PPE CASE

Personal Protective Equipment Conformity Assessment Studies and Evaluations

Point-of-Use Assessment for Self-Contained Self-Rescuers Randomly Sampled from Mining Districts: Second Phase

Sample Period: January 2012 to June 2013

Gary Walbert and William Monaghan
National Institute for Occupational Safety and Health
National Personal Protective Technology Laboratory

Abstract

The National Personal Protective Technology Laboratory (NPPTL)[1], a laboratory in the National Institute for Occupational Safety and Health (NIOSH), and the Mine Safety and Health Administration (MSHA) in Pittsburgh, Pennsylvania have undertaken a study to evaluate the long-term field performance and reliability of self-contained self-rescuer (SCSR) units deployed in U.S. underground coal mines in accordance with federal regulation 30 CFR[2] § 75.1714. This ongoing project provides performance, reliability, and user maintenance compliance data on field deployed SCSR units.

This report presents findings from the second phase SCSR long-term random (LTR2) testing conducted between January 2012 and June 2013. Prior to collection, MSHA provided a copy of their SCSR inventory from which NIOSH compiled a statistically significant random list of 719 SCSR units. From this random list, NIOSH targeted 536 SCSRs for collection. NIOSH returned 379 SCSRs to the laboratory for testing when the collection effort ended for LTR2. NIOSH subsequently tested the 377 SCSR units that passed the manufacturers' recommended visual inspection using an automated breathing and metabolic simulator (ABMS). The tests performed in this study are not approval tests; however, a certified product investigation process (CPIP) may be opened if the products perform poorly during testing at NPPTL, to determine the impact of observed performance degradation or nonconformance of a deployed SCSR.

NIOSH's point-of-use assessments for self-contained self-rescuers (SCSRs) found that mine operators are largely compliant with SCSR manufacturer-specified requirements and the devices tested appear to be sufficiently designed for mining use conditions.

[1] A list of acronyms and abbreviations is available in **Appendix A**.
[2] Code of Federal Regulations. See CFR in references.

Nine of the targeted SCSR units failed the manufacturer's recommended visual inspection either at the mine or at NPPTL. LTR2 sample test results suggest that SCSR units that pass the manufacturer's recommended inspection criteria and breathing and metabolic simulation (BMS) testing can be relied upon to provide life support for mine escape. Although deployment in the mining environment caused a slight degradation in performance for one manufacturer's SCSR tested during LTR2, all have retained their ability to preserve life in the event of an emergency. It was not necessary to open a CPIP audit for SCSR nonconformance issues in this phase of the Long-Term Field Evaluation (LTFE) study.

NIOSH was successful in collecting the target goal of at least 100 of each NIOSH-approved SCSR model deployed in United States underground coal mines during the LTR2 collection phase. This ensured retaining the desired statistical validity of the study.

Introduction

Coal mine operators in the United States are required to make a self-contained self-rescuer (SCSR) available to each underground coal miner. Additional SCSRs are required to be cached on working settings and in outby escape ways. Title 30 Code of Federal Regulations (30 CFR) § 75.1714 requires that each person in an underground coal mine wear, carry, or have ready access to a device approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA). The device must provide respiratory protection with an oxygen (O_2) source for up to one hour. In some mines, shorter duration SCSRs are worn, while cached one-hour units provide the additional duration. SCSRs are sealed for protection from the underground mining environment. The sealed case protects the apparatus from environmental and physical damage, but makes it difficult to inspect the unit for damage. Unlike open-circuit, self-contained breathing apparatus employed in fire services and general industry, no functional assessment can be made prior to actual use. For these reasons, the NIOSH National Personal Protective Technology Laboratory (NPPTL), in cooperation with MSHA, conducts an ongoing, long-term field evaluation (LTFE) of SCSRs deployed in underground coal mines to assess their reliability and performance.

The objective of the LTFE program is to evaluate how well SCSRs endure the underground coal mining environment with regard to both physical damage and the effects of aging. In order to protect miners' safety, mines must conduct regular inspections of deployed units to ensure readiness. The criteria for these inspections are established by the manufacturers and include damage assessment of specific components by either visual inspection or non-destructive testing. Among the visual inspection criteria are evaluation of heat and humidity indicators or pressure gauges, verification of the service time date, assurance that the case seal is intact, and visual assessment of physical indications of wear or damage. All users must comply with the manufacturer's specified conditions for storage and use. SCSRs failing inspection, or not in compliance with the conditions of storage and use, no longer meet the NIOSH/MSHA approval and must be removed from service.

During the first ten phases of the LTFE program, referred to as LTFE 1 through LTFE 10, NIOSH targeted collection of SCSR units that were deployed for the longest period of time and exhibited signs of environmental impact. Reports published that describe the findings of LTFE 1 through LTFE 10 (Kyriazi et al. 1986; Kyriazi and Shubilla 1992, 1994, 1996, 2000, 2002, 2004, 2006, 2008) were successful at identifying performance and reliability issues, resulting in SCSR product improvements. However, the SCSR sample size and collection criteria limited the statistical validity of the results.

In 2009, implementation of a new sampling strategy allowed for randomization of the SCSR population tested. As part of the new strategy, NIOSH initially compiled a list of 719 SCSR units from the MSHA *SCSR Inventory and Report*. From this list, NIOSH attempted to collect 536 SCSR units across the 11 MSHA mining districts that would pass the manufacturer's recommended visual inspections at the mine for each phase. This sampling strategy improved the statistical significance over observations and findings/conclusions made in recent LTFE studies. Since 2009, NIOSH has referred to the LTFE collections as LTR1, LTR2, LTR3, etc., to indicate the randomization of the sampling operation and phase of the collection. NIOSH based LTR1, LTR2, and LTR3 collections on this random sampling protocol which also negated the influence of different mining environments such as coal seam height, size of the mine, and other environmental factors that bias the sample. The new LTFE collection strategy targets the same number of each SCSR model currently approved for use in underground coal mines, regardless of market share.

Beginning with the first phase long-term random (LTR1) collection phase, and continuing with LTR2, NIOSH subjected SCSR units to strict visual inspections. The intent was to only permit units that passed the visual inspection into the study.

All of the SCSR units tested as part of LTR2 are ones which have been approved by NIOSH and MSHA under the requirements of Title 42, Code of Federal Regulations, Part 84 (42 CFR, Part 84), Subpart H. It is very important to keep in mind that the tests performed as part of LTR2 are focused on detecting any change in the performance of deployed respirators. Tests conducted as part of LTR2 are not performed as part of Subpart-H certification. LTR2 test conditions and endpoints are also different than tests conducted in Subpart-H certification. Unlike the Subpart H certification testing which relies solely on human subjects to evaluate the SCSR units, LTR2 tests are performed using an Automated Breathing and Metabolic Simulator (ABMS). The LTR2, breathing and metabolic simulation (BMS) tests are designed to be highly reproducible so comparisons between new and old units are valid. Although human-facilitated results and machine results are similar, they are different and the data reported from machine testing is not to be considered a direct equivalent to a Subpart H certification man test. The BMS tests are also intended to stress the functionality of the SCSR units towards the high end of their life support capabilities. While this report offers results that are sometimes less than optimal, it is important to remember that one of the goals is to assure that SCSR units, as found in mines, will provide the expected life-support capacity when they are properly used and cared for. Unless specifically noted otherwise, the report should be viewed as providing that evidence.

Methods

SCSRs Collected and Evaluated

The SCSR units evaluated in the LTR2 study included units manufactured by Ocenco Incorporated and Dräger. The Ocenco EBA 6.5 and the Ocenco M-20 (Figures 1 and 2) are compressed oxygen-supplying SCSRs. The EBA 6.5 has a rated duration of 60 minutes; the M-20 has a rated duration of 10 minutes.

Figure 1. Ocenco EBA 6.5 self-rescuer

Figure 2. Ocenco M-20 self-rescuer

Figure 3. Dräger Oxy K Plus S self-rescuer

Figure 4. Dräger Oxy K Plus (top) and Oxy K Plus S (bottom) self-rescuers

The Dräger Oxy K Plus S (Figure 3) and Oxy K Plus (top of Figure 4) are chemical oxygen-producing SCSR units that employ an oxygen gas starter for initial operation while chemical oxygen generation is induced from the canister via the user's exhaled breath. The Oxy K Plus and Oxy K Plus S are the same SCSR but have a different case opening mechanism and procedure (demonstrated in Figure 4). The Oxy

K Plus/Oxy K Plus S SCSR has a rated duration of 60 minutes. All SCSR units included in the study utilize a chemical bed to reduce carbon dioxide (CO_2) to within acceptable limits.

CSE SR-100 SCSR units were not collected during this sampling period due to MSHA's mandatory removal of these devices from service in accordance with the NIOSH Respirator User Notice "Loss of Start-Up Oxygen in CSE SR-100 Self-Contained Self-Rescuers" of April 26, 2012.

Sampling Strategy

For statistical analysis purposes, NIOSH attempted to collect and return for testing at least 100 of each NIOSH-approved SCSR model deployed in United States underground coal mines for the LTR2 study. To obtain the units, NIOSH requested a list from MSHA of all units currently in mine use. In response, MSHA generated a list of approximately 250,000 SCSR serial numbers across all 11 mining districts, using the MSHA *SCSR Inventory and Report*. From the list, NIOSH compiled a random list of at least 137 units of each model. Targeting more SCSR units for collection than was needed was necessary in case there were issues with obtaining specific SCSR models. Given that the Dräger Oxy K Plus/Oxy K Plus S SCSR units are similar, with the exception of their case opening mechanism, this strategy proved successful as at least 105 units of each model were collected by NIOSH for laboratory testing. Table 1 lists the number of each SCSR returned to NPPTL for testing during the LTR2 collection phase along with the manufacturing dates:

Table 1. Summary of LTR2 SCSR Collection

Manufacturer	Model	Number of units collected	Manufacture date range
Dräger	Oxy K Plus	96	02/2006 – 01/2011
Dräger	Oxy K Plus S	67	04/2005 – 06/2011
Ocenco	EBA 6.5	111	06/1997 – 08/2011
Ocenco	M20	105	11/2006 – 06/2012

Tests and Evaluations

The following tests and evaluations were conducted on each SCSR unit obtained: (1) visual inspection which miners are required to make before each shift; (2) phenolphthalein indicator check; (3) quantitative leak test; (4) oxygen flow test; and (5) BMS test. In addition to the visual checks, the Dräger inspection manual states that the Oxy K Plus/Oxy K Plus S SCSR should be tested in the field every 90 days with an acoustic solids movement detector (ASMD) to determine the condition of the chemical bed used to generate oxygen. This test is also performed at NPPTL using a laboratory-scale ASMD as a final screening just prior to testing; however, NIOSH did not perform this test because the equipment necessary to do so was not available. While the units were provided to NIOSH with the understanding that they should have passed the mine's ASMD assessment, we acknowledge that unassessed, or even improperly assessed bed degradation could have had a negative impact on at least some of the results being reported herein.

Visual Inspection

Three-hundred seventy-nine SCSR units passed the manufacturer's recommended visual inspections at the mine and were collected for further evaluation by NIOSH, including a second visual inspection at NPPTL prior to laboratory testing. Manufacturers' recommended visual inspections focus on the integrity of the case, seal, latches, mouthpiece plug, and indicators that are viewable without opening or activating the respirator. The case of the Dräger Oxy K Plus/Oxy K Plus S chemical unit has moisture and heat indicators that signify water penetration or excessive temperature exposure, respectively. Ocenco Incorporated oxygen units have pressure indicators that measure oxygen cylinder pressure. Damage to the case, missing case latches, broken seals allowing contaminant penetration, excessive heat exposure, moisture penetration into the case, or low O_2 gauge pressures are reasons for a unit to fail the visual inspection. If all visual inspections pass, the SCSR is safe for use. If a unit does not meet the manufacturer's prescribed limits for these indicators when inspected at the mine, it must be taken out of service. SCSR units that failed the visual inspection at NPPTL were removed from the study. It should be noted that NPPTL only performed the same visual inspections that a miner is required to conduct prior to using the unit or taking it underground.

