PPE CASE

Personal Protective Equipment Conformity Assessment Studies and Evaluations

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

Sample Period: February 2013 to December 2014

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Abstract

An ongoing Long-Term Field Evaluation (LTFE)[1] study, carried out jointly by the National Personal Protective Technology Laboratory (NPPTL), a laboratory in the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA), evaluates the long-term field performance and reliability of self-contained self-rescuer (SCSR) units deployed in U.S. underground coal mines. The LTFE study provides performance, reliability, and user maintenance compliance data on field-deployed SCSR units.

This report presents findings from the third phase long-term random (LTR3) testing of SCSR units that was conducted between February 2013 and December 2014. Prior to collection, MSHA provided a copy of the SCSR inventory from which NIOSH compiled a statistically-significant random list of 620 SCSR units to target for collection. NIOSH returned 319 SCSR units to the laboratory when the collection effort ended. Three hundred ten (310) SCSR units that passed the manufacturers' recommended visual inspections were subsequently tested using an automated breathing and metabolic simulator (ABMS). The tests performed in this study are not approval tests; however, products that exhibit any suspected nonconforming characteristics during their inspection and testing at NPPTL are identified. A certified product investigation process (CPIP) may subsequently be opened to determine the impact of observed performance degradation or potential nonconformance of deployed SCSR units. It was not necessary to open a CPIP audit for SCSR nonconformance issues in this phase of the LTFE study.

> *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.

Twenty-five of the targeted SCSR units failed the manufacturers' recommended visual inspections either at the mine or at NIOSH. LTR3 sample test results suggest that SCSR units that pass the manufacturers' 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 some performance degradation in most of the SCSRs tested during LTR3, all retained their ability to preserve life in the event of an emergency.

As in the first phase long-term random (LTR1) SCSR unit collection efforts, NIOSH failed to collect 100 of each NIOSH-approved SCSR model deployed in United States underground coal mines. A revised strategy to meet this study design goal is being formulated and will be enacted for future LTFE collection phases in order to retain the desired statistical validity of the study.

Introduction

Coal mine operators in the United States are required to make SCSR units available to each underground coal miner. Additional SCSR units are required to be cached on working settings and in 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 NIOSH and MSHA. The device must provide respiratory protection with an oxygen (O_2) source for at least one hour. In some mines, shorter duration SCSR units 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, NIOSH NPPTL, in cooperation with MSHA, conducts an ongoing, long-term field evaluation of SCSR units deployed in underground coal mines to assess their reliability and performance.

The objective of the LTFE program is to evaluate how well SCSR units 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 nondestructive testing. Among the visual inspection criteria are evaluation of heat and humidity indicators on pressure gauges, verification of the remaining service time based on the manufacturing date, assurance that the case seal is intact, and visual assessment of physical indications of wear or damage. All in-service units must comply with the manufacturer's specified conditions for storage and use. SCSR units failing inspection or not in compliance with the conditions of storage and use, no longer conform with NIOSH/MSHA approval criteria and must be removed from service.

During the first ten phases of the LTFE program, referred to as LTFE 1 through LTFE 10, NIOSH NPPTL (and during the early phases, the U.S. Bureau of Mines) collected SCSR units mines were willing to surrender for replacement units. 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 how well the results represented the deployed SCSR population.

In 2009, a new sampling strategy was implemented. The new strategy involved randomizing the SCSR population to identify a statistically valid sample, rather than a convenience sample collected under the previous strategy. In keeping with this strategy for LTR3, NIOSH compiled a random list of approximately 620 SCSRs from the MSHA SCSR Inventory and Report, representing all 11 MSHA mining districts. From this list, NIOSH attempted to collect all SCSR units that would pass manufacturers' recommended visual inspections at the mine. This sampling strategy attempted to improve the significance of test results by sampling a broader range of SCSR deployment types and environments. Since 2009, NPPTL 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 that typically targets the same number of each SCSR model currently approved for use in underground coal mines. Beginning with the LTR1 collection phase and continuing with the LTR3 collection phase, NIOSH subjected the SCSR units to strict visual inspection. The intent was to collect performance test data only for units that passed the visual inspection.

The Automated Breathing and Metabolic Simulator (ABMS) machine is used to assess the performance of SCSR units collected for the LTR3 study and provides a reproducible measure for comparison. All tests are conducted at a constant work rate until the oxygen supply is expended in order to facilitate duration comparisons between NIOSH NPPTL stored and deployed units. Test data is averaged over the first 60 (for one-hour SCSR units) or ten (for ten-minute SCSR units) minutes of testing to eliminate the test duration variability effect in the determination of stressor levels. The SCSR units tested in this phase were not NIOSH-approved using the ABMS.

All of the SCSR units tested as part of LTR3 have been approved by both NIOSH and MSHA under the requirements of Title 42, Code of Federal Regulations, Part 84 (42 CFR, Part 84), Subpart H. It is important to keep in mind that the tests performed as part of LTR3 are focused on detecting any change in the performance of deployed respirators. Tests conducted as part of LTR3 are not performed as part of Subpart H certification. LTR3 test conditions and endpoints are also different from tests conducted in Subpart H certification. Unlike the Subpart H certification testing which relies solely on human subjects to evaluate the SCSR units, LTR3 tests are performed using an ABMS. The LTR3 breathing and metabolic simulation (BMS) tests are designed to be highly reproducible so comparisons between new and old units are valid. Although human-facilitated and machine results are similar, they are not exactly the same 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 LTR3 study included units manufactured by Ocenco Incorporated, CSE Corporation, and Dräger. The Ocenco EBA 6.5 and the Ocenco M-20 (Figures 1 and 2) are compressed-oxygen SCSR units.

Photo by NPPTL

Figure 1. Ocenco EBA 6.5 self-rescuer

Photo by NPPTL

Figure 2. Ocenco M-20 self-rescuer

Photo by NPPTL

Figure 3. CSE SRLD self-rescuer

Photo by Dräger

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

The EBA 6.5 has an approved duration of 60 minutes; the M-20 has an approved duration of 10 minutes. The CSE SRLD (Figure 3), Dräger Oxy K Plus (top of Figure 4), and Dräger Oxy K Plus S (bottom of Figure 4) are chemical-oxygen-SCSR units that employ an oxygen gas starter for initial operation while chemical oxygen is subsequently generated through chemical reaction as the sorbent absorbs carbon dioxide from the user's exhaled breath. The Oxy K Plus and Oxy K Plus S are the same SCSR but have different case opening mechanisms and procedures (demonstrated in Figure 4). The SRLD and Oxy K Plus/Oxy K Plus S SCSR units both have approved durations of 60 minutes.

Sampling Strategy

For statistical analysis purposes, NIOSH NPPTL attempted to collect at least 100 of each NIOSH-approved SCSR model deployed in United States underground coal mines for the LTR3 study. To obtain the units, NIOSH requested a list from MSHA of all units currently in mine use. In response, using the MSHA SCSR Inventory and Report, MSHA generated a list of approximately 25,000 SCSR unit serial numbers across all 11 mining districts. From the list, NIOSH NPPTL compiled a random list of at least 140 units of each model. Targeting more SCSR units for collection than was needed was necessary in case there were issues with obtaining specific SCSRs. This approach increased the likelihood of collecting at least 100 units of each model for laboratory testing. Despite this strategy, slightly less than 100 of each SCSR model were collected mostly due to SCSR units not passing visual inspection, mine closures, and SCSR units found to be missing upon collection attempt. Table 1 lists the number of each SCSR model returned to NIOSH NPPTL for testing during the LTR3 collection phase along with their manufacturing date ranges.

Table 1. Summary of LTR3 SCSR Collection

Manufacturer	Model	Number of units collected	Manufacture date range
CSE	SRLD	84	11/2011 – 07/2012
Dräger	Oxy K Plus	35	06/2006 – 12/2010
Dräger	Oxy K Plus S	44	12/2010 – 10/2011
Ocenco	EBA 6.5	70	12/2003 – 06/2012
Ocenco	M-20	86	11/2006 – 06/2012

Tests and Evaluations

The following tests and evaluations were conducted on each SCSR unit obtained: (1) visual inspection that 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 CSE and Dräger inspection manuals state that the SRLD and Oxy K Plus/Oxy K Plus S SCSR units, respectively, be tested in the field every 90 days with a solids movement sound detector to determine the condition of the chemical bed used to remove carbon dioxide and generate oxygen. This test is normally performed at NIOSH NPPTL using laboratory-scale solids movement sound detectors as a final screening just prior to testing. However, the equipment to assess the Dräger SCSR units' chemical bed integrity was not available at NIOSH NPPTL during LTR3 testing and the equipment to assess the CSE SRLD SCSR units' chemical bed integrity wasn't available until early in the supplemental testing period conducted in 2017. Therefore, NIOSH performed this assessment for only a small portion of the CSE SRLD units evaluated for LTR3. While the units were provided to NIOSH with the understanding that they should have passed the mine's solids movement sound detector 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 nineteen (319) SCSR units passed the manufacturers' recommended visual inspections at the mines and were collected for further evaluation by NIOSH, including a second visual inspection at NIOSH NPPTL prior to BMS testing. Manufacturers' recommended visual inspections focus on the integrity of the case, seal, latches, and indicators that are viewable without opening or activating the respirator. The cases of the CSE SRLD and Dräger Oxy K Plus chemical units have moisture and heat indicators to signify water penetration or excessive temperature exposure, respectively. Ocenco Incorporated compressed-gas oxygen units have pressure indicators that indicate oxygen cylinder pressure. Damage to the case, missing case latches, broken seals, excessive heat exposure, or low O_2 gauge pressures are reasons for a unit to fail the visual inspection. The SCSR is safe for use if all visual inspections pass. 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 NIOSH NPPTL were also removed from the study. It should be noted that NIOSH 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, for those having a 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 sorbent/oxygen generator particles or chemical sorbent particles for oxygen-supplied SCSR units had broken down and entered the breathing circuit where it could be inhaled by the user. The phenolphthalein soaked swab changing to pink in color after swabbing indicates the presence of these granular particles in the breathing zone of the SCSR unit.

Quantitative Leak Test

SCSR units that passed the visual inspection check proceeded to the quantitative leak test (QNT). This test assesses breathing circuit integrity but is not required for approval. The leak test employs a vacuum source to induce a vacuum of 300 mm H_2O column within the SCSR breathing circuit while measuring the inward leakage rate with an in-line mass flow meter. The vacuum source's gas return tubing is connected and sealed on its opposite end to the mouthpiece of the SCSR unit being tested. A mass flow meter is installed in the tubing between the vacuum source and the mouthpiece connector to measure the flow rate of gas being evacuated from the SCSR unit's breathing circuit when the vacuum source is activated.

As the vacuum is adjusted to and stabilizes at 300 mm H_2O column, the evacuated gas flow rate decreases and stabilizes. The stable evacuated gas flow rate is considered to be the SCSR unit leak rate. 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 (https://www.cdc.gov/niosh/npptl/pdfs/PPEC-SCSR-Mining-SecondPhase-508.pdf).

Mouthpiece connectors 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 to the vacuum source's evacuated gas return tubing 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 minimum 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 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. 42 CFR, Part 84, §84.94, gas flow test for a closed-circuit apparatus, requires a minimum constant-flow rate of 1.5 L/min for combination constant flow and demand-flow SCSR units for their entire operation. Since it is not possible to measure the minimum sustained oxygen flow rate over the duration of the SCSR unit's operation, a flow measurement greater than or equal to 1.5 L/min at the start of testing provides a partial indicator of conformance to this requirement.

Acoustics Solids Movement Detector Test

The Acoustic Solids Movement Detector (ASMD) is a device used to identify loose particles that lead to channeling of breathing gas flow in the chemical bed of chemical-oxygen-generating CSE SRLD SCSR units. SRLD SCSR units with such damage promote a decrease in breathing gas residence time in the chemical bed and the hastening of CO_2 breakthrough. The ASMD analyzes the sound induced in an SRLD SCSR unit by shaking it in a controlled manner. The sound level produced by the SRLD SCSR when shaken is used as an indicator of shock and vibration damage incurred by the chemical bed within the SCSR. In the field, this assessment is made qualitatively using a handheld ASMD instrument. A laboratory version of the handheld ASMD rotates the SRLD SCSR at 10 rpm in an anechoic chamber to quantitatively measure sound levels in decibels (dB). A blank SCSR calibration unit filled with cement is used to measure a baseline sound level. This calibration unit is used to adjust the sound level measured for units under test. Mine-deployed SRLD SCSR units for which sound levels higher than 60 dB are measured fail the test. NIOSH performs the laboratory version of the ASMD test as part of LTFE inspection of all chemical-oxygen generating CSE SRLD SCSR units. CSE SRLD SCSR units failing the ASMD test are not included for evaluation in the LTFE program study.

