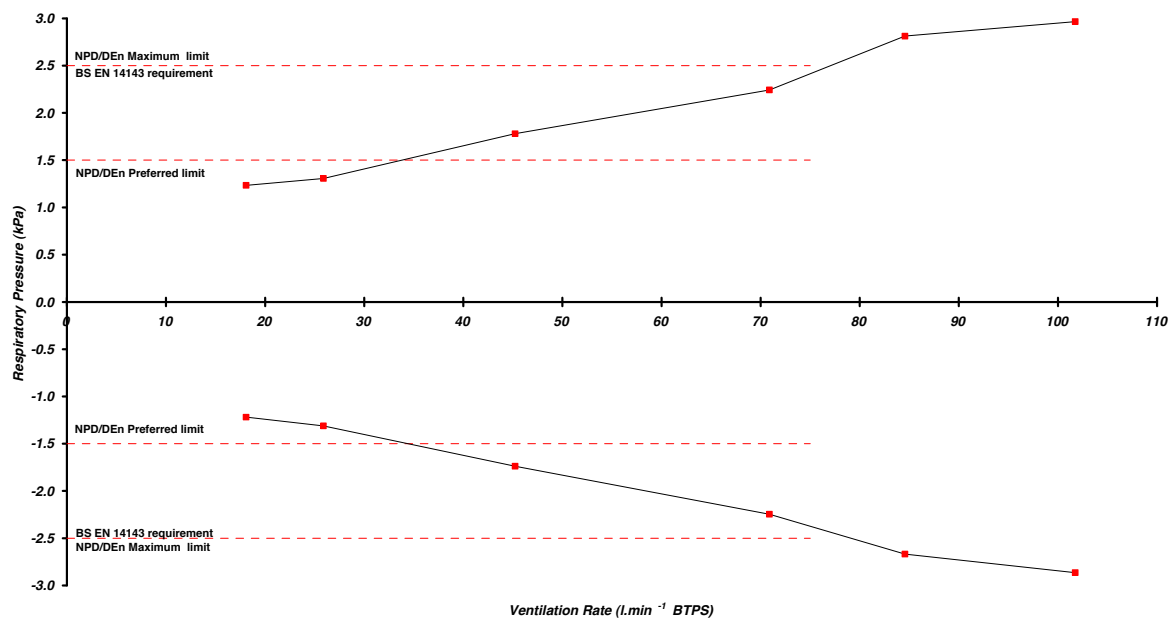


Figure 2-2: Peak-to-end respiratory pressures: BS EN 14143; NPD/Den Guidelines

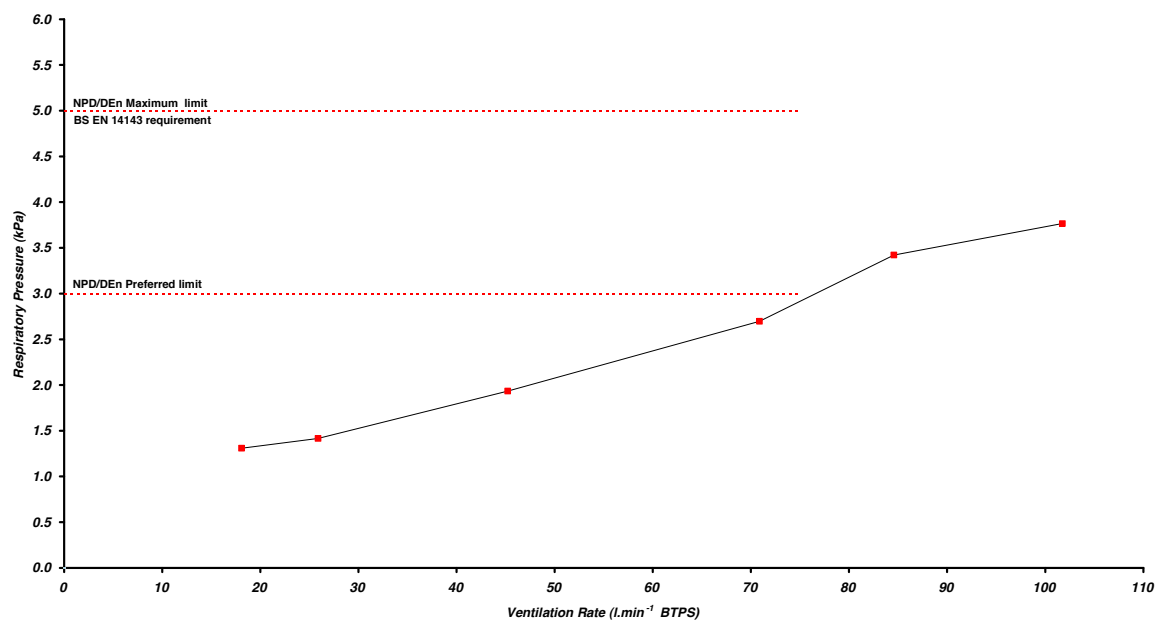


Figure 2-3: Peak-to-peak respiratory pressures: BS EN 14143; NPD/Den Guidelines

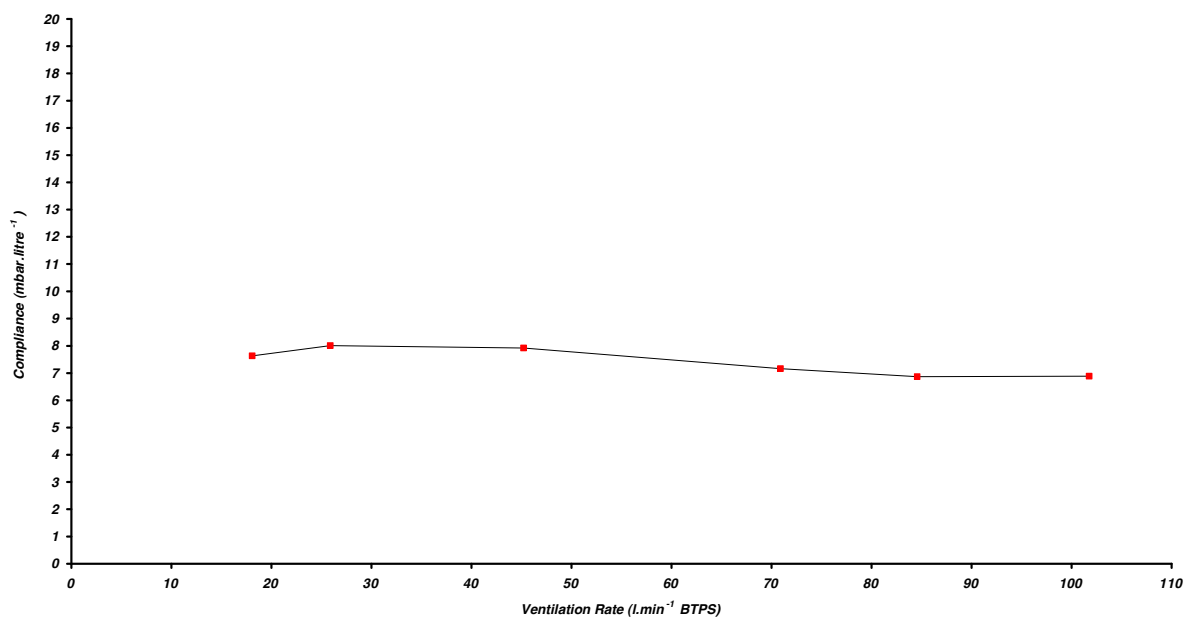


Figure 2-4: Compliance

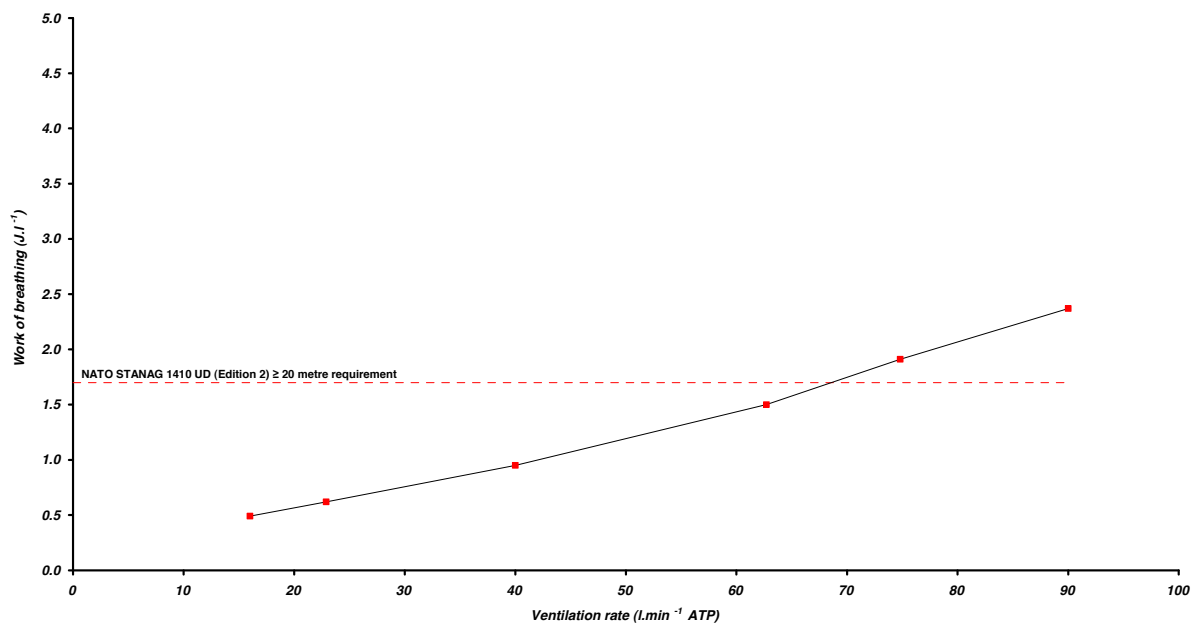


Figure 2-5: Work of breathing: NATO STANAG 1410 (UD) Edition 2