Phenolphthalein Indicator Check

Upon opening the SCSR case and removing the mouthpiece plug, each mouthpiece and inner portion of the breathing tube was wiped with a swab soaked in phenolphthalein. This action indicated whether the granular chemical sorbent had broken down and entered the breathing circuit where it could be inhaled by the user. The presence of chemical sorbent in the breathing zone of the SCSR is indicated by the phenolphthalein soaked swab changing to pink in color after swabbing.

Quantitative Leak Test

SCSR units that passed the visual inspection check proceeded to the quantitative (QNT) leak test. This test assesses breathing circuit integrity but is not required for approval. The leak test employs an exhaust blower to induce a vacuum of 300 mm H_2O within the SCSR breathing circuit while measuring the inward leakage rate with a mass flow meter. At maximal work rates, inhalation pressure/vacuum should not exceed +300 or -300 mm H_2O (Hodgson, 1993) and inward leakage rates should be less than 500 milliliters per minute (ml/min) to reasonably assure user protection for a period equal to or greater than the rated service time. The inward leakage threshold of 500 ml/min is a function of the 200-ppm, one-hour threshold limit value (TLV) for carbon monoxide (CO). An inward leakage rate of 500 ml/min in a 10% CO atmosphere at a peak inhalation rate of 250 liters per minute over one hour corresponds to a CO volume fraction of 0.0002 or 200 ppm. Leakage rates were documented and SCSR units that exceeded the 500 ml/min leakage rate continued with the remaining pre-test evaluations and were subsequently tested.

Mouthpiece connectors that are shaped as closely as possible to the internal dimensions of the SCSR mouthpiece opening are used to seal the SCSR to the ABMS trachea. Custom fabrication of these mouthpieces to match the SCSR mouthpiece opening is required to optimize the fit and prevent the connection from being a source of inward leakage. Care is taken when inserting the connector into the SCSR mouthpiece to be tested and securing it tightly with a wire tie. Putty is used, as necessary, to enhance this seal and stop any residual inward leakage. The mouthpiece connector is tightly sealed via rubber tubing to the vacuum source for the QNT. Leakage within the breathing circuit of the SCSR being tested under vacuum is confirmed by pinching and sealing the breathing hose just below the mouthpiece connector.

Oxygen Flow Test

After assessing the breathing circuit integrity, each Ocenco EBA 6.5 SCSR was tested for maximum sustained oxygen flow rate. This was performed by disconnecting the oxygen supply line from the breathing bag, connecting it to a flow meter, and fully opening the oxygen supply valve for approximately 30 seconds. The maximum sustained oxygen flow rate was subsequently recorded and the supply valve was fully closed. The oxygen supply line was subsequently reattached securely to the breathing bag connector with a wire tie. This test is part of the approval process as described in Title 42 Code of Federal Regulations (CFR), Part 84, §84.94, gas flow test; closed-circuit apparatus. For combination constant flow and on-demand SCSR units, the approval standard requires a minimum constant flow rate of 1.5 L/min. If the maximum sustained oxygen flow rate is greater than or equal to 1.5 L/min, the unit meets this test requirement.

BMS Test

The SCSR units tested in this phase were not NIOSH-approved using the ABMS. The units were approved using man-test 4 for the stated service time (either 10 or 60 minutes), as described in 42 CFR Part 84, Subpart H. Due to resource constraints, it was not feasible to conduct man-test 4 on 400 SCSR units. The BMS test was used as a surrogate for man-test 4. The computer-controlled ABMS (Figure 5) produces CO_2 and simulates O_2 consumption at fixed breathing frequencies and tidal volumes to simulate human metabolic processes (Deno, 1984 and Kyriazi, 1986). The ABMS machine is an ideal device for evaluating inhaled CO_2 and O_2 concentrations in SCSR units due to its high degree of accuracy and repeatability in duplicating human CO_2 production and O_2 consumption. By design, an ABMS replicates breathing ventilation (respiratory frequency, tidal volume, flow, temperature, and humidity), O_2 consumption, and CO_2 production. An ABMS produces human respiratory air qualities at approximately 33°C and saturated with water vapor. Due to its complexity, an ABMS is managed by a computer program. The computer uses a routine of energy expenditures (protocol) to make adjustments and provide measurements of respiratory gas concentrations, pressures, and temperatures.

NIOSH tested the SCSR units on the ABMS using a constant average metabolic work rate test (Table 2). The constant average work rate used is similar to the 50th percentile miner (body weight of 87 kg or 192 lbs.) performing the one hour man-test 4 as described in 42 CFR Part 84, Subpart H. The ABMS was programmed to simulate human respiration at a VO_2 of 1.35 L/min, VCO_2 of 1.15 L/min, a ventilation rate of 30 L/min, and respiratory frequency of 18 breaths per minute. During testing, the ABMS monitored metabolic stressors which include inhaled levels of CO_2 and O_2, wet- and dry-bulb temperatures, and inhalation and exhalation breathing resistances (pressures) continuously until the test was terminated. Tests on the ABMS are terminated upon one of three endpoints: exhaustion of the O_2 supply as indicated by inhalation pressures reaching -200 mm H_2O, coinciding with an empty breathing bag; average inhaled CO_2 levels exceeding 10%; or O_2 levels falling below 15%. When these limits are exceeded, the ABMS gas metabolism is compromised and further data are not acceptable for analysis.

Although the average work rate is the same, LTR testing is not equivalent to approval testing. Human subjects may differ from each other and from BMS tests in terms of CO_2 production rate, ventilation rate, and respiratory frequency. These parameters affect apparatus duration as well as all of the monitored variables. Treadmill tests cannot be considered equivalent to BMS tests, even though the O_2 consumption rate is the same. However, BMS tests can be used to provide an indication of SCSR duration performance. Approval testing under 42 CFR, Part 84, Subpart H using human subjects imposes high and low work rates that the average work rate used in LTR testing does not. Also, stressor levels are continuously monitored during LTR testing, whereas they are sampled only between work activities performed by human subjects in approval testing. In addition, LTR testing continues until the apparatus is empty or stressor levels exceed allowable parameters, whereas testing during approval ends at the rated duration, even if the capacity of the apparatus exceeds it.

Figure 5. Automated Breathing and Metabolic Simulator

Table 2. Constant Average Metabolic Work Rate

Metabolic workload	Rate
O_2 Consumption	1.35 L/min
CO_2 Production Rate	1.15 L/min
Ventilation Rate	30 L/min
Tidal Volume	1.68 l/breath
Respiratory Frequency	17.9 breaths/min
Peak Respiratory Flow Rate:	
Peak Inhalation	89 L/min
Peak Exhalation	71 L/min

Units not passing the manufacturer's recommended visual inspection, exhibiting defects that are determined to be a result of insufficient quality control during the manufacturing process (i.e., not meeting the requirements of 42 CFR Part 84.41, Quality Control Plans), or not meeting the rated duration are referred to the certified product investigation process (CPIP) coordinator for investigation into the cause of these results and to determine if any further action is warranted. None of the LTR2 SCSR units referred to the CPIP coordinator for review required further action.

SCSR Stressor Test Data

NIOSH averaged the minute average values of the stressors monitored during the BMS testing of each SCSR over its rated service time in order to normalize test performance results. Use of full test duration results introduces stressor data variances that prevent valid comparisons between individual tests. NIOSH plotted all stressor data as a function of SCSR manufacturing date in order to draw out deployment time effects.

All average stressor data from the testing of deployed units were averaged for each SCSR type to obtain a composite average for comparison. This information, along with stressor minimums and maximums for each set of tests, was tabulated to assess the deployed units' performance.

Results and Discussion

SCSR Collection

NIOSH targeted 536 units deployed in United States underground coal mines for collection for LTR2. On the randomly generated collection lists, 137 units represented Ocenco EBA 6.5, 176 units represented Ocenco M-20, and 223 units represented Dräger Oxy K Plus/Oxy K Plus S models. Of the 536 units targeted, NIOSH collected 386 SCSR units at the mine. After identifying seven visual inspection failures, 379 SCSRs were returned to NPPTL for testing, yielding a collection rate of 70.7%. Figure 6 depicts the status of the 536 SCSRs targeted in the LTR2 collection. A total of 150 SCSRs were either missing or not available for various reasons including mine closure, removed from service, and not feasible to be collected (Figure 5). This amounts to 28.0% of the SCSR units on the targeted collection list.

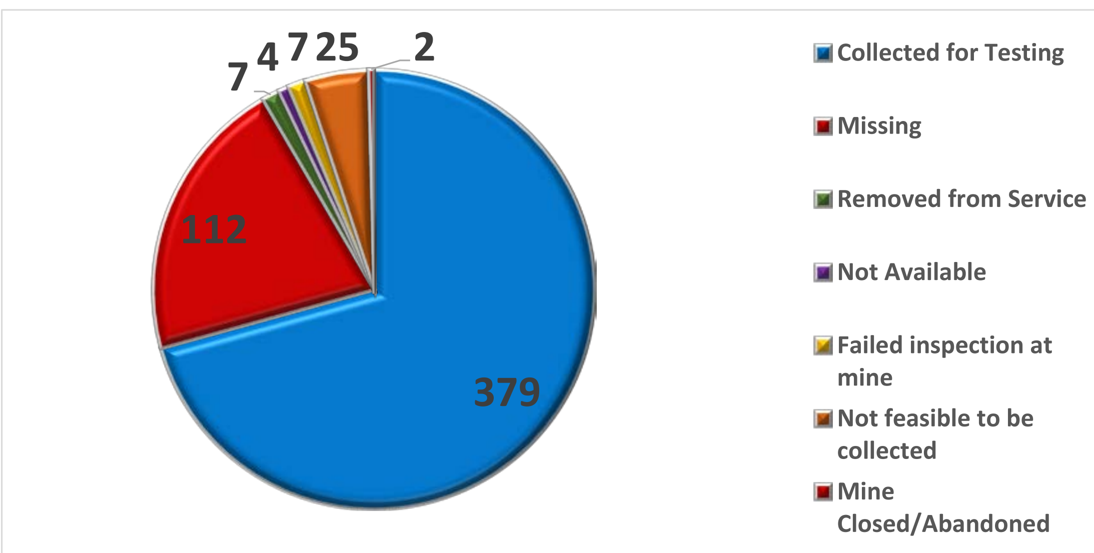

Figure 6. LTR2 Collection Dispersion

From the collection of 379 SCSR units, two units failed the visual inspection at NPPTL leaving 377 units that qualified for BMS testing. The SCSR units that qualified for BMS testing included: 163 Dräger Oxy-K Plus/Oxy K Plus S, 109 Ocenco EBA 6.5, and 105 Ocenco M-20 units (Figure 7).