Breathing and Metabolic Simulation Test

The computer-controlled ABMS (Figure 5) injects CO_2 into and removes O_2 from its breathing circuit while operating 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 inspired CO_2 and O_2 concentrations in SCSR units due to its high degree of accuracy and repeatability in simulating 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. The National Instruments' LabVIEW-based software application manages the operation of the ABMS. Test input parameters required to initiate a simulation operation include the VO_2, VCO_2, respiration rate, and tidal volume set points. LabVIEW software subroutines work to control the piston operation, and maintain the VO_2 and VCO_2 set points through the control of the injection rates of CO_2 and N_2 streams into the breathing circuit and the exhaust gas flow (containing O_2) out of the breathing circuit. Measurements of respiratory gas constituents, O_2 and CO_2, breathing resistances, and wet and dry bulb temperatures are recorded at 60 Hz. These measurements are used to provide real-time test data displays and in the final analysis of test performance.

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 included inspired levels of CO_2 and O_2, inspired wet- and dry-bulb temperatures, and peak 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 inspired CO_2 levels exceeding 10%; or inspired 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 Subpart H 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 (i.e., the length of time that an SCSR unit will operate at a constant work rate before the oxygen supply becomes fully expended). 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 in approval testing. In addition, LTR testing continues until the apparatus breathing gas supply is expended or stressor levels exceed allowable parameters, whereas testing during approval ends at the rated duration, even if the capacity of the apparatus exceeds it.

Photo by NPPTL

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

In Storage Unit Evaluations

SCSR units maintained in storage at NIOSH NPPTL for the next phase of the LTFE program were evaluated using the ABMS for performance comparisons with deployed units. Twelve CSE SRLD, eight Dräger Oxy K Plus, nine Ocenco EBA 6.5, and eight Ocenco M-20 SCSR units were tested between January 21 and February 19, 2016 using the same work rate at which the deployed SCSR units were tested. Prior to evaluation, manufacturers' recommended visual inspections were performed on the stored SCSR units to ensure qualification for BMS testing.

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 enable comparison with other SCSR units of the same type. 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 determine if deployment time effects existed.

All average stressor data from the testing of deployed units and new units stored at NIOSH NPPTL for each SCSR type were averaged to obtain a composite average to detect any change in performance of deployed SCSR units. 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 NPPTL targeted collection of 620 units deployed in United States underground coal mines for LTR3. On the randomly generated collection lists, 140 units represented CSE SRLD, 140 units represented Ocenco EBA 6.5, 200 units represented Ocenco M-20, and 140 units represented Dräger Oxy K Plus/Oxy K Plus S models. Of the 620 units targeted, NPPTL collected 335 SCSR units at the mines. After identifying 16 visual inspection failures, 319 SCSR units were returned to NIOSH NPPTL for testing, yielding an overall collection rate of 51.5%. Figure 6 depicts the status of the 620 SCSRs targeted in the LTR3 collection. A total of 285 targeted SCSR units were either missing or not available for various reasons including mine closures, removed from service, or not feasible to be collected (Figure 6). This amounts to 46.0% of the SCSRs on the targeted collection list.

A revised LTFE collection strategy will be implemented for future collection phases. Part of this new strategy will include determining the quantity of each SCSR type required to achieve the desired statistical validity for the study. NIOSH will work closely with MSHA to develop the design study goal once this quantity is determined. NIOSH will also explore improved communication strategies for confirming SCSR status prior to collection, and a means to reach smaller mines that may only have one unit to collect.

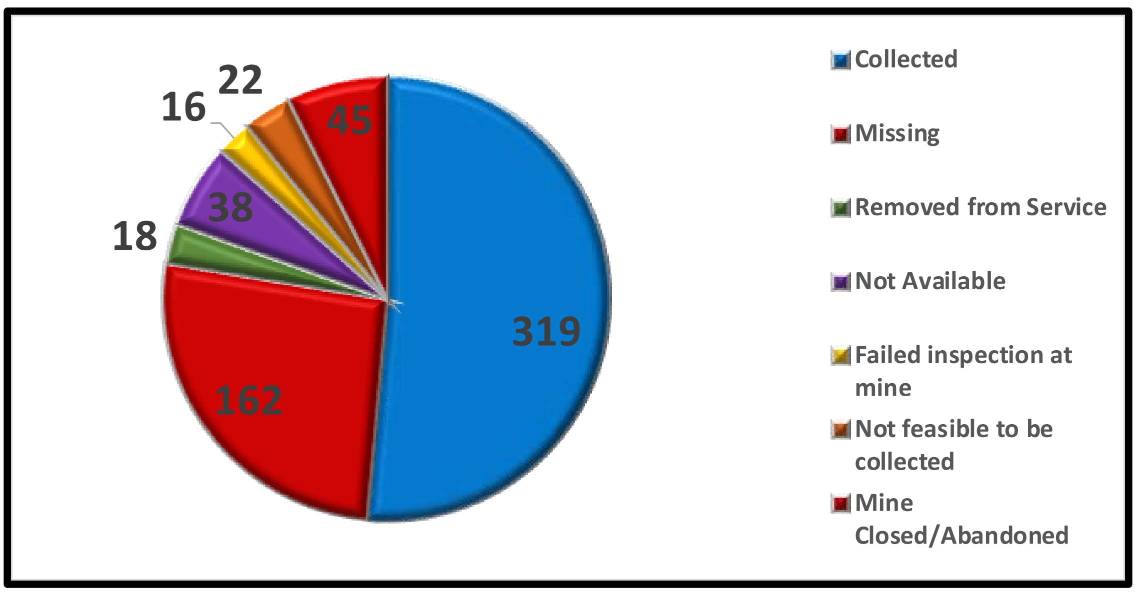

Figure 6. LTR3 Collection Dispersion

From the 319 collected SCSR units, 9 additional units failed the visual inspection at NIOSH NPPTL leaving 310 units that qualified for BMS testing. The SCSRs that qualified for BMS testing included: 84 CSE SRLD, 79 Dräger Oxy K Plus/Oxy K Plus S, 69 Ocenco EBA 6.5, and 78 Ocenco M-20 SCSR units (Figure 7).

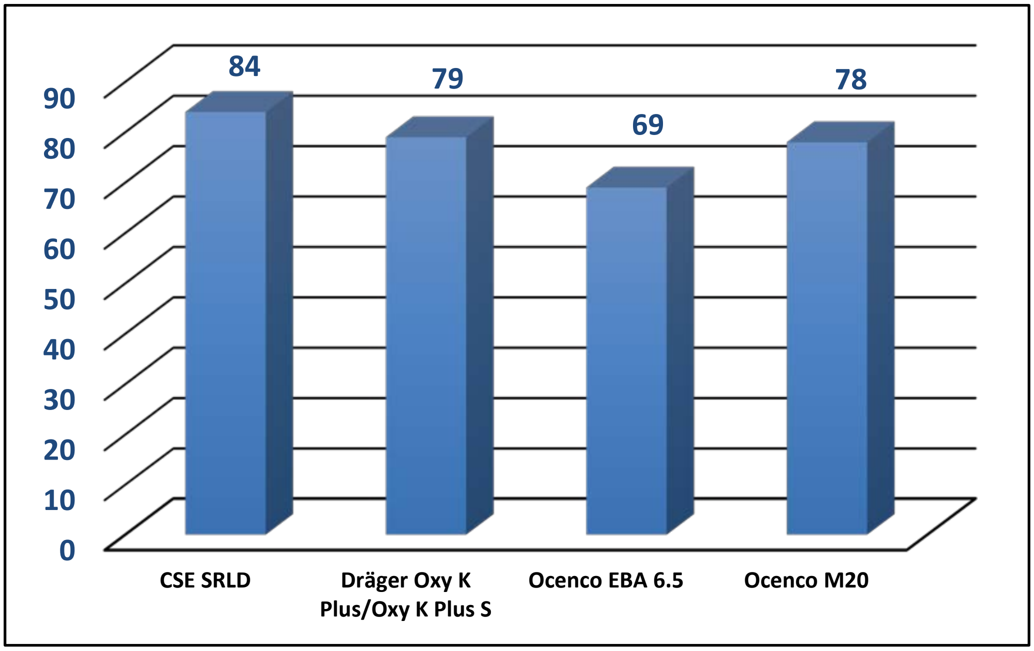

Figure 7. Dispersion of SCSRs Qualified for BMS Testing

When LTR3 collection and testing began in May 2013, NIOSH collected all SCSR units that the mines and MSHA District Offices deemed as passing visual inspection. Of the 335 SCSRs (Table 3) collected at the mines, 16 (4.8%) failed mine visual inspection for reasons including failure of the solids movement sound detector test of the chemical bed, damage to the case or case seal, and activation of moisture penetration or excessive heat indicators. Out of 319 SCSRs collected and transported to NIOSH NPPTL, an additional nine SCSRs (2.7%) failed visual inspection when applying the manufacturer's criteria upon test initiation in the laboratory for reasons including mine dust penetration into the case, white powder in the breathing hose, and case damage. From the 310 qualifying SCSR units, NPPTL obtained 286 valid sets of data.

Table 3. Test Summary for SCSRs 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
CSE SRLD	140	95	84	84	84	65
Dräger Oxy K Plus	60	35	35	35	35	34
Dräger Oxy K Plus S	80	47	44	44	44	41
Ocenco EBA 6.5	140	72	70	69	69	69
Ocenco M-20	200	86	86	78	78	77
Totals	**620**	**335**	**319**	**310**	**310**	**286**

As noted in Table 3, 310 out of 335 (92.5%) of SCSR units collected at the mine passed the manufacturers' visual inspections performed by NIOSH. This visual inspection failure frequency (7.5%) indicates a need to further train miners/mine operators who use/own these SCSR units to fulfill the requirements of the manufacturers' recommended visual inspections. The 25 SCSR units that failed the visual inspection should have been removed from service and would not have been available to collect if the proper visual inspections had been adequately performed by their users.

Units not passing the manufacturers' recommended visual inspections, exhibiting defects, or not meeting the rated duration were referred for investigation into the cause of these results and to determine if any further action was warranted. None of the LTR3 SCSR units referred for review were deemed to require further action.

CSE SRLD SCSR

Eighty-four of the 140 CSE SRLD SCSR units listed on the LTR3 targeted collection list were returned to NIOSH NPPTL for testing. LTR3 collection methods called for the collection of 100 units, yielding a collection rate of 84%. Challenges affecting the collection of CSE SRLD SCSR units included missing units or units listed as not available accounting for 34 units. These two challenges resulted in 24.3% of CSE SRLD SCSR units on the targeted collection list being unavailable for testing. The remaining units were not collected for reasons listed as failure of visual inspection at the mine (11), not feasible to collect (6), out of service (3), idle (1), and database collection error (1). Visual inspection failures at the mines included failure of the handheld sound level test, excessive heat indication, damage to the case, and broken case seal.

All CSE SRLD SCSR units tested passed the manufacturer's recommended visual inspection at NIOSH NPPTL (Figure 8). Valid test data was obtained for 65 of the 84 CSE SRLD SCSR units. The 19 invalid data sets were mainly the result of ABMS operational issues caused by test operator error. ABMS operational issues included excessive leaks at the fixture connection to the mouthpiece, test termination as a result of excessively low pressure, test termination as a result of inadequate O_2 level, excessively high pressure, and lack of breathable volume. These latter four operational issues were deemed to be due to improper start-up procedures employed by the test operator. None of the CSE SRLD SCSR units returned for testing failed the phenolphthalein indicator test.

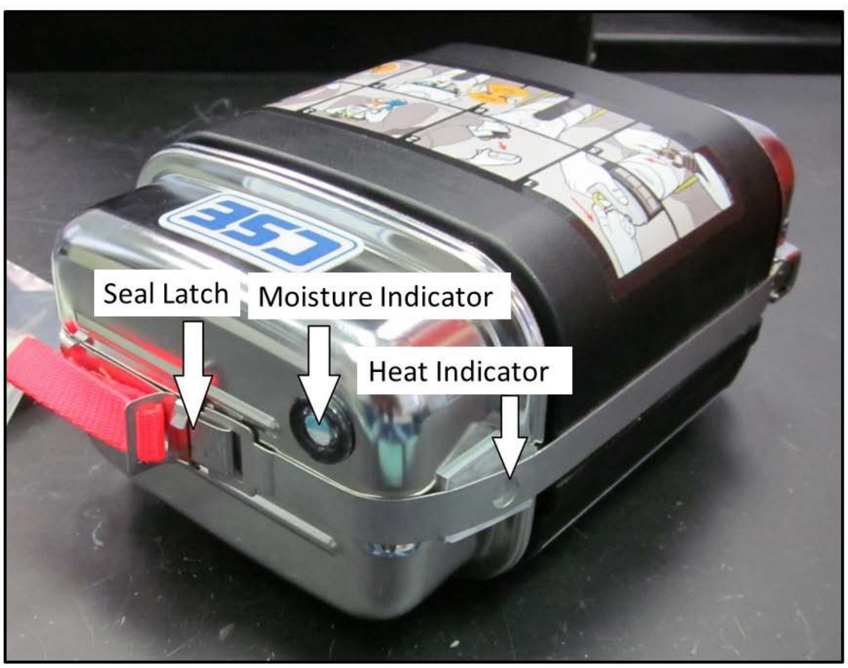

Photo by NPPTL

Figure 8. Areas of Visual Inspection for CSE SRLD

The breathing circuit integrity check of the CSE SRLD SCSR using the QNT leak test procedure showed that all 84 SCSR units tested had a leak rate less than 500 ml/min (i.e., passed).