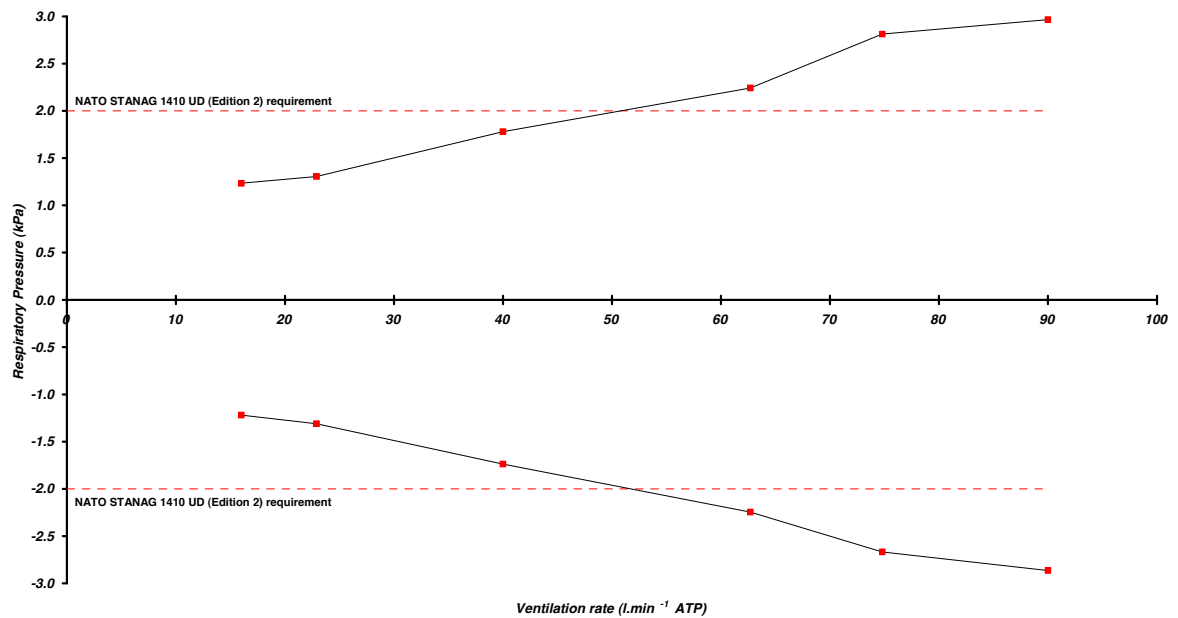


Figure 2-6: Peak-to-end respiratory pressures: NATO STANAG 1410 (UD) Edition 2

2.1.2 Breathing performance; tabulated values (LSSL reference 1709-02)

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)
16.0	18.1	0.49	-1.22	1.23	1.31
22.9	25.9	0.62	-1.31	1.31	1.42
40.0	45.2	0.95	-1.74	1.78	1.93
62.7	70.9	1.50	-2.25	2.24	2.70
74.8	84.6	1.91	-2.67	2.81	3.42
90.0	101.8	2.37	-2.87	2.97	3.77

Table 2-1: Breathing performance values: Radial canister; 40 metres

2.2 Carbon dioxide absorbent canister endurance

2.2.1 Axial CO₂ absorbent canister (LSSL reference 1709-01)

The carbon dioxide absorbent canister maintained the inspired PCO₂ below 0.5 kPa for 146 minutes; and reached 1.0 kPa in 161 minutes (expected fill-weight of soda lime: 2366.0 grams).