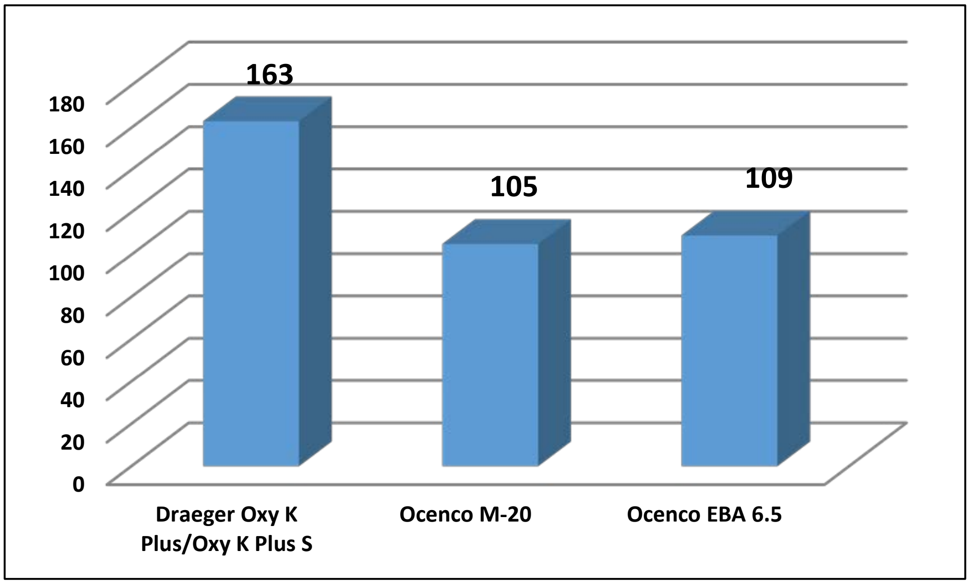

Figure 7. Dispersion of SCSRs Qualified for BMS Testing

When LTR2 collection and testing began in January, 2012, NIOSH decided to collect all SCSR units that the mines and MSHA District Offices deemed as passing visual inspection. Of the 386 SCSR units (Table 3) that were collected at the mines, seven (1.3%) failed mine visual inspection due to either damage to the unit, an open case, or a missing security seal. Out of 379 SCSR units collected and transported to NIOSH, an additional two SCSR units (0.4%) failed visual inspection when applying the manufacturer's criteria upon test initiation in the laboratory. One failure at NPPTL was due to excessive in-leakage at the collar connected to the mouthpiece. The second failure was due to the breathing hose ripping during handling for the QNT leak test. The units failing visual inspection were not evaluated further at NPPTL. From the 377 qualifying SCSR units, NIOSH obtained 358 valid sets of data.

Table 3. Test Summary for SCSR Units Passing Visual Inspection at the Mine, MSHA District Office, and NIOSH Test Laboratory

SCSR Model	Targeted	Collected at Mine	Passed Visual Inspection at Mine	Passed Visual Inspection at NIOSH Test Laboratory	Tested	Obtained Valid Test Data
Dräger Oxy K Plus	122	96	96	96	96	93
Dräger Oxy K Plus S	101	72	67	67	67	67
Ocenco EBA 6.5	137	112	111	109	109	102
Ocenco M-20	176	106	105	105	105	96
Totals	**536**	**386**	**379**	**377**	**377**	**358**

Dräger Oxy K Plus/Oxy K Plus S SCSR

One-hundred sixty-three of the 223 Oxy K Plus/Oxy K Plus S SCSR units listed on the LTR2 targeted collection list were received at NIOSH for testing. LTR2 methods called for the collection of 100 units, yielding a collection rate of 163%. The biggest challenges affecting the collection of Dräger Oxy K Plus/Oxy K Plus S SCSR units included 55 units identified as missing. This challenge resulted in 24.7% of Dräger Oxy K Plus/Oxy K Plus S SCSR units on the targeted collection list being unavailable. The remaining units were not collected for the reason listed as failure of visual inspection at the mine (5).

All 163 Dräger Oxy K Plus/Oxy K Plus S SCSR units tested passed the manufacturer's visual inspection at the NIOSH laboratory (Figure 8). Valid test data was obtained for 93 of the 96 Dräger Oxy K Plus and all Dräger Oxy K Plus S SCSR units. The three invalid tests were due to ABMS operational issues. None of the Dräger Oxy K Plus/Oxy K Plus S SCSR units returned to the NIOSH laboratory for testing failed the phenolphthalein indicator test.

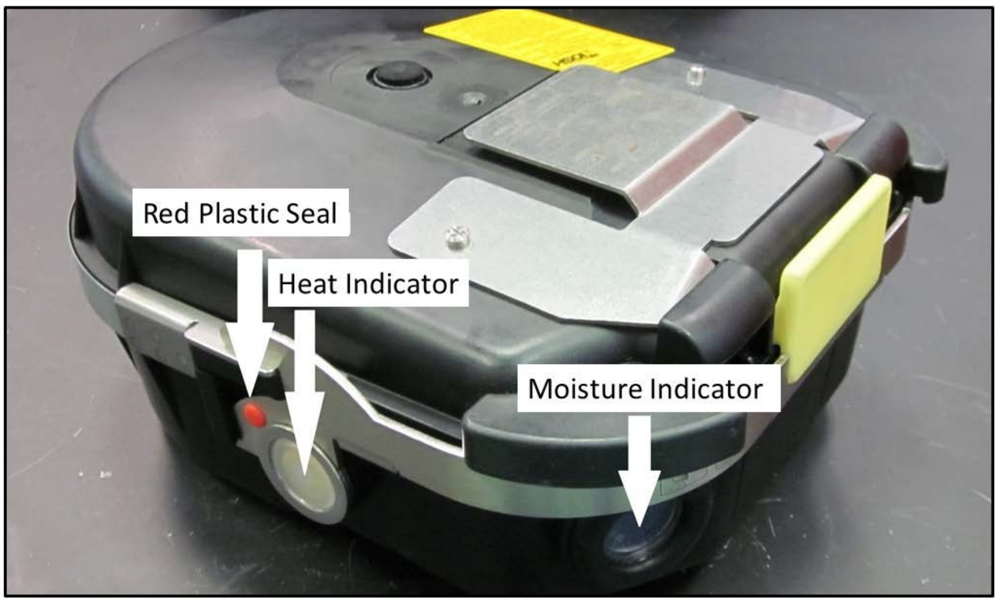

Figure 8. Areas of Visual Inspection for Dräger Oxy K Plus SCSR

The breathing circuit integrity check of the Dräger Oxy K Plus SCSR using the QNT leak test procedure showed that 91 of 93 SCSR units for which valid data was obtained had a leak rate less than 100 ml/min and all had leak rates less than 500 ml/min. The breathing circuit integrity check of the Dräger Oxy K Plus S SCSR using the QNT test procedure showed that 63 of the 67 units tested had a leak rate less than 100 ml/min and 66 of 67 SCSR units had a leak rate less than 500 ml/min.

After test initiation on the ABMS, all SCSR units continued operating until the breathing gas supply was expended. All but one Dräger Oxy K Plus SCSR and all Dräger Oxy K Plus S met or exceeded the NIOSH approved 60 minute service time. The average duration for Dräger Oxy K Plus and Dräger Oxy K Plus S SCSRs tested was 84.8 and 83.4 minutes, respectively.

NIOSH personnel averaged the minute-average values of the stressors monitored during BMS testing of the Dräger Oxy K Plus/Oxy K Plus S SCSR units over the first 60 minutes of the test and the results are presented graphically in Appendix A (Figures 9 through 14). Sixty minute data averaging, consistent with service time, was chosen to eliminate the test duration variability effect in the determination of stressor levels. The deployed Dräger Oxy K Plus/Oxy K Plus S SCSR unit stressor results were sorted within each composite graph by manufacturing dates which ranged in age from oldest to newest, left to right. A linear regression was fit to each stressor plotted from Dräger Oxy K Plus/Oxy K Plus S SCSR testing to draw out the effects of deployment time. No major trends in measured stressors that could be attributed to deployment time were identified.

Test Duration and composite mean stressor levels, including FIO2 (mole fraction inspired oxygen, FICO2 (mole fraction inspired carbon dioxide), PEPRS (peak expired pressure), PIPRS (peak inspired pressure), and TAVGDB (average dry bulb temperature), are shown for the deployed Dräger Oxy K Plus/Oxy K Plus S SCSR units in Table 4. Dräger Oxy K Plus and Oxy K Plus S SCSR units are functionally identical except for the opening procedure. As would be expected, average stressor levels measured for the Oxy K Plus and Oxy K Plus S SCSR units were very similar.

Table 4. Dräger Oxy K Plus/Oxy K Plus S Deployed SCSR Unit Duration and Composite Mean Stressor Levels

	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
Oxy K Plus Deployed Unit Data (93 tests)						
MIN	54	0.6936	0.0070	34.04	-76.98	36.24
MAX	90	0.8950	0.0203	55.98	-43.03	41.85
AVERAGE	84.8	0.8403	0.0089	40.20	-50.65	39.22
Oxy K Plus S Deployed Unit Data (67 tests)						
MIN	68	0.7120	0.0066	31.48	-60.31	30.67
MAX	89	0.8613	0.0139	56.55	-39.88	41.94
AVERAGE	83.4	0.8262	0.0094	38.91	-49.07	38.22

Ocenco EBA 6.5 SCSR

Of the 137 EBA 6.5 SCSR units listed on the LTR2 targeted collection list, 111 were returned to NIOSH for testing. This yielded a collection rate of 111% when compared to LTR2 collection methods calling for the collection of 100 units. Challenges affecting the collection of Ocenco EBA 6.5 SCSR units included missing units or unavailable units accounting for 16 SCSR units. These two challenges resulted in 11.7% of Ocenco EBA 6.5 SCSR units on the targeted collection list being unavailable. The remaining units were not collected and returned for reasons listed as bad communication (6), failure of visual inspection at the mine (1), out for repair (1), no record (1), and removed from service (1).

All but two of the 111 Ocenco EBA 6.5 SCSR units returned for testing passed the manufacturer's visual inspection at NPPTL. The failures were due to excessive in-leakage observed at the collar connected to the mouthpiece and the breathing hose ripping during handling during QNT leak tests. This means that 98.2% of the EBA 6.5 SCSR units that passed the manufacturer's visual inspection at the mine also passed visual inspection at NIOSH. Valid test data was obtained for 102 of the 109 Ocenco EBA 6.5

SCSR units that were tested. The invalid tests were due to ABMS operational issues. None of the Ocenco EBA 6.5 SCSR units returned to the NIOSH laboratory for testing failed the phenolphthalein indicator test.

The breathing circuit integrity check of the Ocenco EBA 6.5 using the QNT leak test procedure showed that 64 of 102 SCSR units tested had a leak rate less than 100 ml/min and 95 of 102 SCSR units had a leak rate of less than 500 ml/min.

After test initiation on the ABMS, all SCSR units continued operating until the breathing gas supply was expended. All SCSR units met or exceeded their NIOSH-approved 60 minute service time with no critical failures. The average duration for all Ocenco EBA 6.5 SCSR units was 102 minutes.

All Ocenco EBA 6.5 SCSR units were subsequently evaluated for maximum sustained oxygen flow rate. The flow rates ranged from 1.69 to 1.98 liters per minute at ambient temperature and pressure. Approval test requirements specify a minimum sustained flow rate of 1.5 LPM; therefore, all Ocenco EBA 6.5 SCSRs passed the oxygen flow test.

NIOSH averaged the minute-average values of the stressors monitored during BMS testing of the Ocenco EBA 6.5 SCSR units over the first 60 minutes of the test and the results are presented graphically in Appendix B (Figures 15 through 20). Sixty minute data averaging, consistent with service time, was chosen to eliminate the test duration variability effect in the determination of stressor levels. NIOSH sorted the deployed Ocenco EBA 6.5 SCSR unit stressor results within each composite graph by manufacturing dates which range in age from oldest to newest, left to right. A linear regression was fit to each stressor plotted from SCSR testing to draw out the effects of deployment time. As can be seen in Figures 28 and 29, breathing resistance increased slightly as a function of deployment time for the Ocenco EBA 6.5 SCSR.

Test Duration and composite average stressor levels, including FIO2, FICO2, PEPRS, PIPRS, and TAVGDB, are shown for the deployed Ocenco EBA 6.5 SCSR units in Table 5.

Table 5. Ocenco EBA 6.5 Deployed SCSR Unit Duration and Composite Mean Stressor Levels

	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
M-20 Deployed Unit Data (102 tests)						
MIN	74	0.3236	0.0011	35.03	-87.98	38.20
MAX	110	0.9270	0.0068	71.87	-38.33	43.99
AVERAGE	102.1	0.5364	0.0030	45.50	-47.47	41.02

Ocenco M-20 SCSR

One hundred five of the 176 Ocenco M-20 SCSR units listed on the LTR2 targeted collection list were returned to NIOSH. This yielded a collection rate of 105% when compared to LTR2 methods calling for the collection of 100 units. Challenges affecting the collection of Ocenco M-20 SCSR units included: insufficient communications with mines (10) and missing units (42). These two challenges alone resulted in 29.5% of Ocenco M-20 SCSR units on the targeted collection list being unavailable. The remaining units were not collected and returned for reasons listed as removed from service (6), no record (4), unavailable (3), out for repair (3), mine closed/abandoned (2), and failed visual inspection at mine (1).