After test initiation on the ABMS, all SCSR units continued operating until the breathing gas supply was expended. All SCSR units but one met or exceeded the NIOSH-approved 60-minute service time. The average duration for CSE SRLD SCSR units tested was 67 minutes.

All CSE SRLD SCSRs tested provided acceptable oxygen levels during the entire 60-minute service time. Inspired CO_2 levels measured for six of the 65 valid mine-deployed SRLD SCSR unit tests exceeded 4% prior to reaching the 60-minute NIOSH-approved service time (Table 4). As shown in Table 4, inspired CO_2 levels measured for 27 of the remaining 59 valid mine-deployed SCSR unit tests exceeded 4% after the 60-minute service time was reached but prior to the expenditure of oxygen. These results are important to note because NIOSH has established a 4.0% inspired CO_2 pass/fail limit for LTFE testing. However, continuous inspired CO_2 measurements were not taken near the end of the 60-minute service time during approval testing of SCSR units under Subpart H. Therefore, the excursions in inspired CO_2 measured near the end of service time and after the service time had been reached for these tests could not have been detected had they occurred. For most users, elevated inspired CO_2 would most typically cause no more than an elevated ventilation rate, which would likely lead to elevated breathing resistance, both of which may cause the user to stop using the unit sooner than if the inspired CO_2 remained low.

Table 4. CSE SRLD SCSR 4% Carbon Dioxide Breakthrough Times

4% Inspired CO_2 Breakthrough Time, minutes	Test Duration, minutes	Mine-Deployed or In Storage	Inspired CO_2 at 60 minutes	Maximum Inspired CO_2, Volume %
40	59	Mine-Deployed	NA	9.70
47	66	Mine-Deployed	6.33	9.43
50	65	Mine-Deployed	6.04	7.90
51	62	Mine-Deployed	7.34	7.96
57	66	Mine-Deployed	4.66	6.58
59	65	Mine-Deployed	4.28	6.25
61	68	Mine-Deployed	3.89	6.38
61	62	Mine-Deployed	3.74	4.34
61	73	Mine-Deployed	4.00	8.70
62	74	Mine-Deployed	3.72	9.81
62	67	Mine-Deployed	3.80	5.98
62	68	Mine-Deployed	3.68	6.07
63	63	Mine-Deployed	3.53	4.32
63	66	Mine-Deployed	3.38	5.02
63	65	Mine-Deployed	3.52	4.59
63	65	Mine-Deployed	3.60	4.86
64	67	Mine-Deployed	3.46	5.10
64	69	Mine-Deployed	3.35	5.87
65	66	Mine-Deployed	3.16	4.49
65	69	Mine-Deployed	3.26	5.39
65	65	Mine-Deployed	3.07	4.25
66	68	Mine-Deployed	2.96	4.71
66	70	Mine-Deployed	3.06	6.02
67	67	Mine-Deployed	2.56	4.09
67	68	Mine-Deployed	2.62	4.54
68	72	Mine-Deployed	2.48	6.15
68	70	Mine-Deployed	2.76	5.02
69	72	Mine-Deployed	2.44	4.99
69	71	Mine-Deployed	2.90	4.66
71	76	Mine-Deployed	2.41	5.88
71	71	Mine-Deployed	2.33	4.14
71	76	Mine-Deployed	2.65	5.83
74	74	Mine-Deployed	2.44	4.23

NIOSH NPPTL averaged the minute-average values of the stressors monitored during BMS testing of mine-deployed CSE SRLD 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 NPPTL sorted the mine-deployed CSE SRLD SCSR unit stressor results within each composite graph by manufacturing dates which range in age from oldest to newest, left to right. The stressor value data points for testing of CSE SRLD SCSR units in storage at NIOSH NPPTL are shown in red for comparison with the mine-deployed units on these plots.
A linear regression is fit to each stressor plotted from testing of mine-deployed CSE SRLD SCSR units to draw out the effects of deployment time. No trends in measured stressors attributable 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 CMH2O (peak expired pressure, cm H_2O column), PIPRS CMH2O (peak inspired pressure, cm H_2O column), and TAVGDB (average inspired dry bulb temperature), are shown for in storage and mine-deployed CSE SRLD SCSR units tested in Table 5. The percent difference between mine-deployed unit mean stressor values and in storage unit mean stressor values, relative to mine-deployed unit mean stressor values, is also shown in Table 5. Mole fraction, as used, is defined as moles of breathing gas constituent, O_2 or CO_2, per 100 moles of breathing gas.

Table 5. CSE SRLD Duration and Composite Mean Stressor Levels

	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
SRLD Deployed Unit Data (65 tests)						
MIN	**59**	**0.6081**	**0.0114**	**41.53**	**-80.11**	**37.02**
MAX	**76**	**0.9243**	**0.0411**	**62.97**	**-53.33**	**45.73**
AVERAGE	**67.2**	**0.7256**	**0.0183**	**53.27**	**-66.24**	**42.02**
% Difference	**2.60**	**-7.89**	**2.12**	**5.36**	**-1.57**	**-0.04**
SRLD NIOSH In Storage Unit Data (12 tests)						
MIN	**63**	**0.7461**	**0.0156**	**45.42**	**-73.65**	**39.96**
MAX	**68**	**0.8360**	**0.0201**	**55.24**	**-59.87**	**43.47**
AVERAGE	**65.5**	**0.7878**	**0.0179**	**50.56**	**-67.30**	**42.04**

CSE SRLD SCSR – Supplemental Testing

Evaluation of 41 additional CSE SRLD SCSR mine-deployed units was performed May 9 through November 8, 2017 using the ABMS to investigate elevated inspired CO_2 nonconforming test results observed during original LTR3 testing. CSE SRLD SCSR units tested in the supplemental study were identified randomly through a search of MSHA's SCSR Inventory and Report for MSHA Mining Districts 2 and 3. Testing focused on checking for the recurrence of one-minute average inspired CO_2 levels exceeding 4.0% before reaching the 60-minute service time. CSE SRLD SCSR units in storage at NPPTL were also evaluated as part of the LTR3 supplemental testing for comparison purposes. One CSE SRLD SCSR in storage unit was tested for each mine-deployed unit tested.

Forty-one of the 94 CSE SRLD SCSR units listed on the LTR3 supplemental testing targeted collection list were returned to NIOSH NPPTL. This yielded a collection rate of 43.6%. NIOSH collected a sufficient number of SRLD SCSR units for evaluation to elicit a recurrence of elevated inspired CO_2 nonconforming test results, based on the rates of occurrence during original LTR3 testing. Challenges affecting the collection of CSE SRLD SCSR units for supplemental LTR3 testing included units that were not available/unable to be found (31) and mine closures (22). The supplemental LTR3 collection effort is summarized in Table 6.

Table 6: Test Summary for Supplemental CSE SRLD 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
CSE SRLD	94	41	41	40	40	40

Sound level assessments were performed at the mine on the 41 CSE SRLD SCSR units collected using a portable, handheld ASMD provided by CSE. This screening is performed to disqualify those SCSR units that fail this test through the detection of loose sorbent particles in the SCSR canister bed that could lead to channeling of breathing gas flow and inefficient CO_2 absorption/O_2 generation. All of the units collected at the mine passed this initial screening test. All but one CSE SRLD SCSR unit was qualified for testing at NIOSH NPPTL. This one disqualification was due to the unit failing the sound level test using the laboratory ASMD. Valid test data was obtained for all 40 units that qualified for BMS testing.

NIOSH tested the last 32 units collected from the mines on the laboratory ASMD to obtain sound level measurements. During this testing, the sound level measured for one SCSR unit exceeded 60 dB, the pass/fail limit for this test as established by CSE. This unit is not included in this study and is identified as failing visual inspection at NIOSH NPPTL in Table 6. Sound levels measured for most of the 31 remaining mine-deployed units using the laboratory ASMD were less than 30 dB (See Figure 9). Sound levels measured for all 32 in storage CSE SRLD SCSR units evaluated on the ASMD were also less than 30 dB (Figure 10). The laboratory ASMD was not operational for sound level measurements for the first nine mine-deployed and in storage units tested.

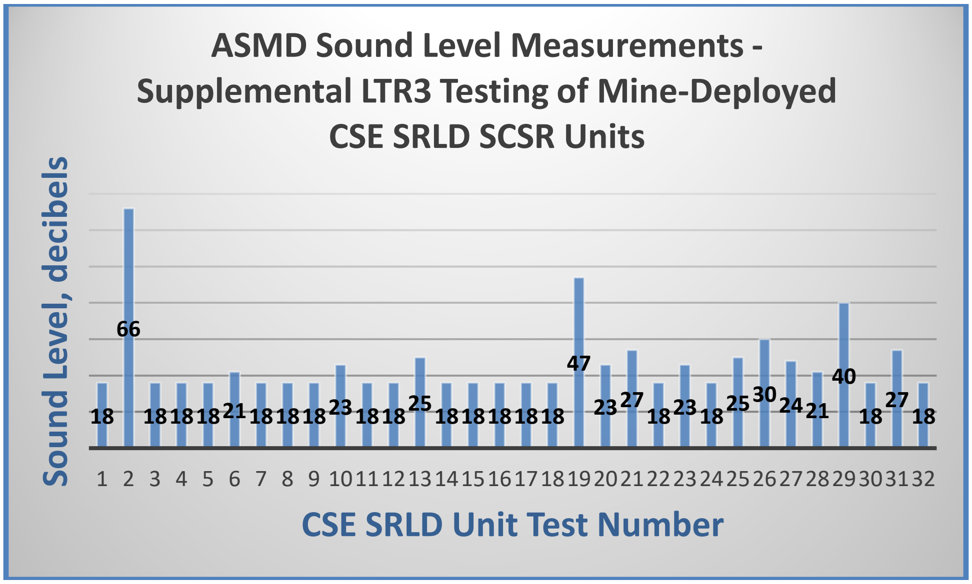

Figure 9. ASMD Sound Level Measurements –
Supplemental LTR3 Testing of Mine-Deployed CSE SRLD SCSR Units

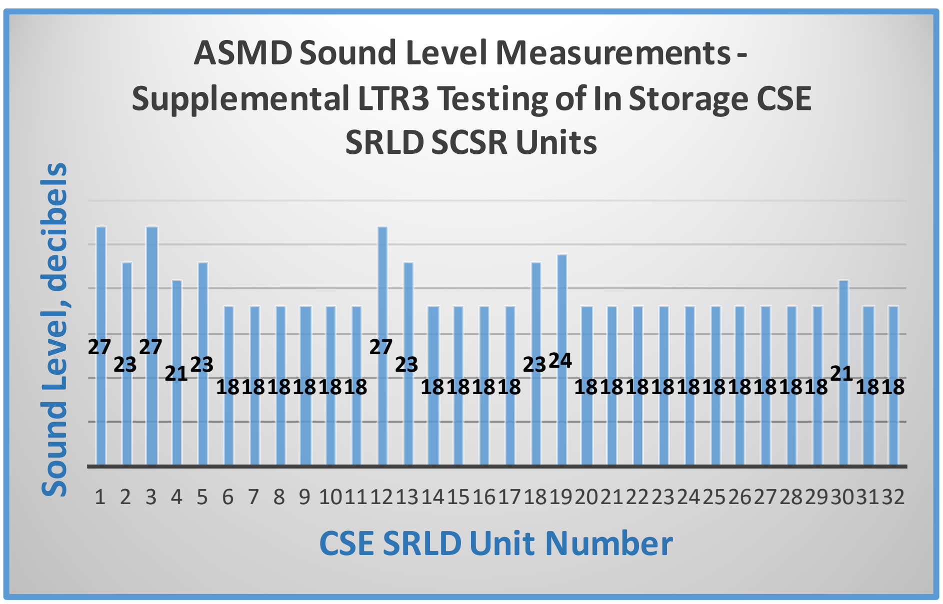

Figure 10. ASMD Sound Level Measurements –
Supplemental LTR3 Testing of In Storage CSE SRLD SCSR Units

The breathing circuit integrity check of mine-deployed CSE SRLD SCSR units using the QNT leak test procedure showed that all had leak rates less than 500 ml/min. The breathing circuit integrity check of in storage CSE SRLD SCSR units also showed that all in storage units had leak rates less than 500 ml/min.