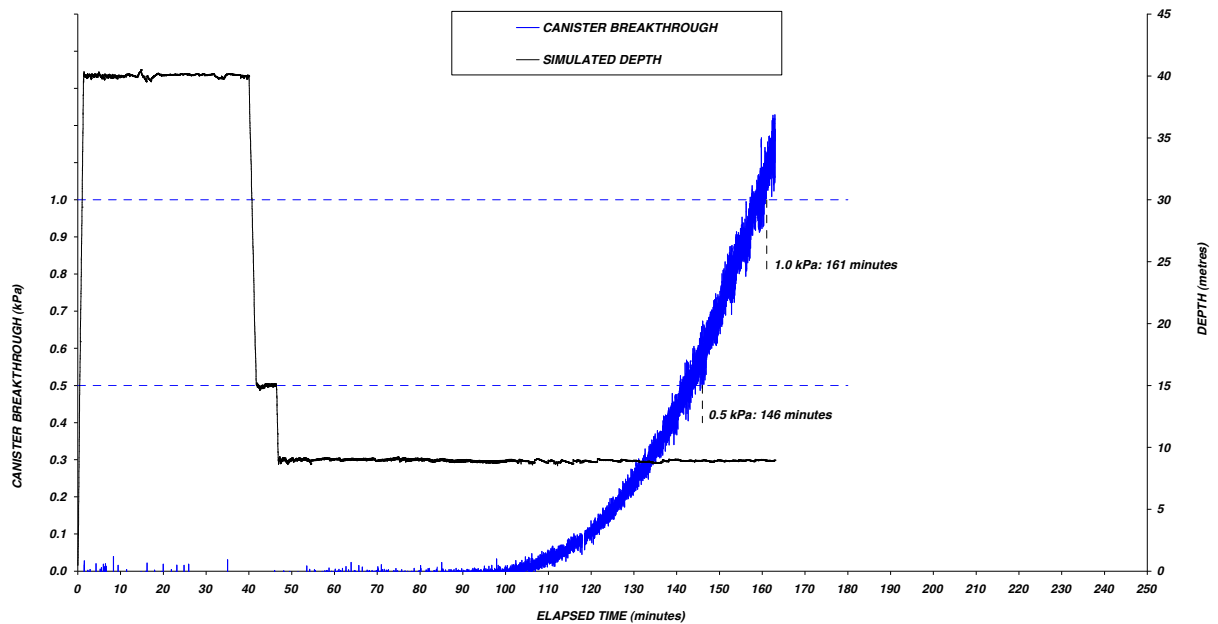


Figure 2-7: Axial CO₂ absorbent canister duration

2.2.2 Radial CO₂ absorbent canister (LSSL reference 1709-03)

The carbon dioxide absorbent canister maintained the inspired PCO₂ below 0.5 kPa for 212 minutes; and reached 1.0 kPa in 230 minutes (actual fill-weight of soda lime: 3067.4 grams).

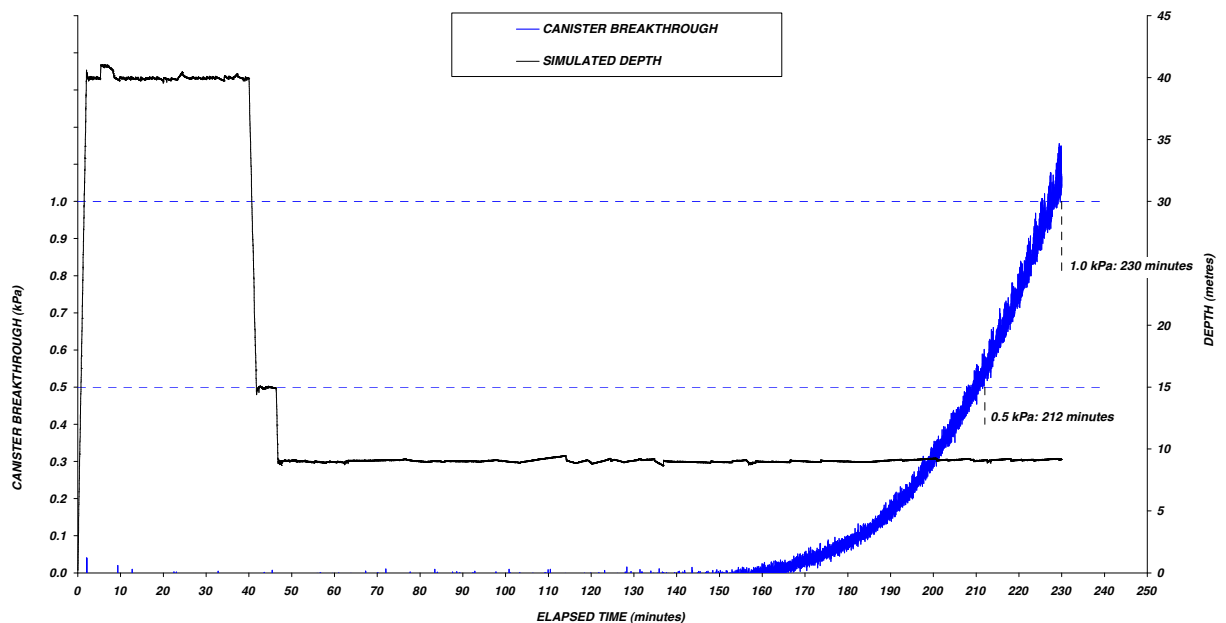


Figure 2-8: Radial CO₂ absorbent canister duration

2.2.3 Gravimetric analysis

The results of the gravimetric analysis of the used soda lime are presented in Table 2-2.

NOTE: The calculations for GAL/018/09 are based on the expected fill weight of the CO₂ absorbent canister; the calculations for GAL/019/09 are based on the actual fill weight.

REFERENCE NUMBERS	FILL WEIGHT (grams)	CO₂ INJECTION (minutes)	R VALUE (l·100g⁻¹)	EFFICIENCY (%)
GAL/018/09 (LSSL 1709-01)	2366.0	165	11.2	45.5
GAL/019/09 (LSSL 1709-03)	3067.4	230	12.2	49.5

Table 2-2: Gravimetric analysis results