All of the 105 Ocenco M-20 SCSR units that were returned for testing passed the manufacturer's visual inspection at NPPTL. Valid test data was obtained for 96 of the 105 Ocenco M-20 SCSR units tested. Eight of the nine tests were deemed to be invalid due to ABMS operational issues. The ninth invalid test was due to data acquisition system issues. None of the Ocenco M-20 SCSR units returned to the NIOSH laboratory for testing failed the phenolphthalein indicator test.
The breathing circuit integrity check of the Ocenco M-20 SCSR units using the QNT leak test procedure showed that 71 of 96 SCSR units tested had a leak rate less than 100 ml/min and 94 of 96 SCSR units had a leak rate of less than 500 ml/min.

After test initiation on the ABMS, all but one Ocenco M-20 SCSR continued operating until the breathing gas supply was exhausted. Testing of this one unit was stopped after 7 minutes because the breathing bag was empty and the inspired O_2 level decreased to less than 7.0%. All but one M-20 SCSR unit exceeded their NIOSH-approved 10 minute service time. The average duration for all Ocenco M-20 SCSR units was 17.6 minutes.

During BMS testing, NIOSH noted that 40 of the 96 M-20 SCSR units tested exceeded 4% CO_2 prior to oxygen expenditure (Table 6). However, none of these 40 exceeded 4% CO_2 before the 10-minute service time was reached.

Table 6. Ocenco M-20 SCSR 4% Carbon Dioxide Breakthrough Times

4% CO_2 Breakthrough Time, minutes	Test Duration, minutes	Maximum CO_2, Volume %
10	15	10.1
13	17	7.1
14	18	5.63
15	18	5.59
15	19	7.11
15	18	5.38
15	15	4.76
15	15	4.09
15	16	4.85
15	17	6.24
16	18	5.03
16	20	7.96
16	17	4.83
16	18	4.68
16	19	7.23
16	16	4.06
17	19	6.19
17	18	4.76
17	17	4.37
17	18	4.33

17	19	5.18
17	20	6.19
17	18	5.19
17	18	4.97
17	18	4.85
17	18	4.96
17	19	5.07
17	20	5.55
17	18	4.63
17	20	7.68
18	18	4.07
18	18	4.62
18	18	4.96
18	19	4.69
18	18	4.04
18	18	4.46
19	20	4.95
19	19	4.89
19	19	4.31
20	20	4.46

NIOSH averaged the minute-average values of the stressors monitored during BMS testing of the Ocenco M-20 SCSR units over the first 10 minutes of the test. The results appear graphically in Appendix C (Figures 21 through 26). Ten minute data averaging, consistent with service time, was chosen to eliminate the test duration variability effect in the determination of stressor levels. NIOSH sorted the deployed Ocenco M-20 SCSR unit stressor results within each composite graph by manufacturing dates which range in age from oldest to newest, left to right. A linear regression was fit to each stressor plotted from Ocenco M-20 SCSR testing to draw out the effects of deployment time. No major trends in measured stressors that could be attributed to deployment time were identified.

Test Duration and composite average mean stressor levels, including FIO2, FICO2, PEPRS, PIPRS, and TAVGDB, are shown for the new and deployed Ocenco M-20 SCSR units in Table 7.

Table 7. Ocenco M-20 Deployed SCSR Unit Duration and Composite Mean Stressor Levels

	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
M-20 Deployed Unit Data (96 tests)						
MIN	**7**	**0.2285**	**0.0018**	**23.67**	**-112.31**	**38.99**
MAX	**21**	**0.8092**	**0.0155**	**53.33**	**-20.61**	**44.84**
AVERAGE	**17.6**	**0.4441**	**0.0069**	**32.21**	**-58.18**	**42.34**

Conclusions

<u>Mine Operators</u>

All 358 SCSR units that obtained valid test data provided sufficiently high inhaled O_2 levels to sustain life over the course of the manufacturers' specified service time. These 358 SCSR units also provided sufficiently low inhaled CO_2 levels to sustain life over the course of the manufacturers' specified service time. Breathing resistances measured for all SCSRs tested were well within limits accepted as tolerable (-300 and +200 mm H_2O) based on research conducted at Noll Laboratory at Penn State University. While only 2.3% of the SCSR units collected at the mines did not meet the visual inspections, miners should continue to inspect their units daily to ensure units not meeting visual inspection are removed from the mines. Overall, only slight degradation in SCSR performance due to deployment time in the mines was observed.

SCSR Manufacturers

A high degree of variability was observed in inhaled O_2 levels for all but one manufacturer's SCSR unit. Inhaled O_2 levels are sensitive to N_2 imbalances in and in-leakage of air into the ABMS breathing circuit. The wide range of inhaled O_2 levels measured for all deployed unit tests may be attributable to these sensitivities.

During BMS testing, 40 of 96 of one manufacturer's SCSR units tested exceeded 4% CO_2 prior to oxygen expenditure; however, none of these 40 units exceeded 4% CO_2 before the service time was reached. NIOSH recognized this potential hazard and new 42 CFR, Part 84 Subpart O regulations for all SCSRs sold after January 4, 2018 prohibit approval of an apparatus that operates with inspired CO_2 levels above 4.0%. SCSR units fail this test and approval if from test start-up to oxygen depletion the one-minute average inspired $CO_2 \geq 4.0\%$.

The inspired breathing resistance of one manufacturer's SCSR increased slightly as a function of mine deployment time. No definite trends in other stressors as a function of deployment time for any other manufacturer' SCSR units were identified. This is an indication that the SCSR units targeted for collection in LTR2 were mainly not affected by deployment time.

Appendix A: Acronyms and Abbreviations

Acronyms and Abbreviations

ABMS	automated breathing and metabolic simulator
BMS	breathing and metabolic simulation
CO	carbon monoxide
CO_2	carbon dioxide
CPIP	certified product investigation process
FICO2	mole fraction inspired carbon dioxide
FIO2	mole fraction inspired oxygen
LTFE	long-term field evaluation
LTR	long-term random field evaluation
MSHA	Mine Safety and Health Administration
N_2	Nitrogen
NIOSH	National Institute for Occupational Safety and Health
NPPTL	National Personal Protective Technology Laboratory
O_2	oxygen
OSHA	Occupational Safety and Health Administration
QNT	quantitative leak test
PEPRS CMH20	peak expired pressure, centimeters of water
PIPRS CMH20	peak inspired pressure, centimeters of water
SCSR	self-contained self-rescuer
TAVGDB	average dry bulb temperature over entire breath, ^oC
TLV	threshold limit value
VCO_2	volume of carbon dioxide
VO_2	volume of oxygen

Unit of Measure Abbreviations

breaths/min	breaths per minute
kg	kilogram(s)
L	liter(s)
L/breath	liter(s) per breath
lb	pound(s)
LPM	liter(s) per minute
mL/min	milliliter(s) per minute
mm	millimeter(s)
mm H_2O	millimeter(s) of water pressure
%	percent
ppm	parts per million