After test initiation on the ABMS, all mine-deployed and in storage CSE SRLD SCSR units continued operating until the breathing gas supply was expended. All mine-deployed and in storage SCSR units met or exceeded the NIOSH-approved 60-minute service time. The average duration for mine-deployed and in storage CSE SRLD SCSR units was 69 and 68 minutes, respectively.

All CSE SRLD SCSR units tested provided acceptable inspired oxygen levels during the entire 60-minute service time. Inspired CO_2 levels measured for three of the 40 mine-deployed SRLD SCSR units tested exceeded 4% prior to reaching the 60-minute NIOSH-approved service time (Table 7). As shown in Table 7, inspired CO_2 levels measured for nine of the remaining 37 mine-deployed SCSR units tested exceeded 4% after the 60-minute service time was reached but prior to the expenditure of oxygen. These results are important to note because NIOSH has established a 4.0% inspired CO_2 pass/fail limit for LTFE testing. However, continuous inspired CO_2 measurements were not taken near the end of the 60-minute service time during approval testing of SCSR units under Subpart H. Therefore, the excursions in inspired CO_2 measured during the latter portion of service time and after the service time had been reached for these tests would not have been detected had they occurred. For most users, elevated inspired CO_2 would most typically cause no more than an elevated ventilation rate, which would likely lead to elevated breathing resistance, both of which may cause the user to stop using the unit sooner than if the inspired CO_2 remained low.

Table 7. CSE SRLD SCSR 4% Carbon Dioxide Breakthrough Times – Supplemental Testing

4% Inspired CO_2 Breakthrough Time, minutes	Test Duration, minutes	Mine-Deployed or In Storage	Inspired CO_2 at 60 minutes	Maximum Inspired CO_2, Volume %
54	72	Mine-Deployed	4.98	9.39
56	70	Mine-Deployed	5.04	9.43
57	71	Mine-Deployed	4.53	9.54
61	69	Mine-Deployed	4.03	6.19
66	73	Mine-Deployed	3.03	6.10
66	68	Mine-Deployed	2.92	4.88
66	72	In Storage	3.18	6.45
67	76	In Storage	3.20	7.51
67	73	In Storage	3.05	7.01
67	75	Mine-Deployed	3.09	8.33
68	72	Mine-Deployed	3.04	5.34
68	73	Mine-Deployed	2.65	6.80
68	70	In Storage	2.62	4.92
69	71	In Storage	3.91	5.05
69	70	In Storage	2.63	4.74
70	74	In Storage	2.81	5.82
70	72	Mine-Deployed	2.87	4.66
70	72	In Storage	2.31	5.29
72	73	Mine-Deployed	2.55	4.49
73	80	Mine-Deployed	2.12	9.56

Inspired CO_2 levels were compared to sound level measurements obtained from testing on the laboratory ASMD for all mine-deployed units (Figure 11). As can be seen, the three highest 60-minute average inspired CO_2 levels were measured for the CSE SRLD SCSR units that had the three highest sound level measurements (≥30 dB). In addition, one-minute average inspired CO_2 levels for these same three units exceeded 4.0% prior to reaching the 60-minute service time. Sound level measurements for all remaining mine-deployed units and all in storage units were ≤27 dB.

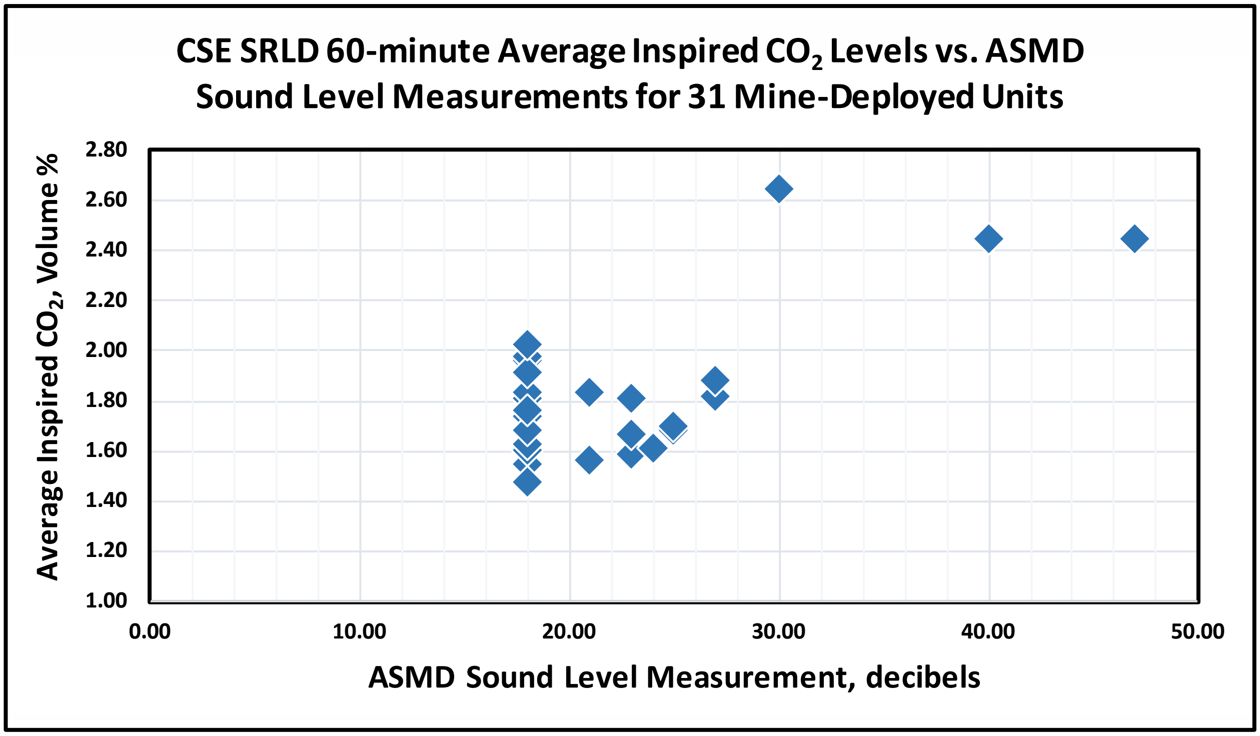

Figure 11. 60-Minute Average Inspired CO_2 Levels vs. ASMD Sound Level Measurements for 31 Mine-Deployed Units – Supplemental Testing

NIOSH NPPTL averaged the minute-average values of the stressors monitored during supplemental LTR3 BMS testing of CSE SRLD SCSR units over the first 60 minutes of each test and the results are presented graphically in Appendix C (Figures 21 through 26 for mine-deployed and Figures 27 through 32 for in storage units). NIOSH sorted the mine-deployed CSE SRLD SCSR unit stressor results within each composite graph by manufacturing dates which range in age from oldest to newest, left to right. In storage unit stressor value data points were plotted in the order in which each unit was tested. A linear regression is fit to each stressor plotted from testing of mine-deployed CSE SRLD SCSR units to draw out the effects of deployment time. No trends in the measured stressors attributable to deployment time were identified.

Test results from in storage unit testing were used to validate results from mine-deployed unit testing. SCSR test duration and composite mean stressor levels, including FIO2, FICO2, PEPRS CMH2O, PIPRS CMH2O, TAVGDB, and TAVGWB (average inspired wet bulb temperature,) are shown for the in storage and deployed CSE SRLD SCSR units in Table 8. The percent difference between deployed-unit mean stressor values and in storage unit mean stressor values, relative to deployed-unit mean stressor values, is shown in Table 8. As can be seen, all stressor differences are less than 2%.

Table 8. CSE SRLD Duration and Composite Mean Stressor Levels – Supplemental Testing

	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB	TAVGWB
SRLD Mine-Deployed Unit Data - Supplemental Testing (40 tests)							
MIN	62	0.7346	0.0148	32.54	-75.42	40.56	32.56
MAX	80	0.8231	0.0265	58.57	-54.05	45.30	38.07
AVERAGE	69	0.7930	0.0185	46.64	-66.31	42.99	35.42
% Difference	0.9	-0.4	1.8	1.3	0.7	-0.4	-1.2
SRLD NIOSH In Storage Unit Data (41 tests)							
MIN	63	0.7648	0.0161	37.67	-74.14	41.45	33.74
MAX	76	0.8196	0.0205	55.39	-59.40	44.57	37.55
AVERAGE	68	0.7964	0.0181	46.06	-65.85	43.18	35.87

SCSR test duration and composite mean stressor levels for supplemental and original LTR3 testing of mine-deployed CSE SRLD SCSR units are shown in Table 9. The percent difference between supplemental LTR3 testing mean stressor values and original LTR3 testing mean stressor values of mine-deployed units, relative to supplemental LTR3 testing mean stressor values, is also shown.

Table 9. Mine-Deployed CSE SRLD Duration and Composite Mean Stressor Levels – Supplemental vs. Original LTR3 Testing

	DURATION	FIO2 FRAC	FICO2 FRAC	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
SRLD Deployed Unit Data - Supplemental LTR3 Testing (40 tests)						
MIN	62	0.7346	0.0148	32.54	-75.42	40.56
MAX	80	0.8231	0.0265	58.57	-54.05	45.30
AVERAGE	69.0	0.7930	0.0185	46.64	-66.31	42.99
% Difference	2.68	9.29	1.09	-12.45	0.11	2.31
SRLD Deployed Unit Data - Original LTR3 Testing (65 tests)						
MIN	59	0.6081	0.0114	41.53	-80.11	37.02
MAX	76	0.9243	0.0411	62.97	-53.33	45.73
AVERAGE	67.2	0.7256	0.0183	53.27	-66.24	42.02

Dräger Oxy K Plus/Plus S SCSR

Seventy-nine of the 140 Oxy K Plus/Oxy K Plus S SCSR units listed on the LTR3 targeted collection list were received at NIOSH NPPTL for testing. LTR3 methods called for the collection of 100 units, yielding a collection rate of 79%. Challenges affecting the collection of Dräger Oxy K Plus/Oxy K Plus S SCSR units included the closure of mines, leading to the unavailability of 25 SCSR units, and 26 units identified as missing. These two challenges resulted in 36.4% 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 reasons listed as unfeasible to collect (6), failure of visual inspection at the mine (3), and out of service (1). The reasons for failure of the visual inspection included moisture indicator collar missing, metal lock clamp missing, and damage to the case.

All 79 Dräger Oxy K Plus/Oxy K Plus S SCSR units tested passed the manufacturer's visual inspection at NIOSH NPPTL (Figure 12). Valid test data was obtained for 75 of the 79 Dräger Oxy K Plus/Oxy K Plus S SCSR units. The four invalid data sets were due to ABMS operational issues. None of the Dräger Oxy K Plus/Oxy K Plus S SCSR units returned to NIOSH NPPTL for testing failed the phenolphthalein indicator test.

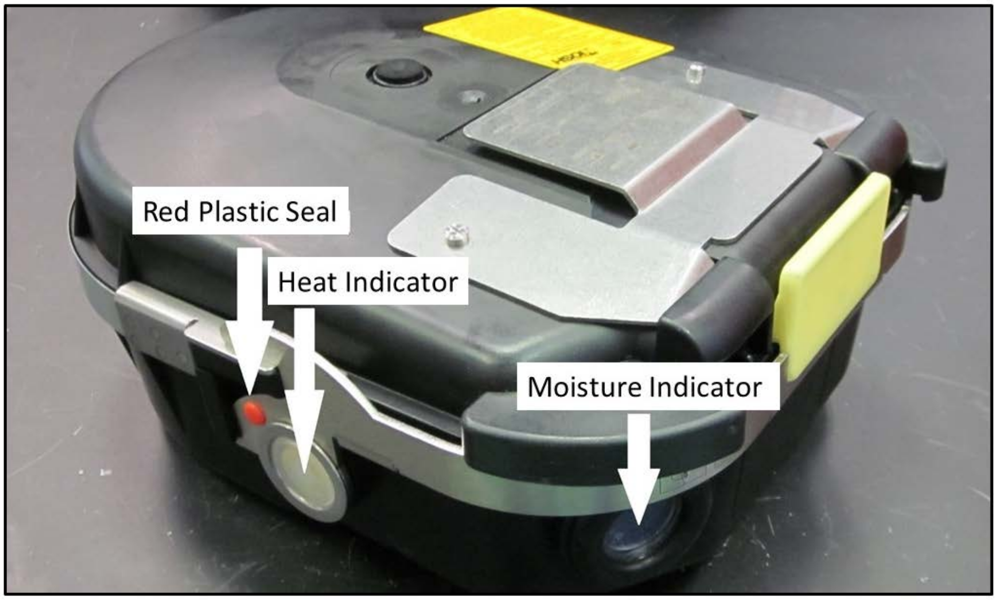

Photo by NPPTL

Figure 12. Areas of Visual Inspection for Dräger Oxy K Plus

The breathing circuit integrity check of the Dräger Oxy K Plus using the QNT leak test procedure showed that 34 of 35 SCSR units had leak rates less than 500 ml/min. The breathing circuit integrity check of the Dräger Oxy K Plus S using the QNT leak test procedure showed that all 44 units had leak rates less than 500 ml/min.