Appendix B: BMS Testing of the Dräger Oxy K Plus/Oxy K Plus S SCSR Stressors

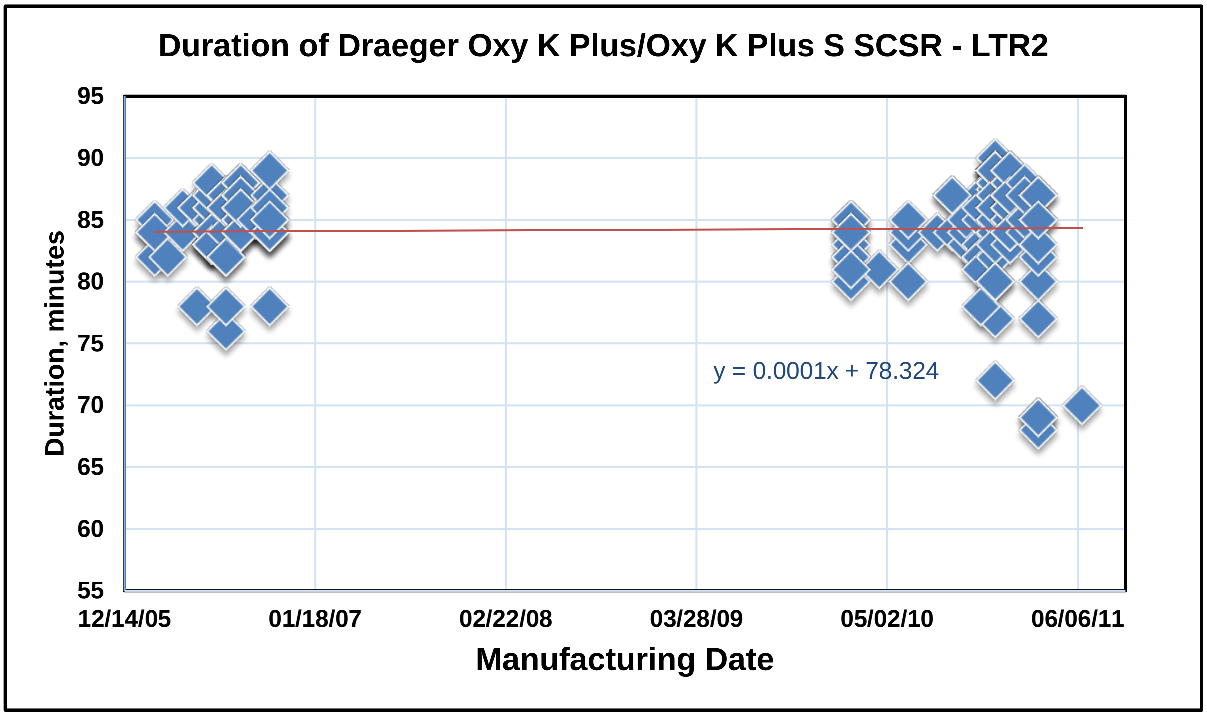

Figure 9. Duration of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

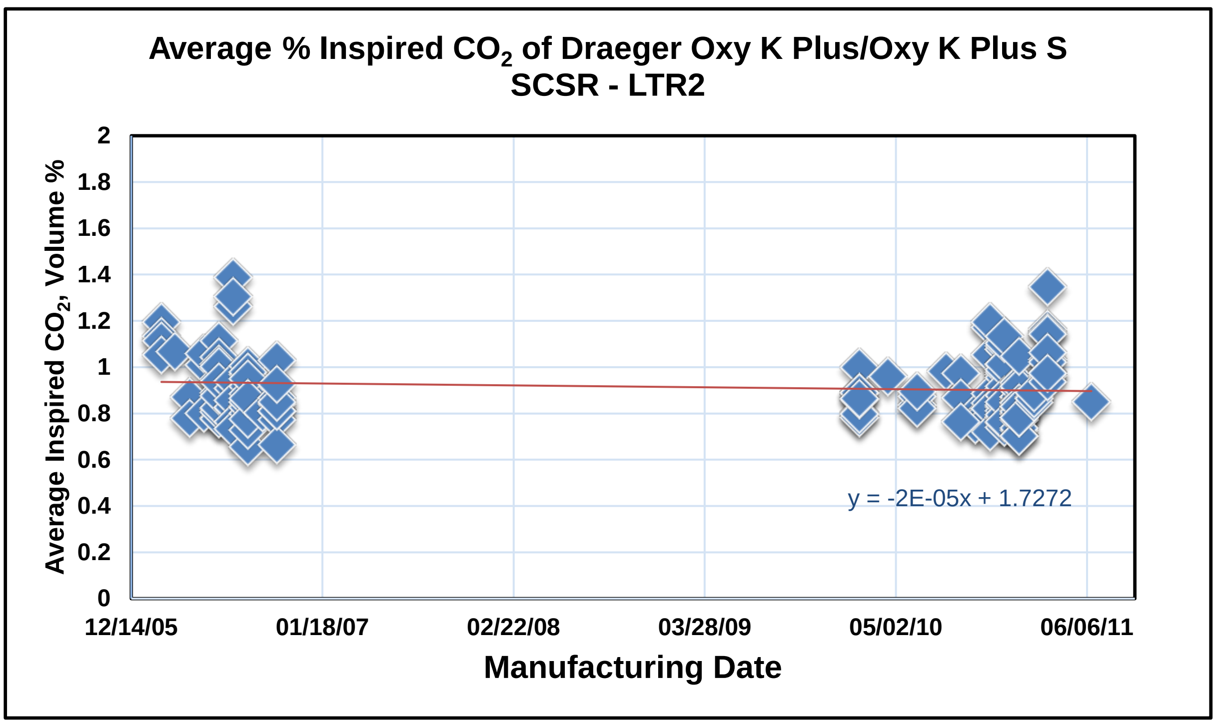

Figure 10. 60-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

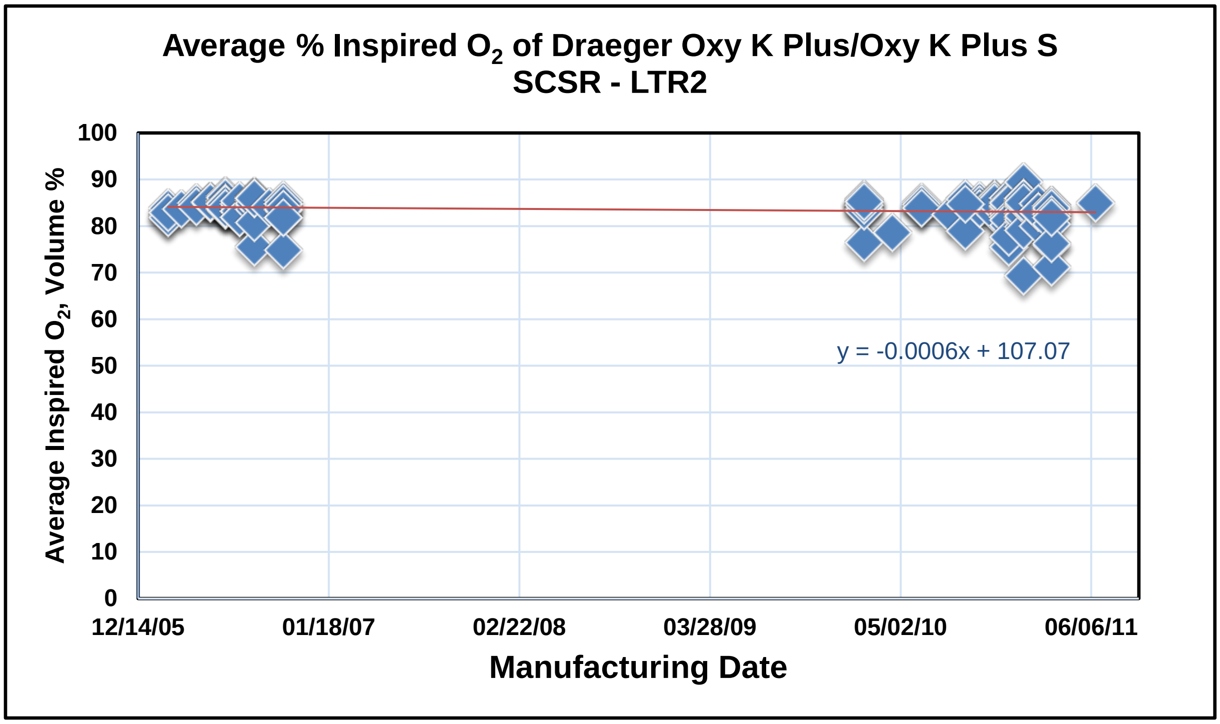

Figure 11. 60-Minute Average Percent Inspired Oxygen of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

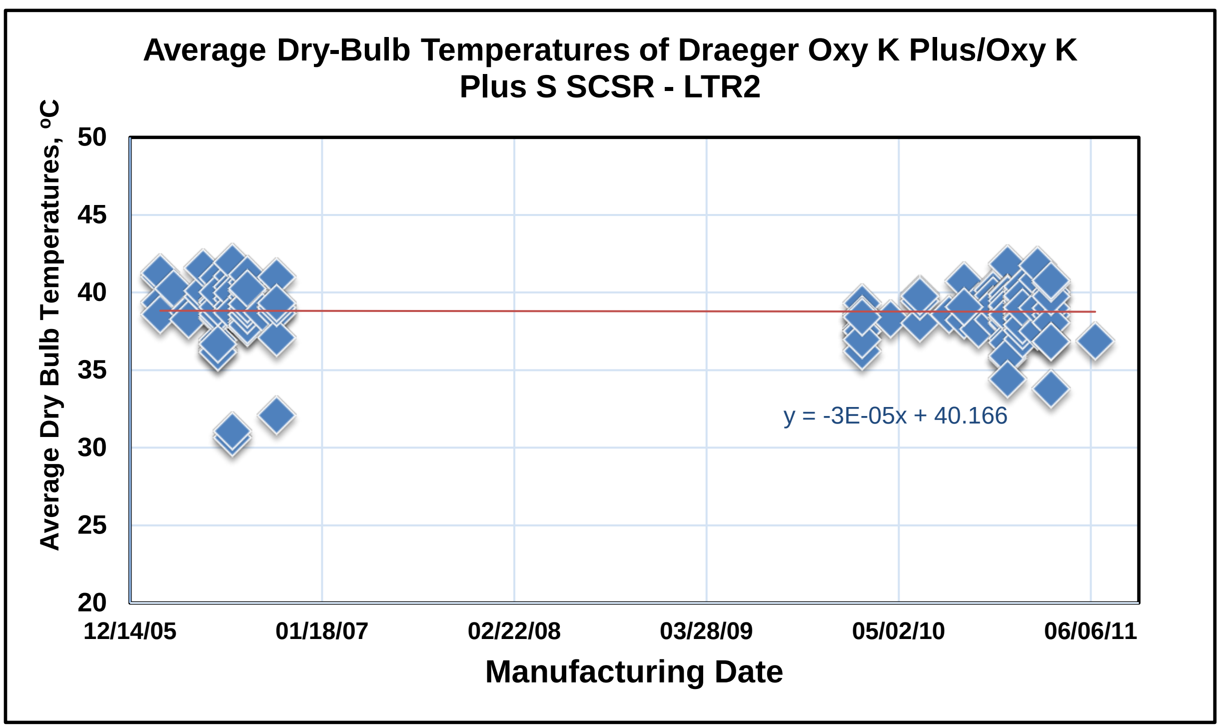

Figure 12. 60-Minute Average Dry-Bulb Temperatures of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

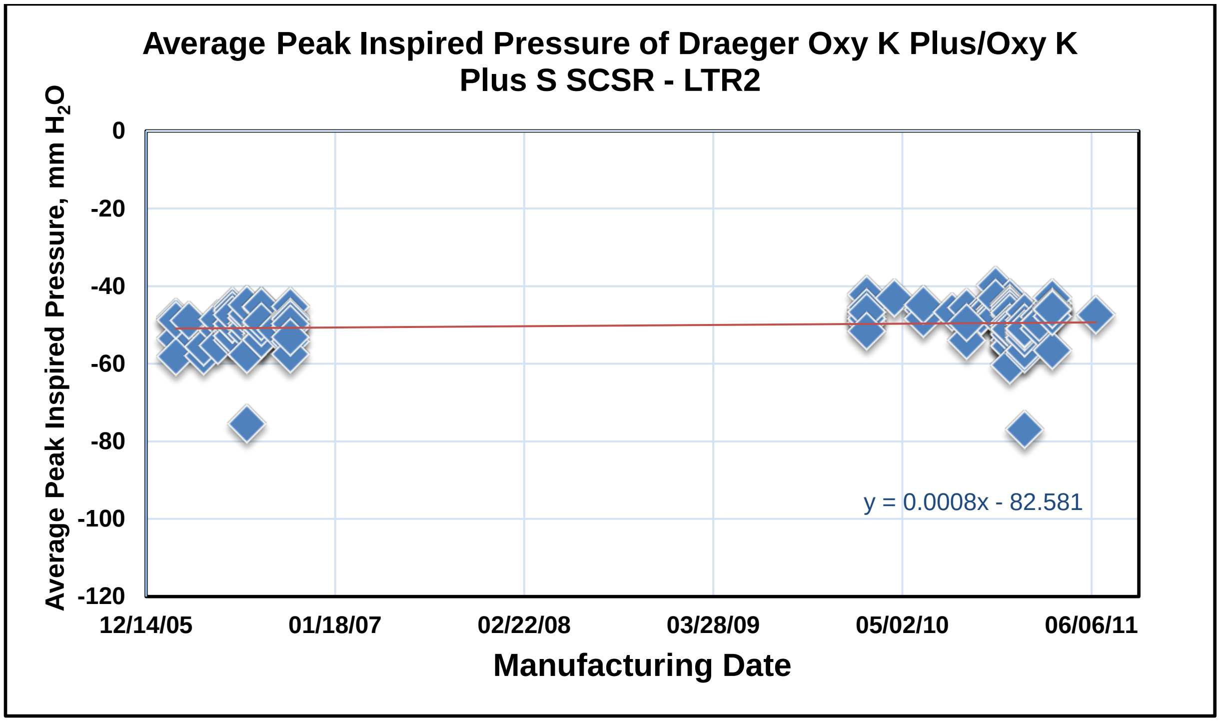

Figure 13. 60-Minute Average Peak Inspired Pressure of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

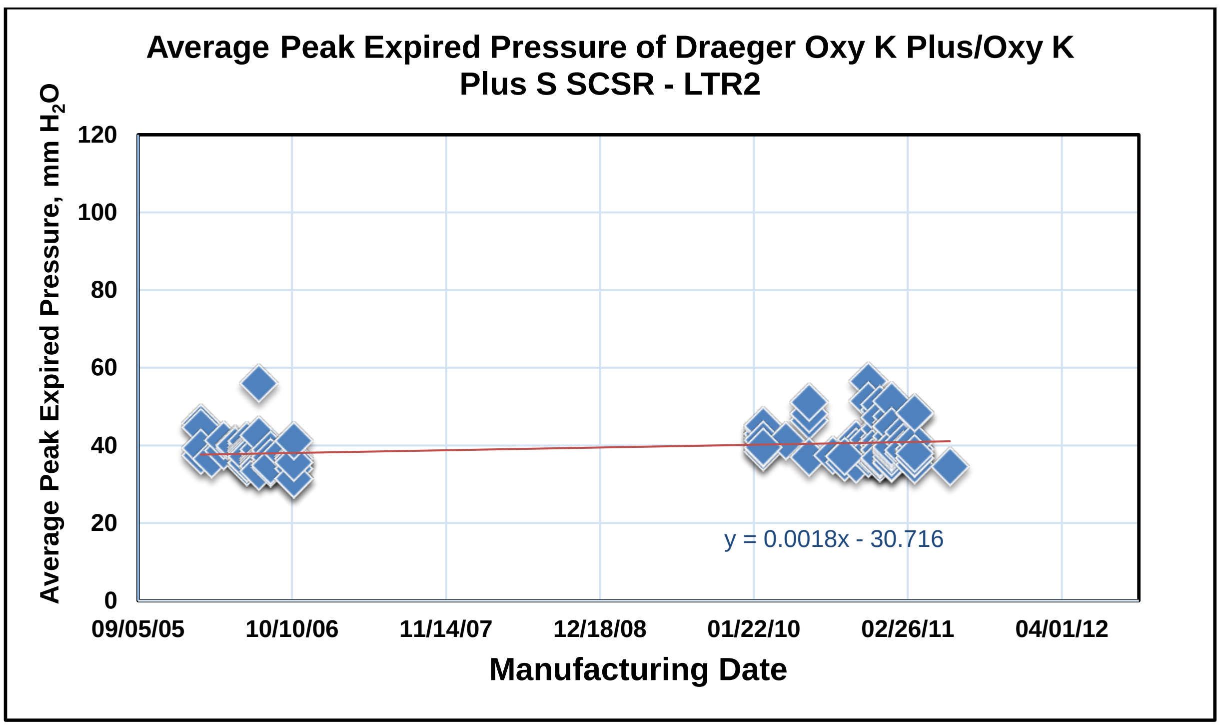

Figure 14. 60-Minute Average Peak Expired Pressure of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