After test initiation on the ABMS, all SCSRs continued operating until the breathing gas supply was expended. All SCSRs met or exceeded the NIOSH-approved 60-minute service time. The average duration for Dräger Oxy K Plus and Dräger Oxy K Plus S SCSR units was 73.0 and 79.2 minutes, respectively.

NIOSH NPPTL 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 D (Figures 33 through 38). The mine-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. The stressor value data points for the Dräger Oxy K Plus S SCSR units in storage at NIOSH NPPTL are shown in red for comparison with the mine-deployed units. A linear regression is fit to each stressor plotted from Dräger Oxy K Plus/Oxy K Plus S SCSR unit testing to draw out the effects of deployment time. No trends in measured stressors attributable to deployment time were identified.

Test duration and composite mean stressor levels, including FIO2, FICO2, PEPRS CMH2O, PIPRS CMH2O, and TAVGDB, are shown for the in storage Dräger Oxy K Plus S and mine-deployed Dräger Oxy K Plus/Oxy K Plus S SCSRs in Table 10. The percent difference between mine-deployed unit mean stressor values versus in storage unit mean stressor values, relative to deployed unit mean stressor values, is also shown in Table 10.

Table 10. Dräger Oxy K Plus Duration and Composite Mean Stressor Levels

	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
Oxy K Plus Deployed Unit Data (34 tests)						
MIN	67	0.7723	0.0073	31.43	-49.82	34.69
MAX	87	0.8804	0.0144	48.54	-40.78	40.16
AVERAGE	73.0	0.8189	0.0127	35.53	-45.70	37.35
% Difference	2.56	-2.54	-9.13	4.98	7.08	5.86
Oxy K Plus S Deployed Unit Data (41 tests)						
MIN	68	0.6986	0.0092	25.99	-94.66	30.94
MAX	92	0.8465	0.0157	48.79	-40.85	40.67
AVERAGE	79.2	0.7993	0.0119	36.17	-45.81	35.54
% Difference	10.25	-5.05	-16.37	6.68	7.32	1.09
Oxy K Plus S NIOSH In Storage Unit Data (8 tests)						
MIN	70	0.8192	0.0127	30.96	-44.40	33.83
MAX	73	0.8689	0.0166	37.71	-41.10	36.11
AVERAGE	71.1	0.8397	0.0138	33.76	-42.46	35.16

Ocenco EBA 6.5 SCSR

Of the 140 EBA 6.5 SCSR units listed on the LTR3 targeted collection list, 70 were returned to NIOSH NPPTL for testing. LTR3 collection methods called for the collection of 100 units, yielding a collection rate of 70%. Challenges affecting the collection of Ocenco EBA 6.5 SCSR units included the closure of mines, leading to the unavailability of eight SCSRs, and 54 missing or unavailable units. These two challenges resulted in 44.3% of Ocenco EBA 6.5 SCSR units on the targeted collection list being unavailable. The remaining units were not returned for reasons listed as unfeasible to collect (5), failure of visual inspection at the mine (2), and out for service (1). The reasons for failure of the visual inspection included a crimped hose and damage to the case.

All but one of the 70 Ocenco EBA 6.5 SCSR units returned for testing passed the manufacturer's visual inspection at NIOSH NPPTL. The one failure was due to the presence of a large crack on the back of the case. This means that 98.6% of the EBA 6.5 SCSR units that passed the manufacturer's recommended visual inspection at the mine also passed visual inspection at NIOSH NPPTL. Valid test data was obtained for the 69 Ocenco EBA 6.5 SCSR units that were tested. None of the Ocenco EBA 6.5 SCSR units returned to NIOSH NPPTL for testing failed the phenolphthalein indicator test.

The breathing circuit integrity check of the Ocenco EBA 6.5 using the QNT procedure showed that 54 of 69 SCSR units had leak rates of less than 500 ml/min. The units with high leak rates were rechecked and leakage at the juncture of the plastic valve frame and the mouthpiece (Figure 13) was identified as the cause. This was discovered by pressing the junction (where the wire tie is connected) of the check valve frame and observing a reduction in the leak rate. Sealing the hoses below the collar confirmed the location of the leak as no reduction in leak rate was observed when this action was performed.

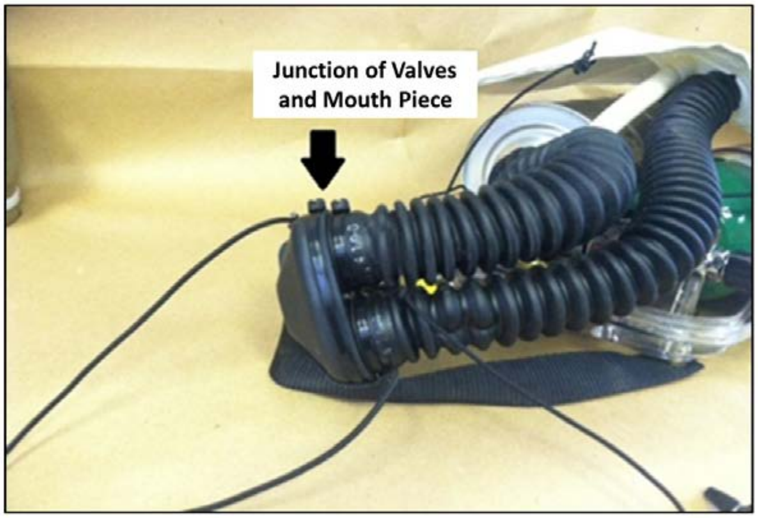

Photo by NPPTL

Figure 13. Ocenco EBA 6.5 Junction of Check Valves at Mouthpiece

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 SCSRs was 99 minutes.

All Ocenco EBA 6.5 SCSR units were subsequently evaluated for minimum sustained oxygen flow rate. The flow rates ranged from 1.67 to 2.0 liters per minute at ambient temperature and pressure.

NIOSH NPPTL averaged the minute-average values of the stressors monitored during BMS testing of the Ocenco EBA 6.5 SCSRs over the first 60 minutes of the test and the results are presented graphically in Appendix E (Figures 39 through 44). NIOSH sorted the mine-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. The stressor value data points for Ocenco EBA 6.5 SCSR units in storage at NPPTL are shown in red for comparison with the deployed units. A linear regression is fit to each stressor plotted from SCSR testing to draw out the effects of deployment time. As can be seen in Figures 43 and 44, breathing resistance increased as a function of deployment time for the Ocenco EBA 6.5 SCSR.

Test duration and composite average stressor levels, including FIO2, FICO2, PEPRS CMH2O, PIPRS CMH2O, and TAVGDB, are shown for the in storage and mine-deployed Ocenco EBA 6.5 SCSR units in Table 11. The percent difference between mine-deployed unit mean stressor values versus in storage unit mean stressor values, relative to deployed unit mean stressor values, is also shown in Table 11.

Table 11. Ocenco EBA 6.5 Duration and Composite Mean Stressor Levels

	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
EBA 6.5 Deployed Unit Data (69 tests)						
MIN	83	0.3245	0.0007	32.32	-113.10	32.59
MAX	107	0.9475	0.0070	98.73	-38.03	42.34
AVERAGE	99.3	0.7168	0.0028	47.16	-49.71	38.90
% Difference	3.40	27.29	2.59	1.41	8.71	-0.69
EBA 6.5 NIOSH In Storage Unit Data (9 tests)						
MIN	98	0.5171	0.0025	40.00	-54.60	37.90
MAX	108	0.6205	0.0032	59.04	-40.33	40.38
AVERAGE	102.8	0.5631	0.0027	46.51	-45.73	39.17

Ocenco M-20 SCSR

Eighty-six of the 200 Ocenco M-20 SCSR units listed on the LTR3 targeted collection list were returned to NIOSH NPPTL. LTR3 methods called for the collection of 100 units, yielding a collection rate of 86%. The main challenge affecting the collection of Ocenco M-20 SCSR units was the identification of 77 units as missing. This challenge resulted in 38.5% of Ocenco M-20 SCSR units on the targeted collection not being available for testing. The remaining units not returned for testing included reasons listed as out of service (13), mine closures (12), unavailable (9), and security latch missing (3). The security latch for the Ocenco M-20 is shown in Figure 14.

Photo by NPPTL

Figure 14. Ocenco M-20 Security Latch

All but eight of the 86 Ocenco M-20 SCSR units returned for testing passed the manufacturer's recommended visual inspection at NIOSH NPPTL. Six visual inspection failures were due to the presence of mine dust inside the case, on the outside of the unit and mouthpiece. Two other visual inspection failures were due to white powder at the breathing bag entrance and in the bag, respectively. This means that 91% of the Ocenco M-20 SCSR units that passed the manufacturer's visual inspection at the mine also passed visual inspection at NIOSH NPPTL. Valid test data was obtained for 77 of the 78 Ocenco M-20 SCSRs tested. One data set was deemed invalid after it was determined that the unit tested was new and just out of the box. One of the Ocenco M-20 SCSR units returned to NIOSH NPPTL for testing failed the phenolphthalein indicator test. This wasn't surprising given the discovery of white powder and mine dust within the breathing bag and in the case, respectively, for several units. This unit subsequently continued in the circuit of tests and all stressors were measured within normal limits.

The breathing circuit integrity check of the Ocenco M-20 SCSR units using the QNT procedure showed that 50 of 78 SCSR units tested had a leak rate less than 100 ml/min, and 72 of 78 SCSR units tested 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 14 minutes because the breathing bag was empty and the percent inspired O_2 level had decreased to less than 7.0%. All M-20 SCSR units exceeded the NIOSH-approved 10-minute service time. The average duration for all Ocenco M-20 SCSR units was 16 minutes.

While all 77 SCSR units provided acceptable inspired CO_2 levels for the NIOSH-approved service time of 10 minutes, 12 of the 77 M-20 SCSR units exceeded 4% CO_2 prior to oxygen expenditure (Table 12). However, none of the 12 exceeded 4% CO_2 before the 10-minute service time was reached.

Table 12. Ocenco M-20 SCSR 4% Carbon Dioxide Breakthrough Times

4% CO_2 Breakthrough Time, minutes	Test Duration, minutes	Maximum CO_2, Volume %
12	14	4.87
15	17	5.64
15	18	6.3
16	18	4.88
16	18	5.48
16	16	4.26
16	19	7.3
17	18	5.47
18	19	5.8
18	18	4.44
19	19	4.38
19	20	4.8

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 F (Figures 45 through 50). Ten-minute data averaging, consistent with service time, was chosen to eliminate the test duration variability effect in the determination of stressor levels. NIOSH NPPTL sorted the mine-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. Stressor value data points for Ocenco M-20 SCSR units in storage at NIOSH NPPTL are shown in red for comparison with the mine-deployed units. A linear regression is 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 are identified. An increase in inspired breathing resistance as a function of increased deployment time is suggested in Figure 49.

Test duration and composite average mean stressor levels, including FIO2, FICO2, PEPRS, PIPRS, and TAVGDB, are shown for the in storage and mine-deployed Ocenco M-20 SCSR units in Table 13. The percent difference between mine-deployed unit mean stressor values versus in storage unit stressor mean values, relative to mine-deployed unit mean stressor values, is also shown in Table 13.

Table 13. Ocenco M-20 Duration and Composite Mean Stressor Levels						
	DURATION	FIO2	FICO2	PEPRS CMH2O	PIPRS CMH2O	TAVGDB
M-20 Deployed Unit Data (77 tests)						
MIN	11	0.2352	0.0022	23.57	-82.73	34.84
MAX	20	0.8080	0.0159	57.05	-40.37	44.38
AVERAGE	16.2	0.4977	0.0062	31.11	-54.39	38.92
% Difference	17.90	9.65	-4.49	12.62	1.37	-3.89
M-20 NIOSH In Storage Unit Data (8 tests)						
MIN	18	0.3893	0.0052	16.33	-64.14	39.34
MAX	20	0.5053	0.0078	31.93	-44.30	41.49
AVERAGE	19.0	0.4538	0.0065	27.62	-53.66	40.49

Conclusion

Mine Operators

All 326 SCSR units for which valid test data was obtained (286 original and 40 supplemental) demonstrated the expected life support capacity over the course of the manufacturers' specified service time. Breathing resistances measured for all SCSRs tested were well within limits accepted as tolerable (-300 to +200 mm H_2O) based on research conducted at Noll Laboratory at Penn State University. As 7.5% of the SCSR units collected at the mines did not meet the visual inspections, miners should continue to inspect their units daily to ensure those not meeting visual inspection requirements are removed from the mines. Overall, very little degradation in SCSR performance due to deployment time in the mines was observed.