Appendix C: BMS Testing of the Ocenco EBA 6.5 SCSR Stressors

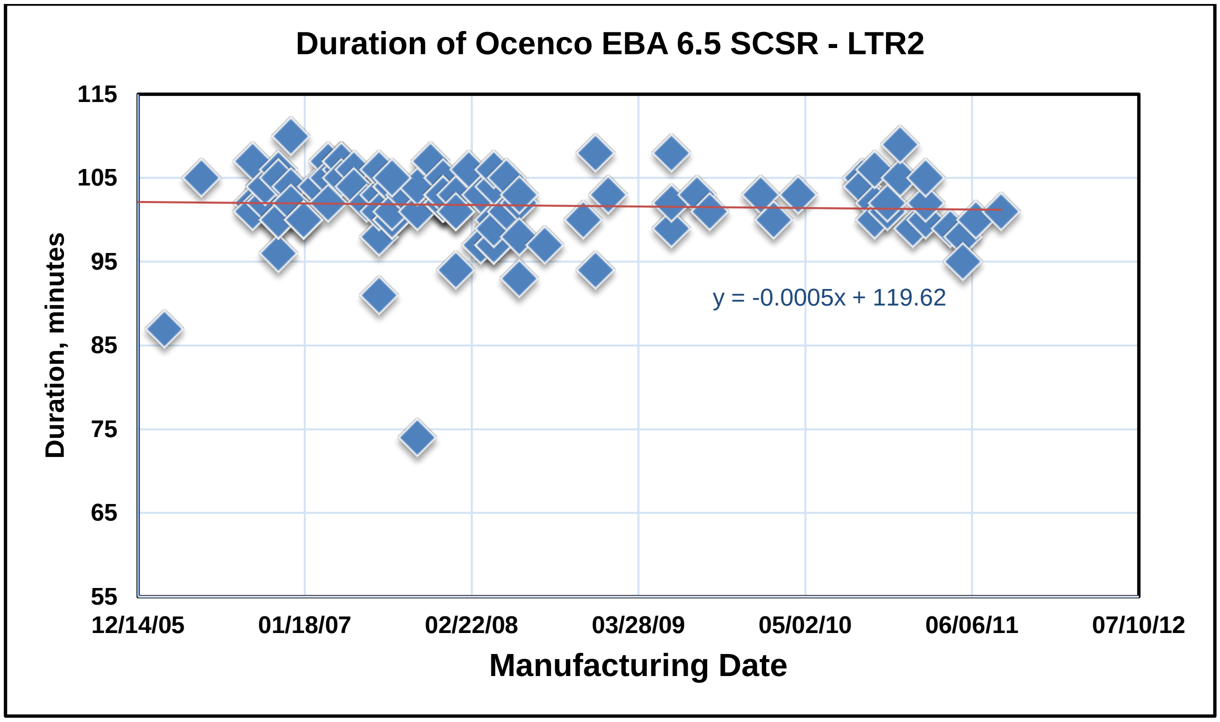

Figure 15. Duration of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

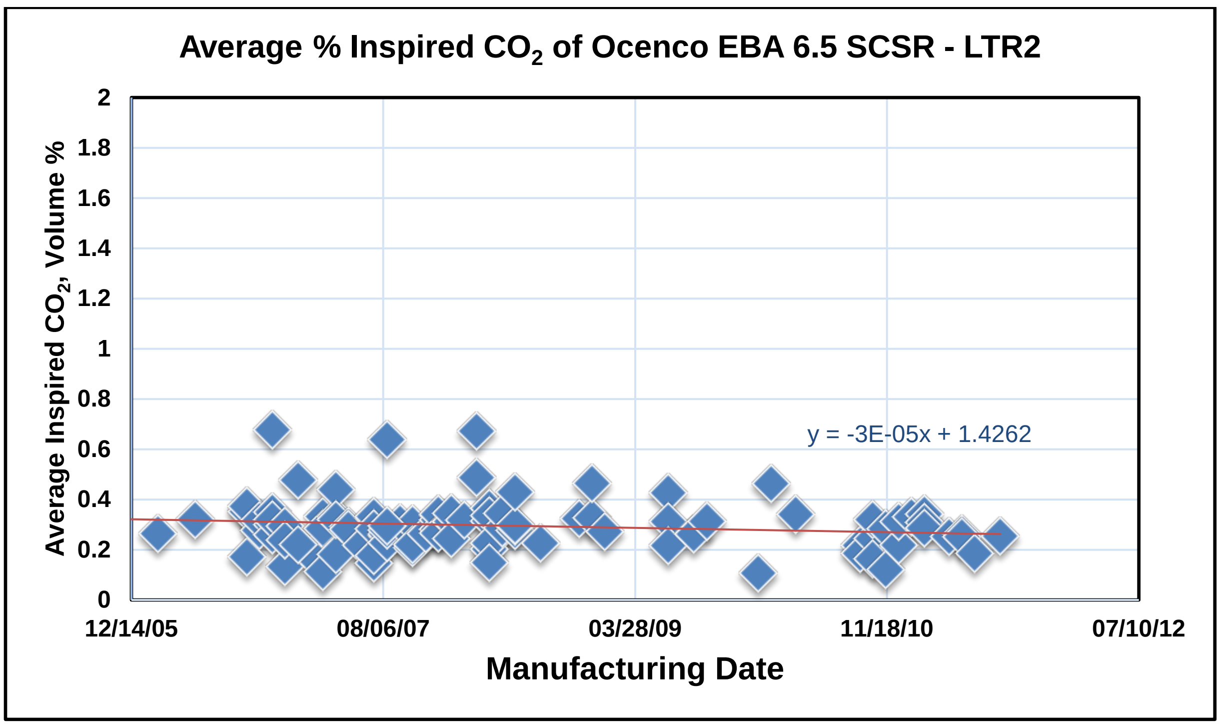

Figure 16. 60-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

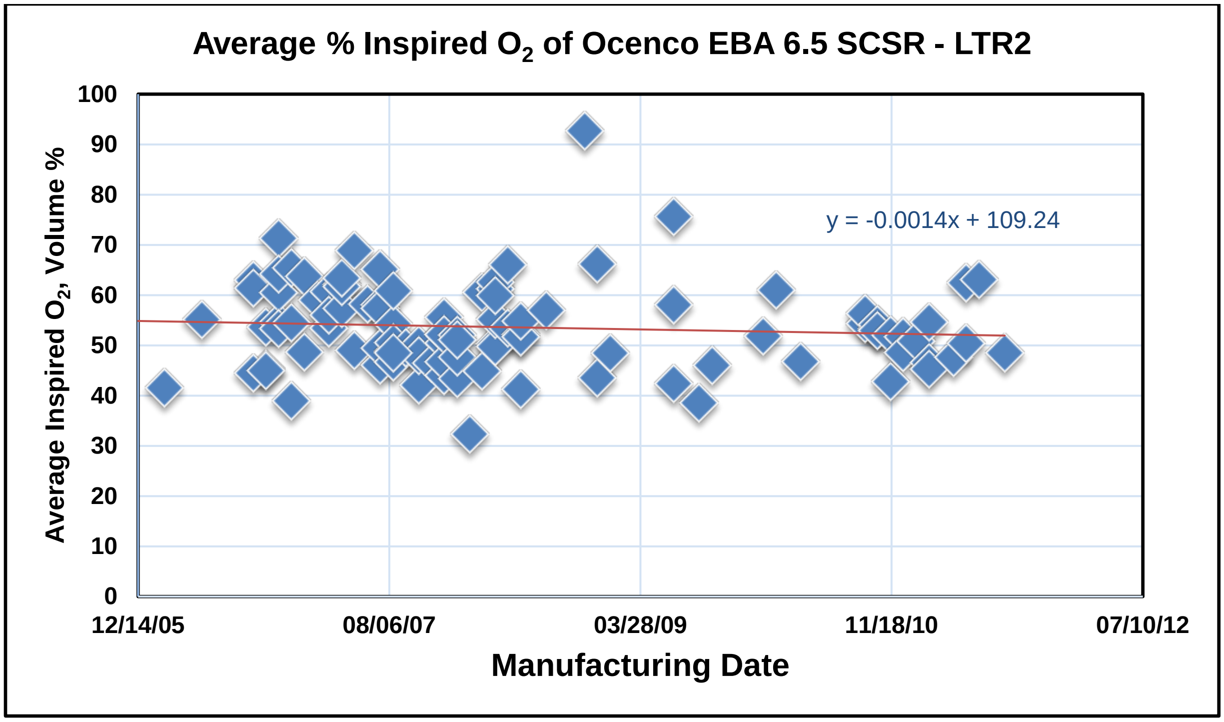

Figure 17. 60-Minute Average Percent Inspired Oxygen of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

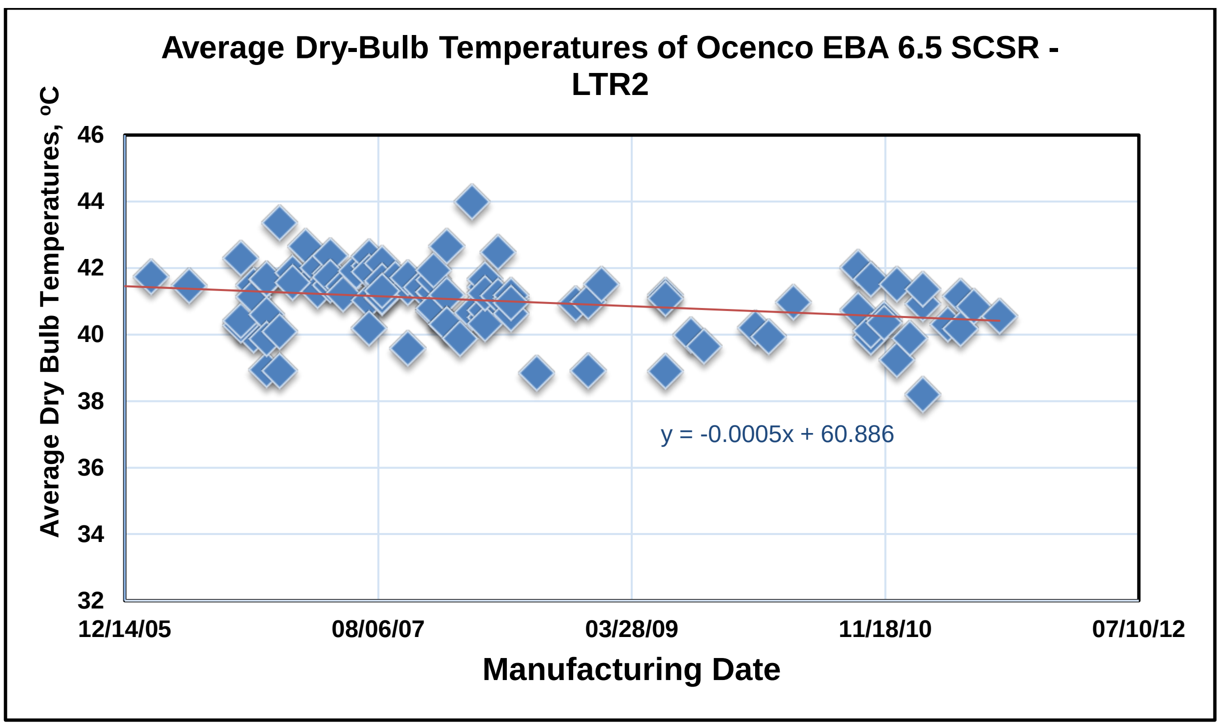

Figure 18. 60-Minute Average Dry-Bulb Temperatures of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