Manufacturers

Significant differences observed in measured stressor levels between deployed units and stored units may be due to the smaller sample of stored units tested. During supplemental LTR3 testing of CSE SRLD SCSR units, one stored unit was tested for each of 40 deployed units tested and very minor differences (<1.8%) in all measured stressor levels were observed. This observation provides some support for the need to perform more frequent stored unit testing. Future LTFE evaluations will incorporate additional contemporaneous testing of stored units to validate deployed unit test results. The frequency of in storage unit testing is to be determined.

During 65 original LTR3 tests, inspired CO_2 levels for six mine-deployed CSE SRLD SCSR units exceeded 4.0% prior to the 60-minute service time being reached. During 40 supplemental tests, inspired CO_2 levels for three additional mine-deployed CSE SRLD SCSR units exceeded 4.0% prior to reaching the 60-minute service time. Thus, supplemental test results corroborated these original results at the same rate of occurrence (7.5%).

Twenty-nine of the last 32 mine-deployed CSE SRLD SCSR units and 32 of the last in storage CSE SRLD SCSR units tested during supplemental LTR3 testing had quantitative sound level measurements ≤27 dB. Inspired CO_2 levels measured for these 53 tests ranged from 1.48% to 2.05%. Inspired CO_2 levels for the three remaining mine-deployed CSE SRLD SCSR units with the three highest quantitative sound level measurements were >2.45%. This suggests direct correlation between quantitative sound level measurements and inspired CO_2 levels for these units. It is further observed that a reduction in the current pass/fail level (cited as 60 dB by CSE), while eliminating more units capable of keeping CO_2 concentrations in the desired range, has at least the potential to eliminate units likely to yield CO_2 concentrations above that range.

Consistent operation of the ABMS and simulation of the manufacturer's start-up procedure for the SCSR being tested is critical in obtaining valid and consistent test data for future LTFE studies. NIOSH NPPTL has prepared detailed work instructions for these test processes which will be reviewed and updated as necessary. Training of ABMS test operators in these work instructions will be performed on a regular basis to assure the ABMS is consistently operated per these procedures.

There are numerous challenges associated with collecting a statistically valid sample of units, testing those units, and reporting on the results in a timely manner. Consequently, NIOSH NPPTL has initiated an effort to explore alternative collection and reporting strategies with the objectives of positively impacting mine operator and user safety and influencing manufacturer technology improvements.

Appendix A: Acronyms and Abbreviations

Acronyms and Abbreviations

ABMS	automated breathing and metabolic simulator
BMS	breathing and metabolic simulation
CFR	code of federal regulations
CO	carbon monoxide
CO_2	carbon dioxide
CPIP	certified product investigation process
dB	decibels
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 column
PIPRS CMH20	peak inspired pressure, centimeters of water column
SCSR	self-contained self-rescuer
TAVGDB	average dry bulb temperature over inspired breath, ^{o}C
TAVGWB	average wet bulb temperature over inspired breath, ^{o}C
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 CSE SRLD SCSRs Stressors

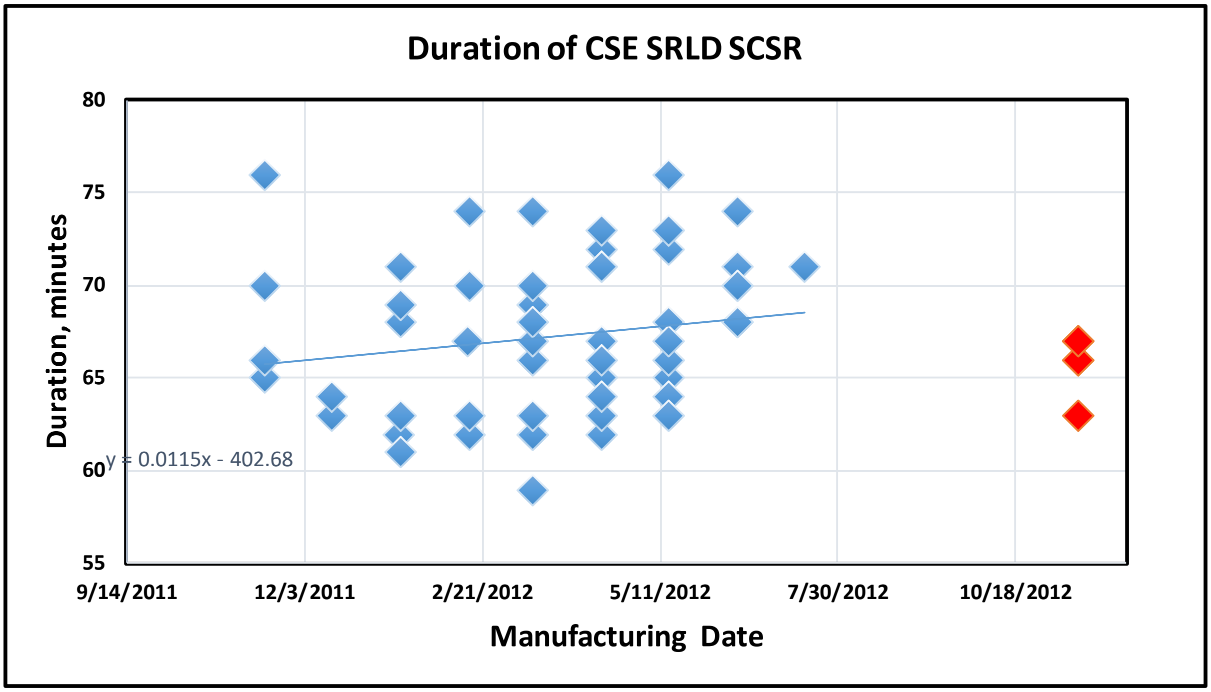

Figure 15. Duration of Deployed and New CSE SRLD Self-Contained Self-Rescuers

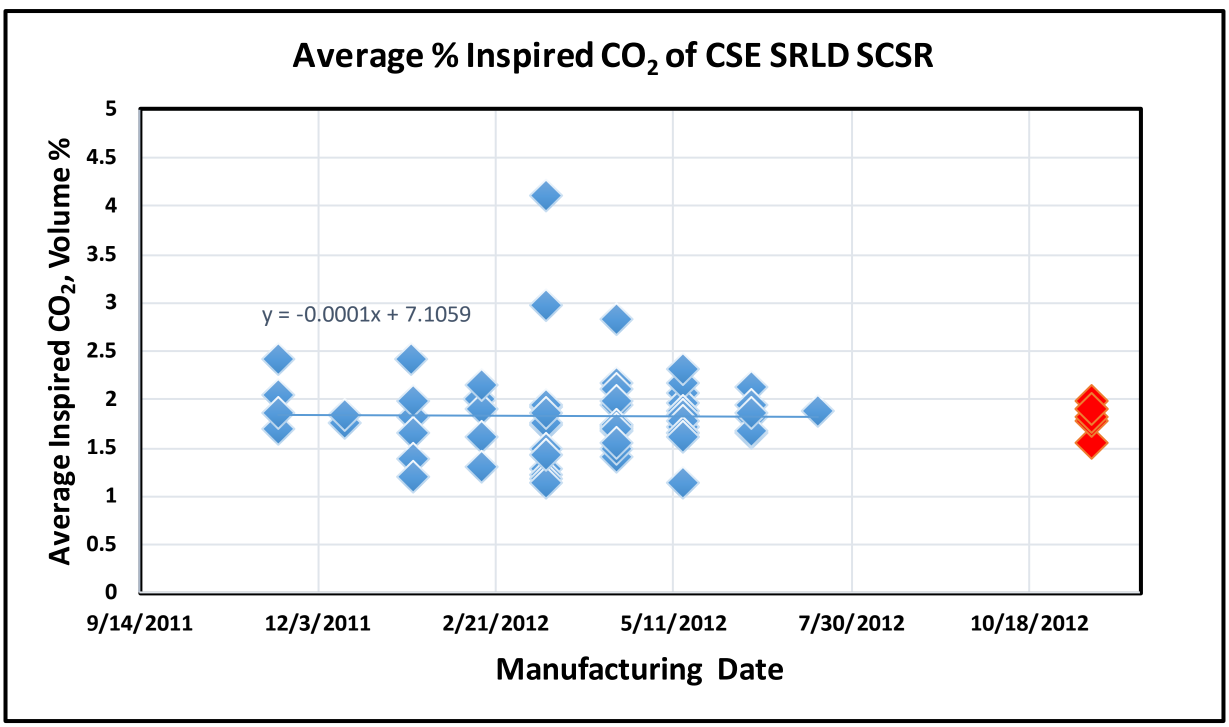

Figure 16. 60-Minute Average Percent Inspired Carbon Dioxide of Deployed and New CSE SRLD Self-Contained Self-Rescuers

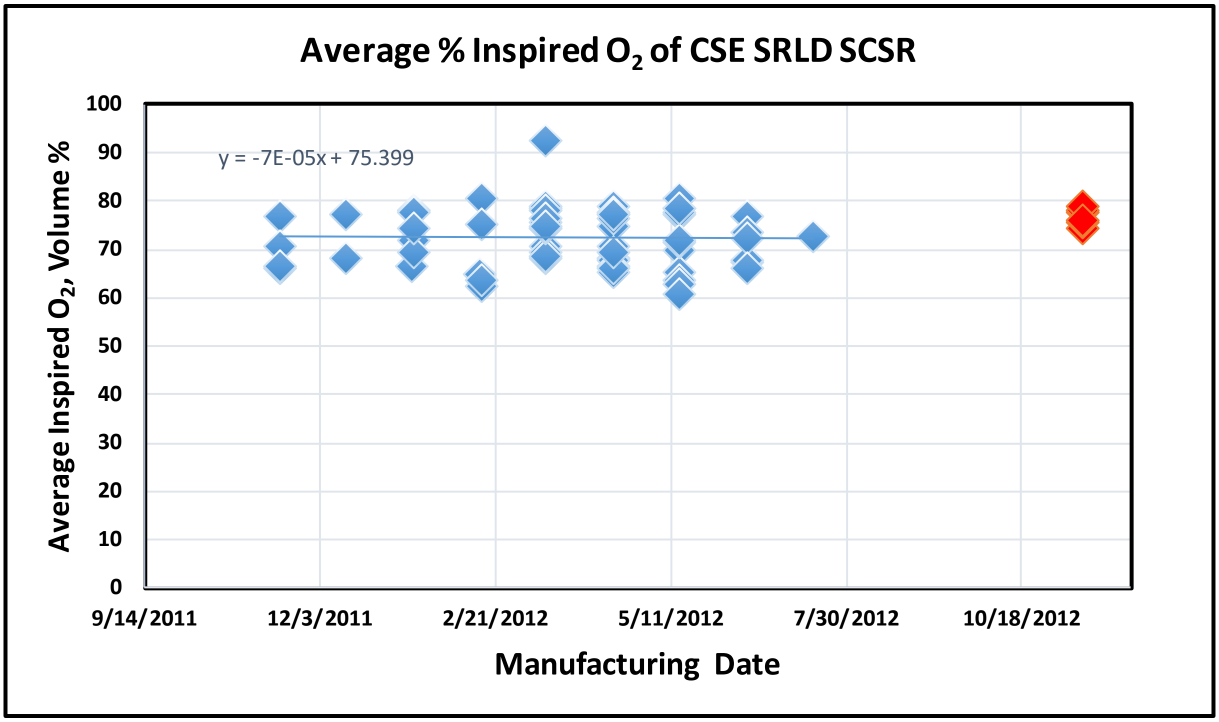

Figure 17. 60-Minute Average Percent Inspired Oxygen of Deployed and New CSE SRLD Self-Contained Self-Rescuers

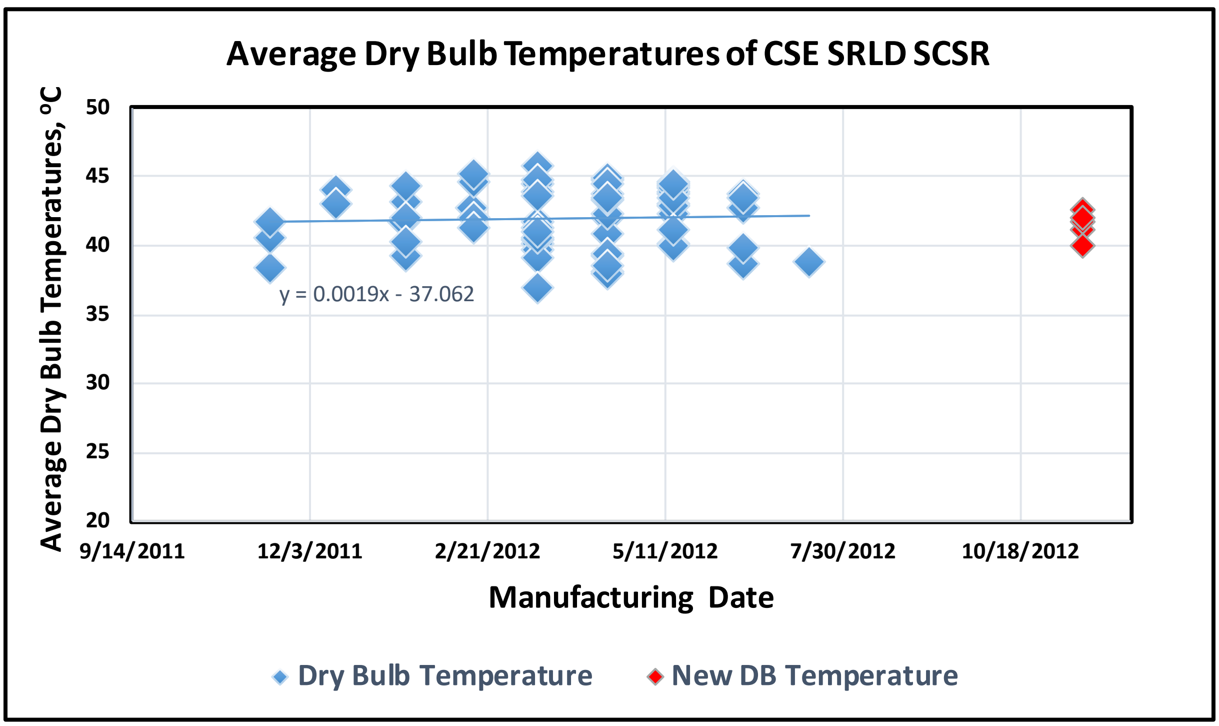

Figure 18. 60-Minute Average Dry-Bulb Temperatures of Deployed and New CSE SRLD Self-Contained Self-Rescuers

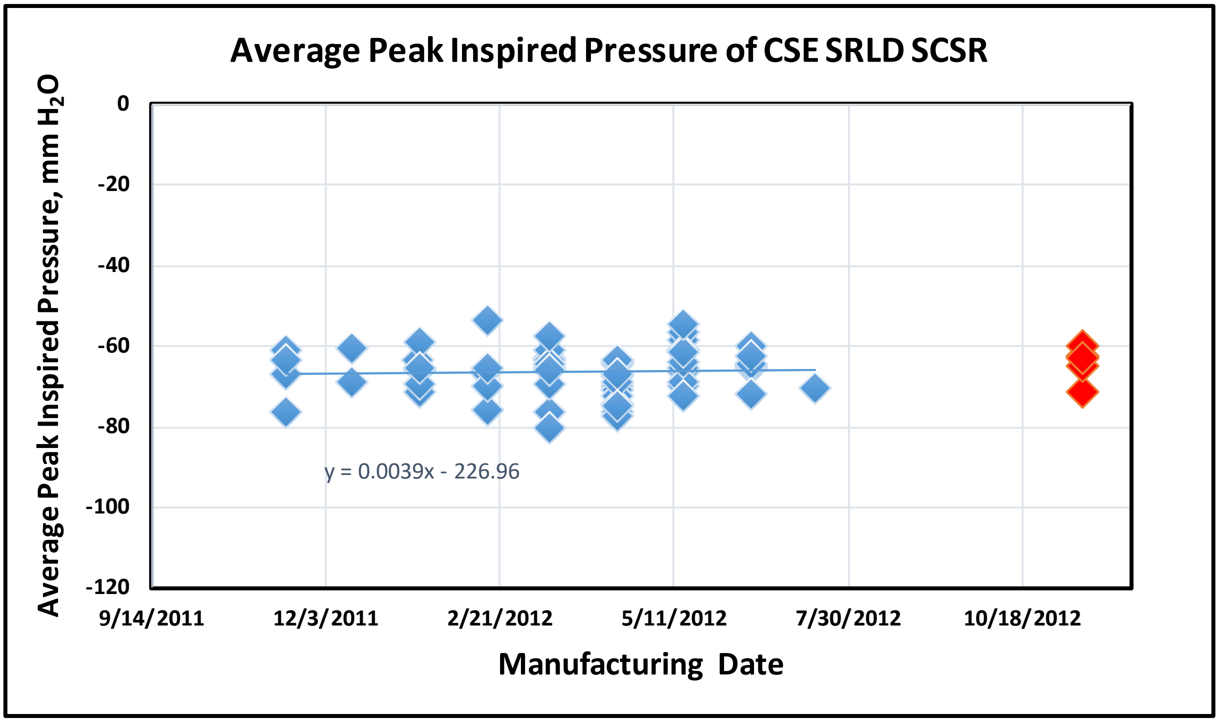

Figure 19. 60-Minute Average Peak Inspired Pressure of Deployed and New CSE SRLD Self-Contained Self-Rescuers

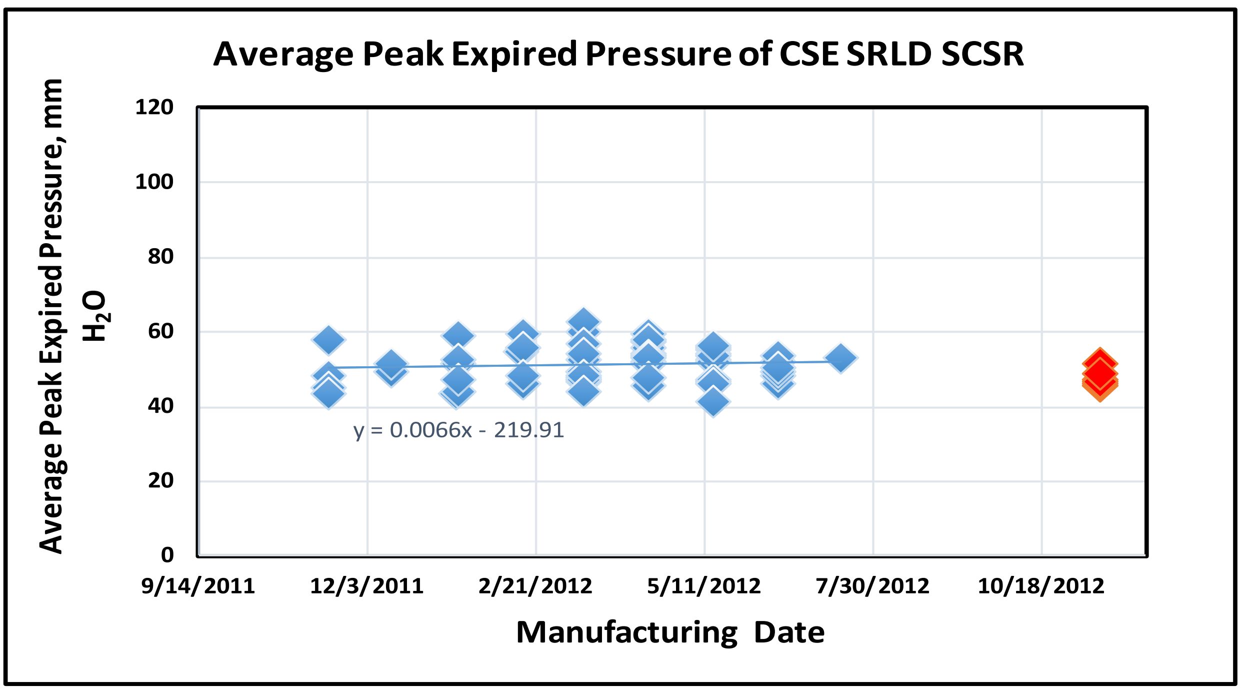

Figure 20. 60-Minute Average Peak Expired Pressure of Deployed and New CSE SRLD Self-Contained Self-Rescuers

Appendix C: BMS Testing of the CSE SRLD SCSRs Stressors – Supplemental LTR3 Testing

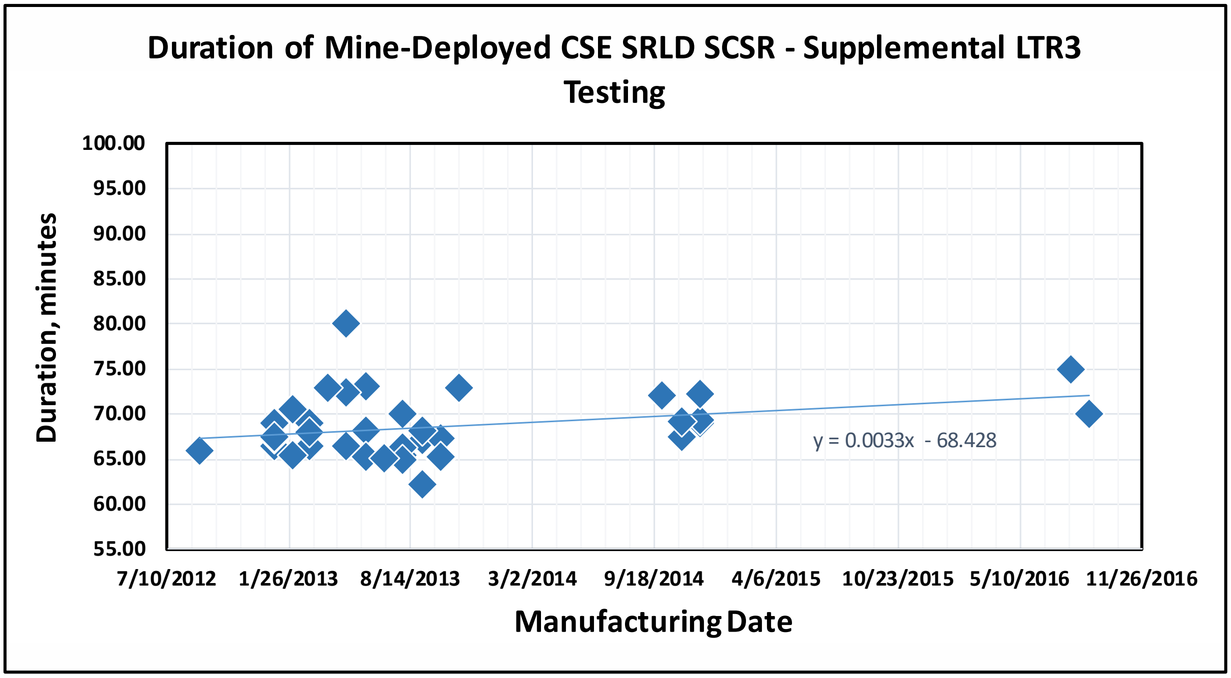

Figure 21. Duration of Deployed CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

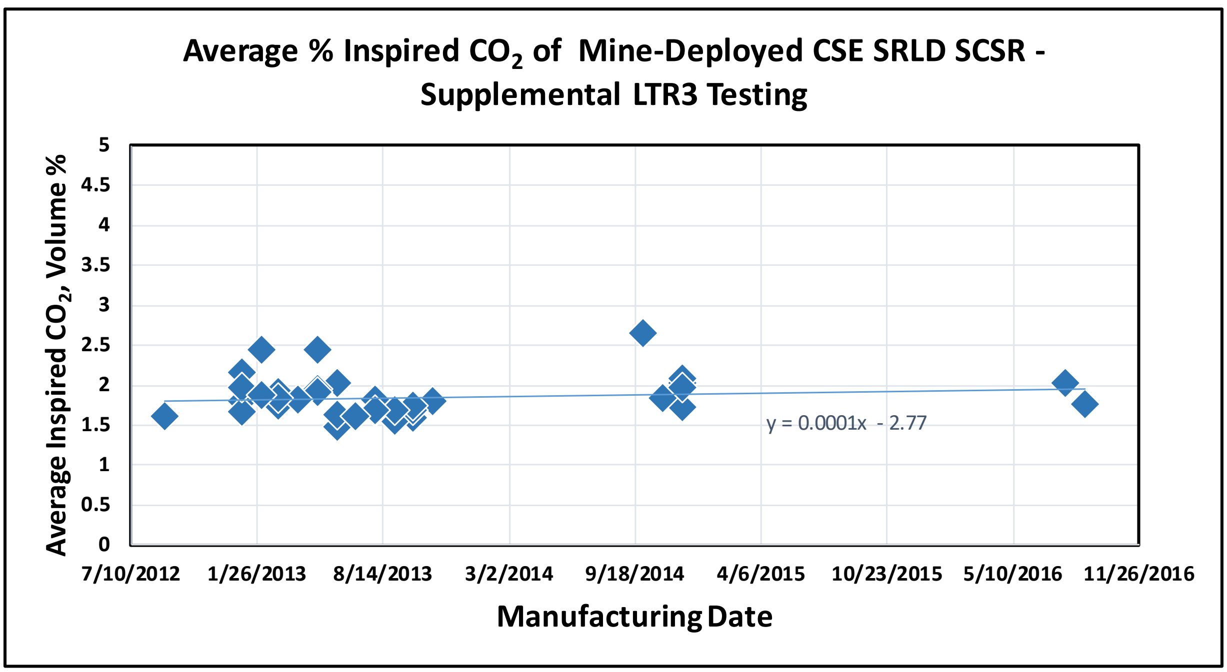

Figure 22. 60-Minute Average Percent Inspired Carbon Dioxide of Deployed CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