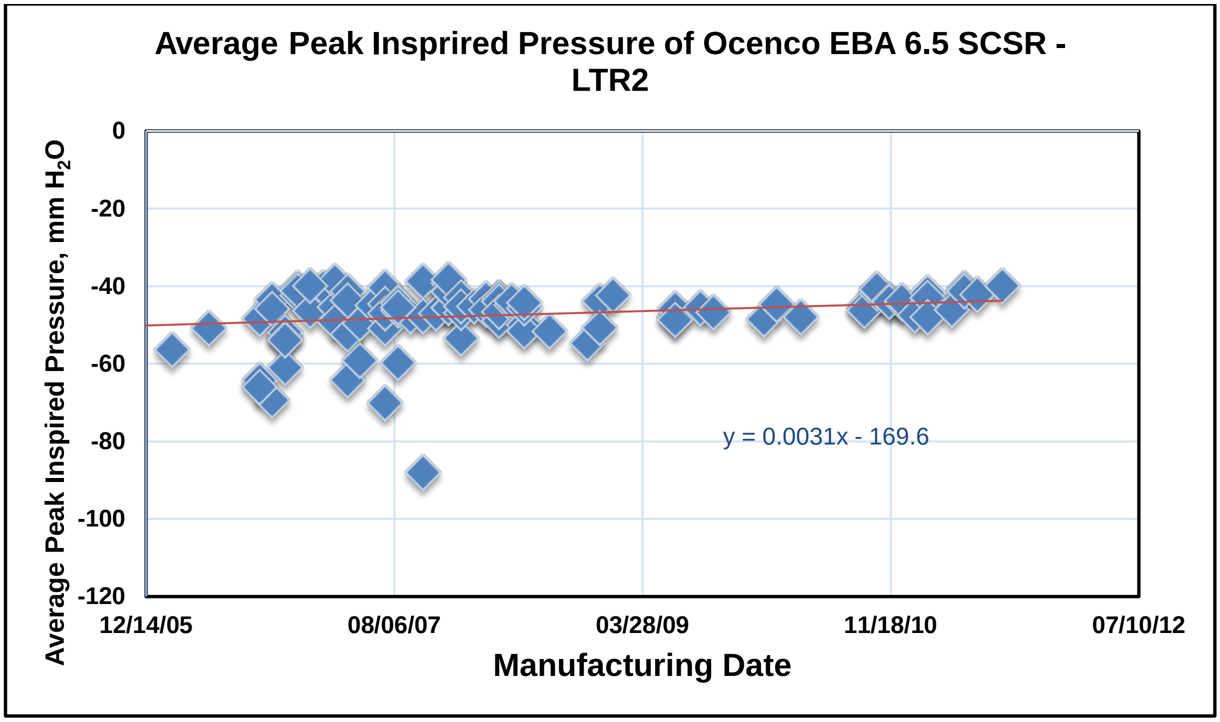

Figure 19. 60-Minute Average Peak Inspired Pressure of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

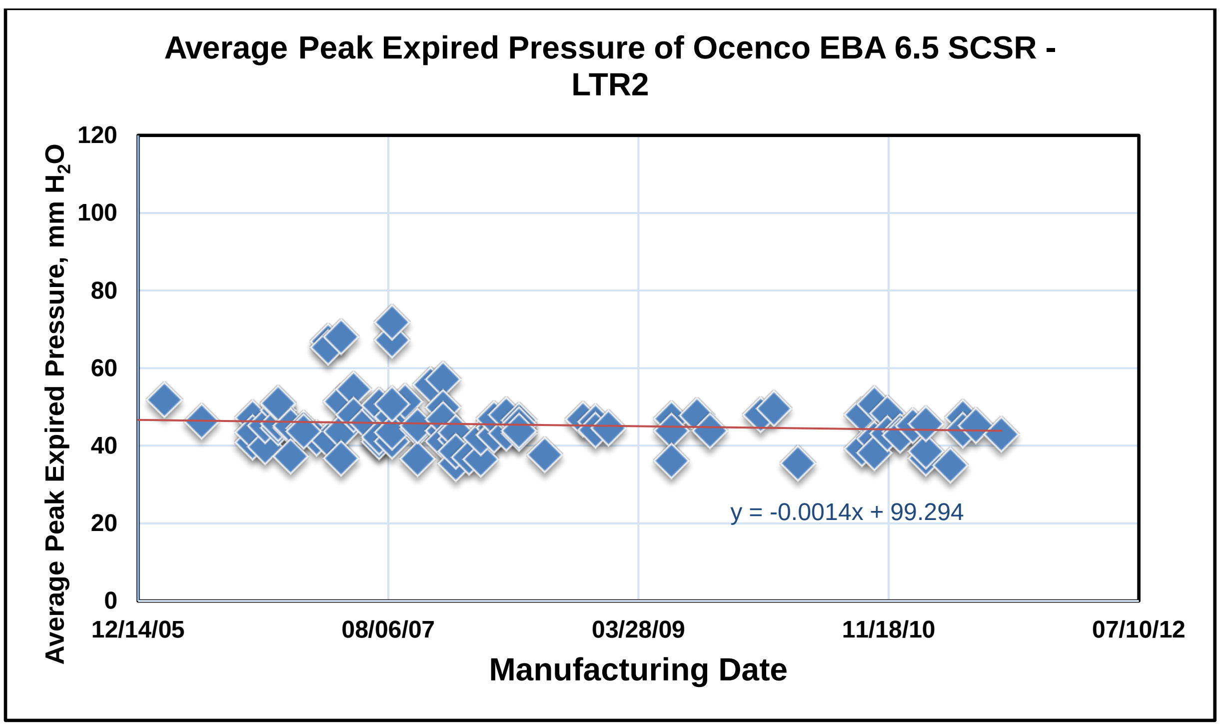

Figure 20. 60-Minute Average Peak Expired Pressure of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

Appendix D: BMS Testing of the Ocenco M-20 SCSR Stressors

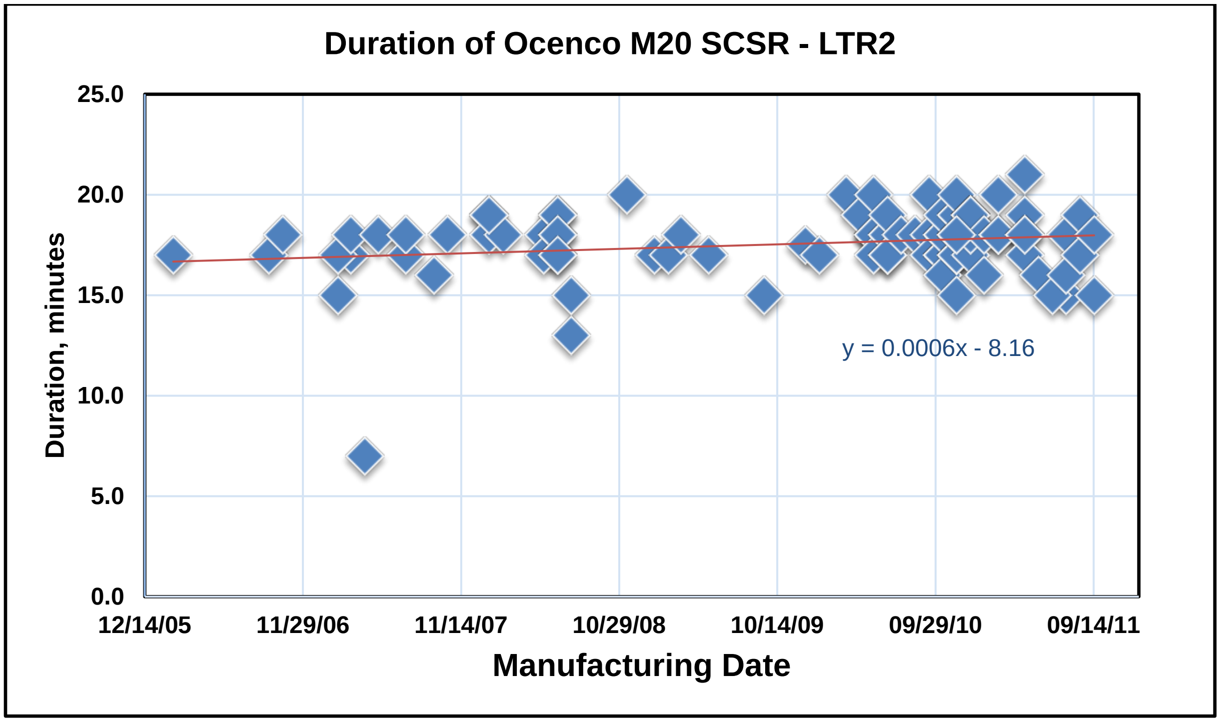

Figure 21. Duration of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

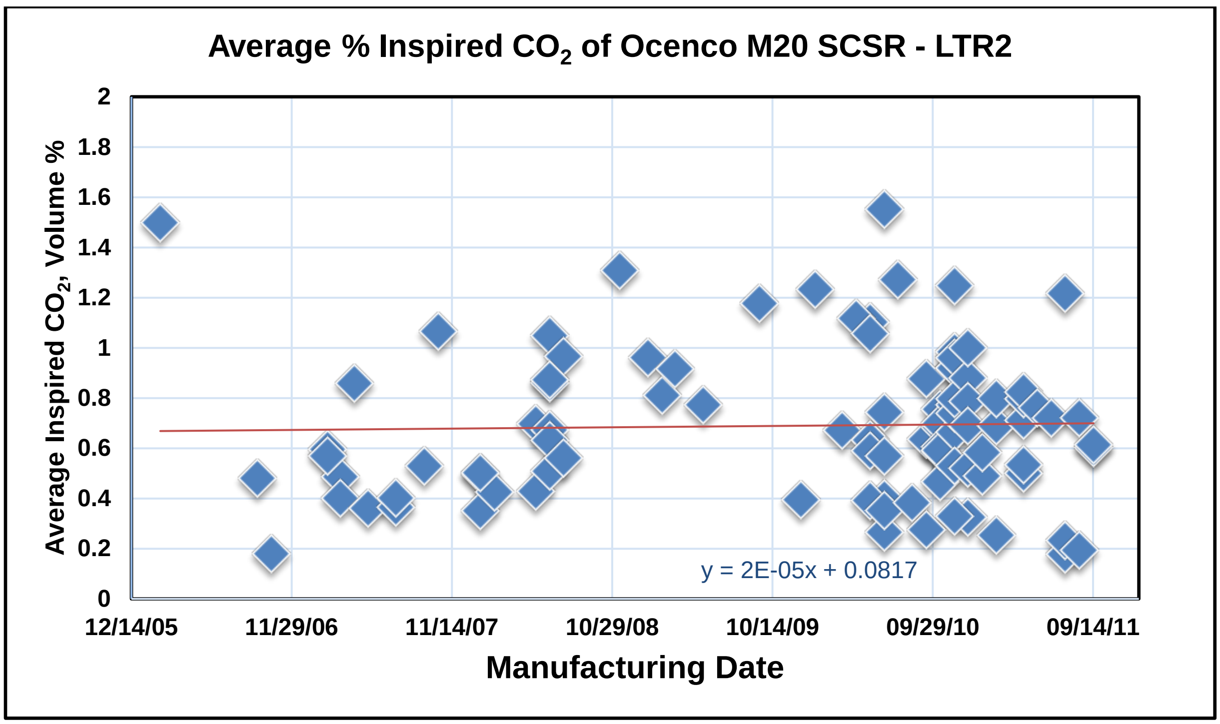

Figure 22. 10-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

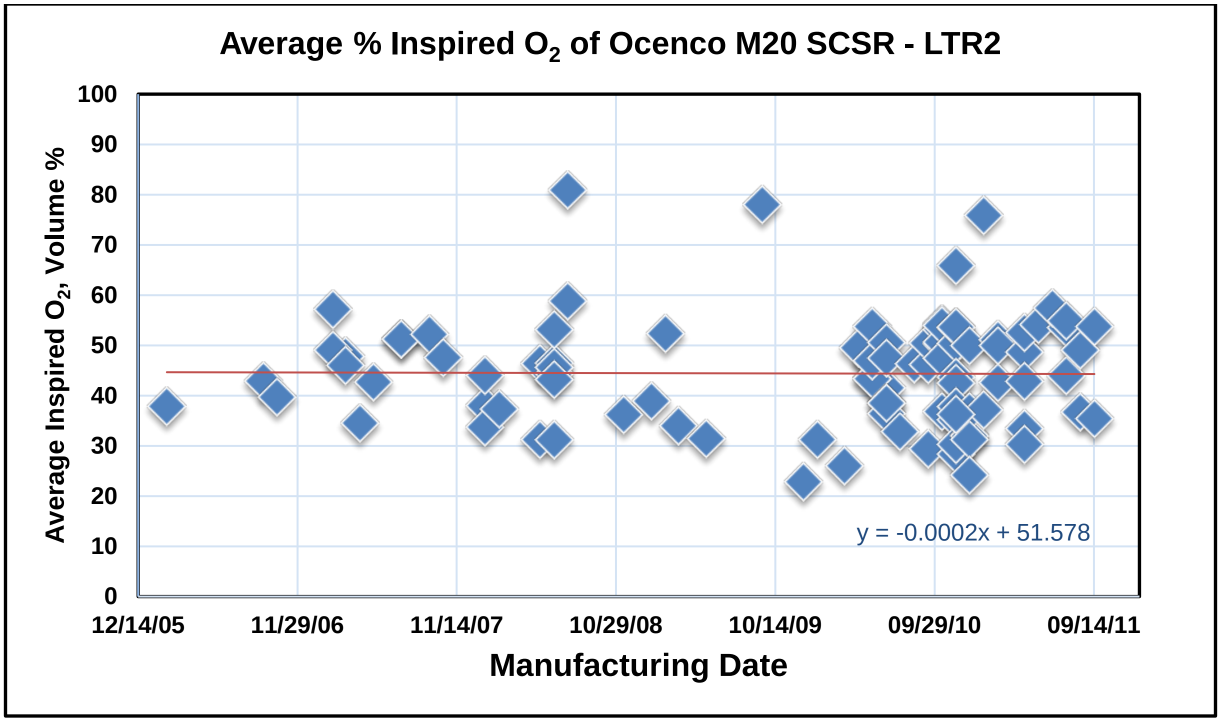

Figure 23. 10-Minute Average Percent Inspired Oxygen of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

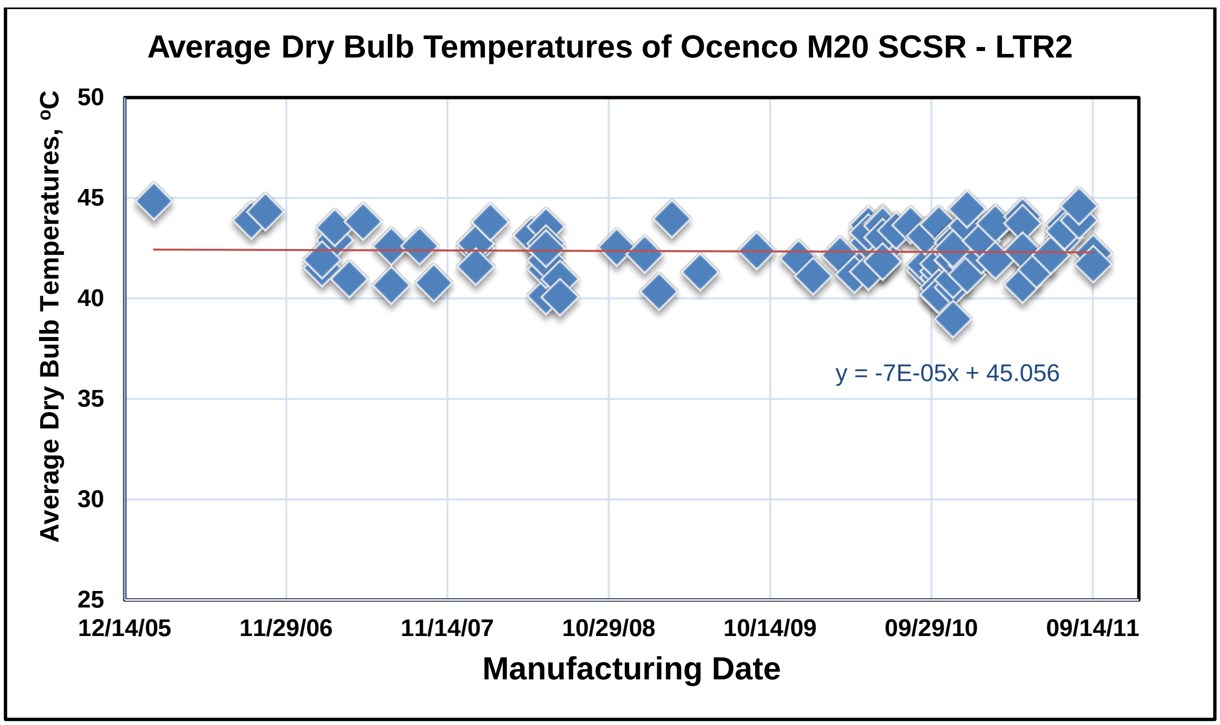

Figure 24. 10-Minute Average Dry-Bulb Temperatures of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

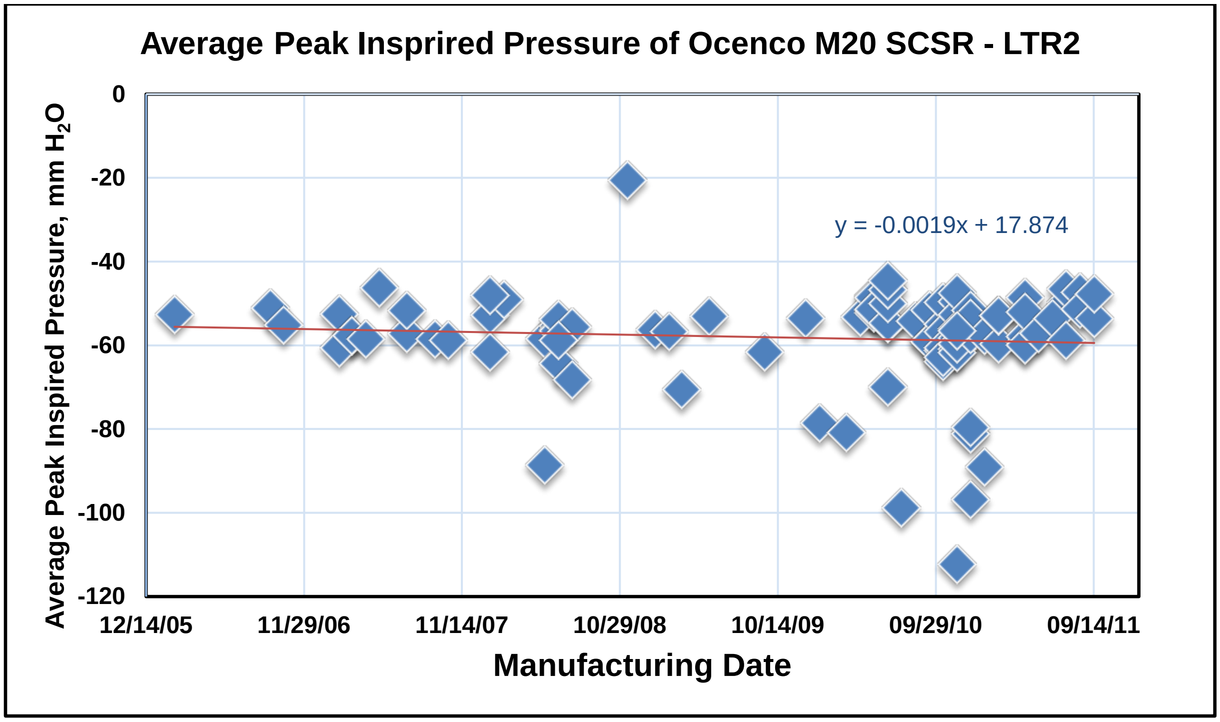

Figure 25. 10-Minute Average Peak Inspired Pressure of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

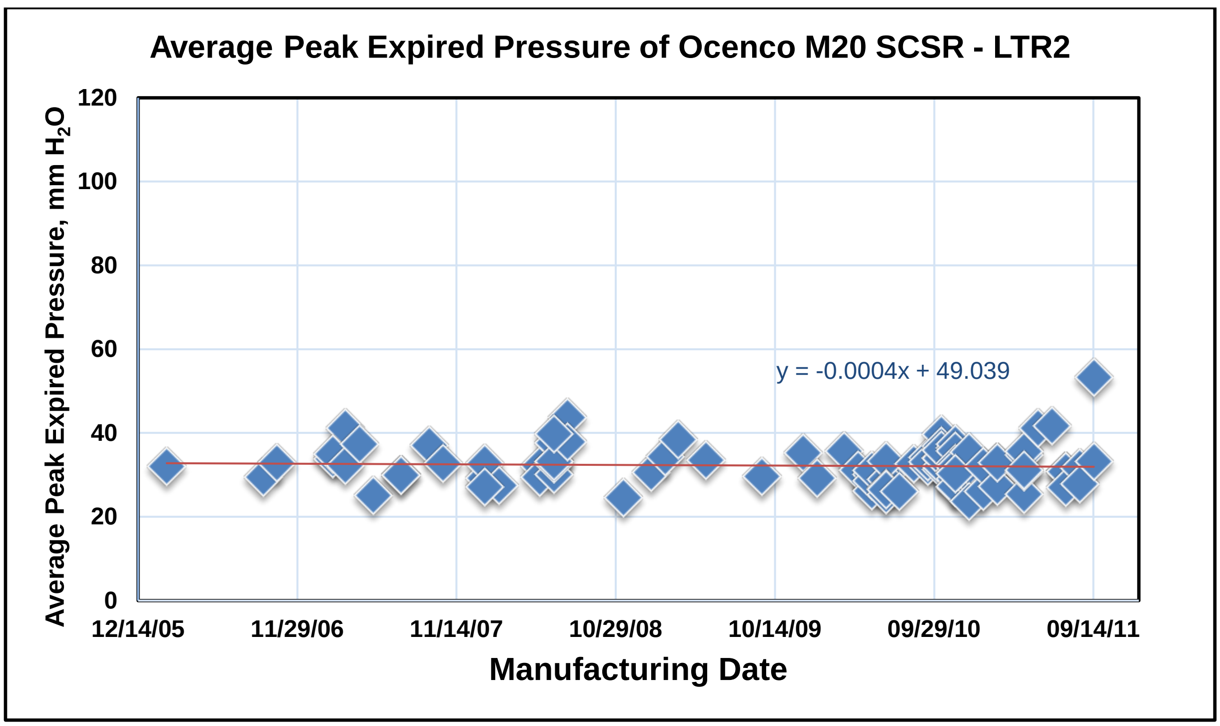

Figure 26. 10-Minute Average Peak Expired Pressure of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

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[3] Formerly of NIOSH, National Personal Protective Technology Laboratory

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