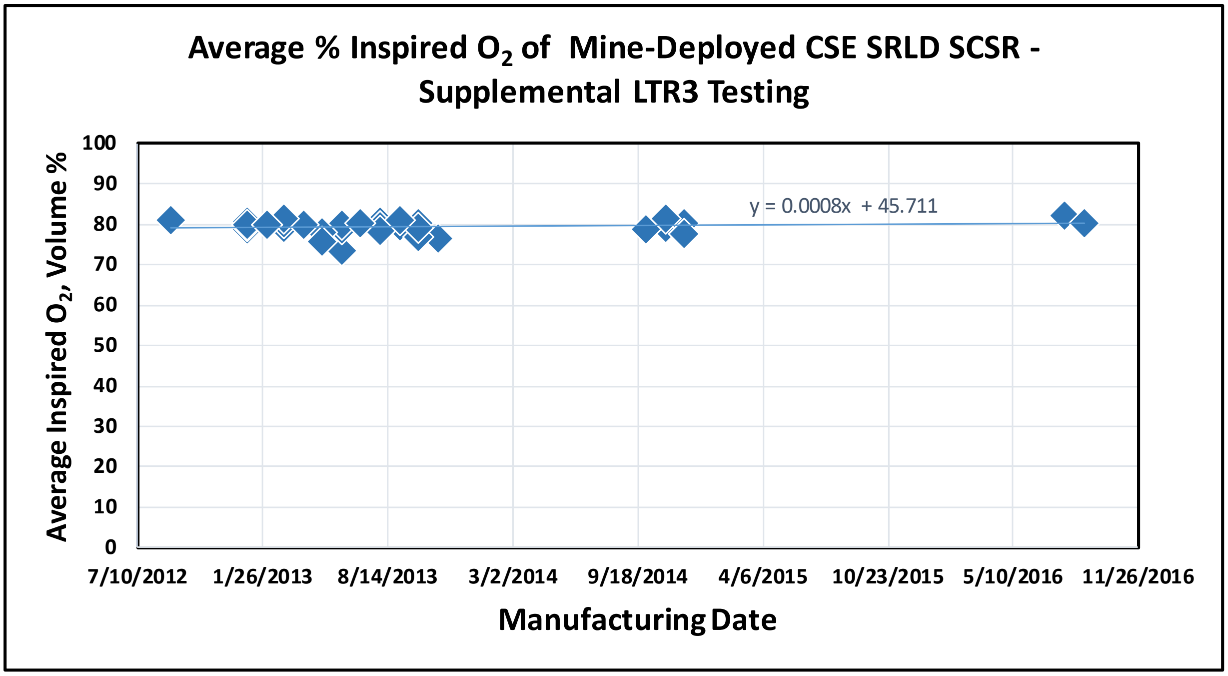

Figure 23. 60-Minute Average Percent Inspired Oxygen of Deployed CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

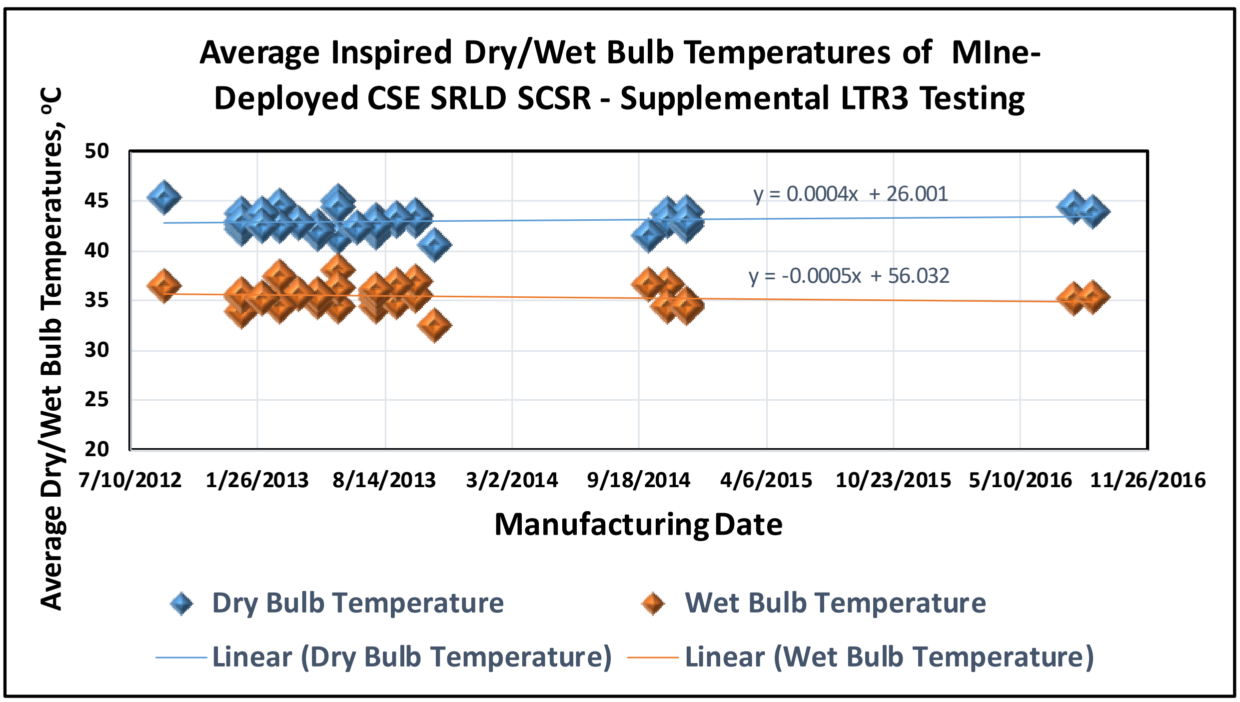

Figure 24. 60-Minute Average Dry/Wet-Bulb Temperatures of Deployed CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

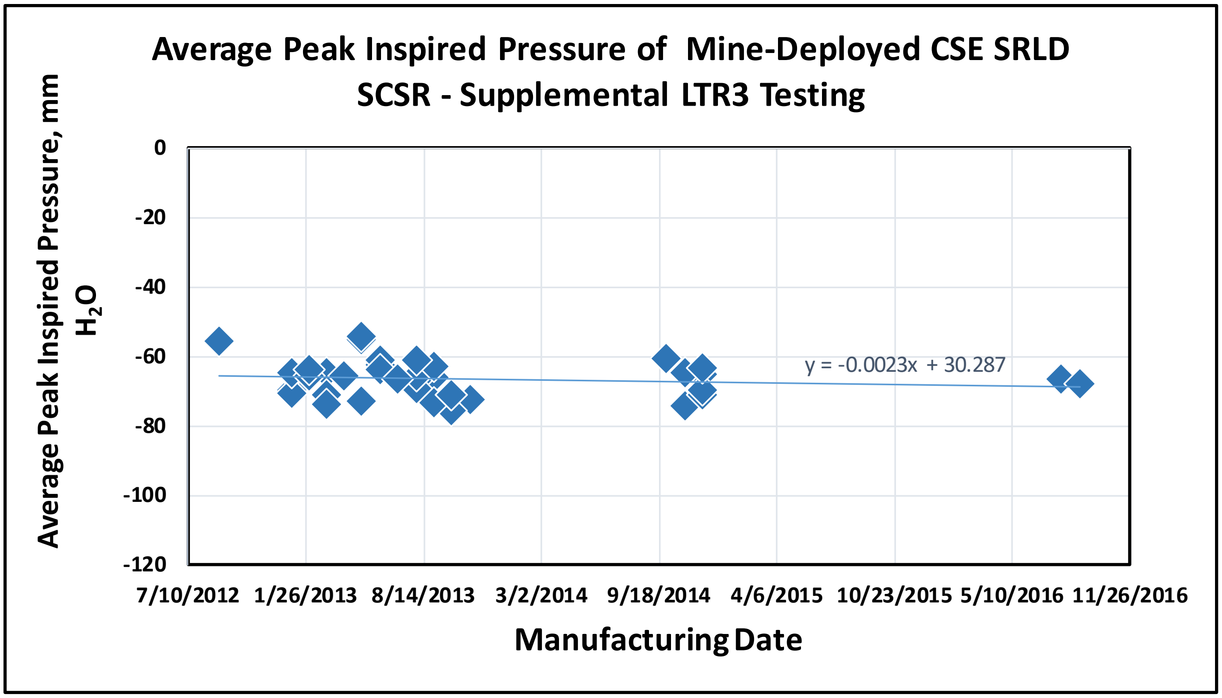

Figure 25. 60-Minute Average Peak Inspired Pressure of Deployed CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

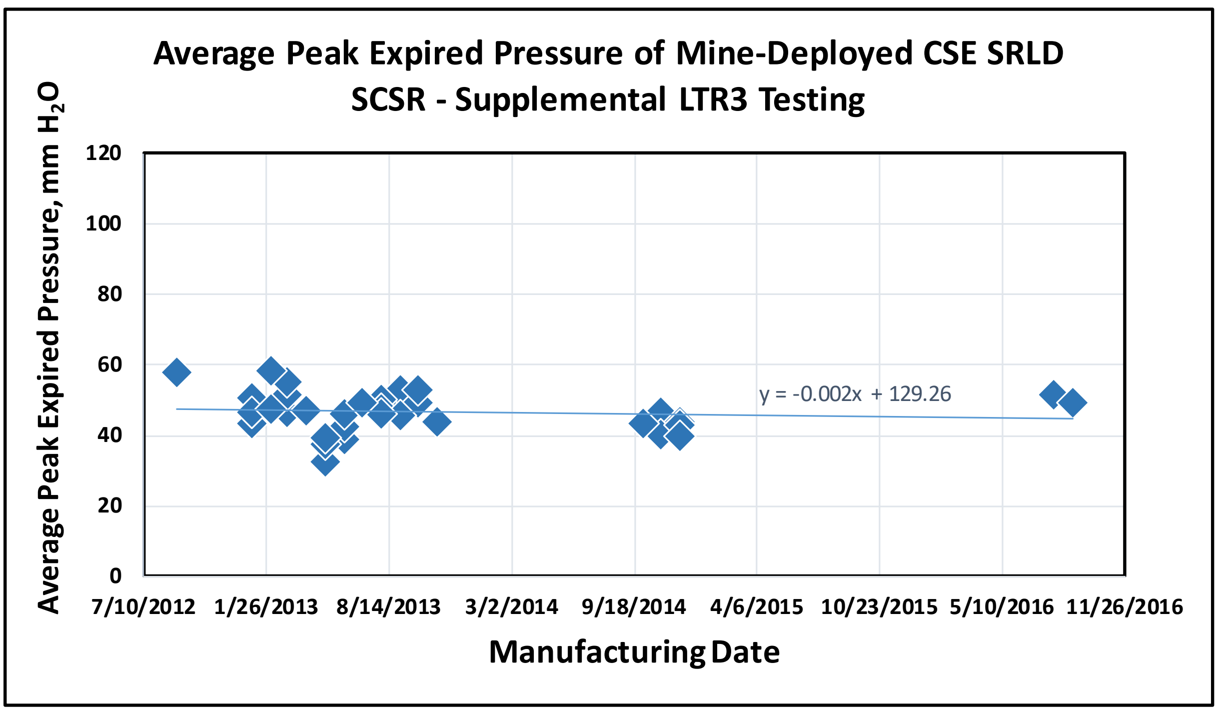

Figure 26. 60-Minute Average Peak Expired Pressure of Deployed SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

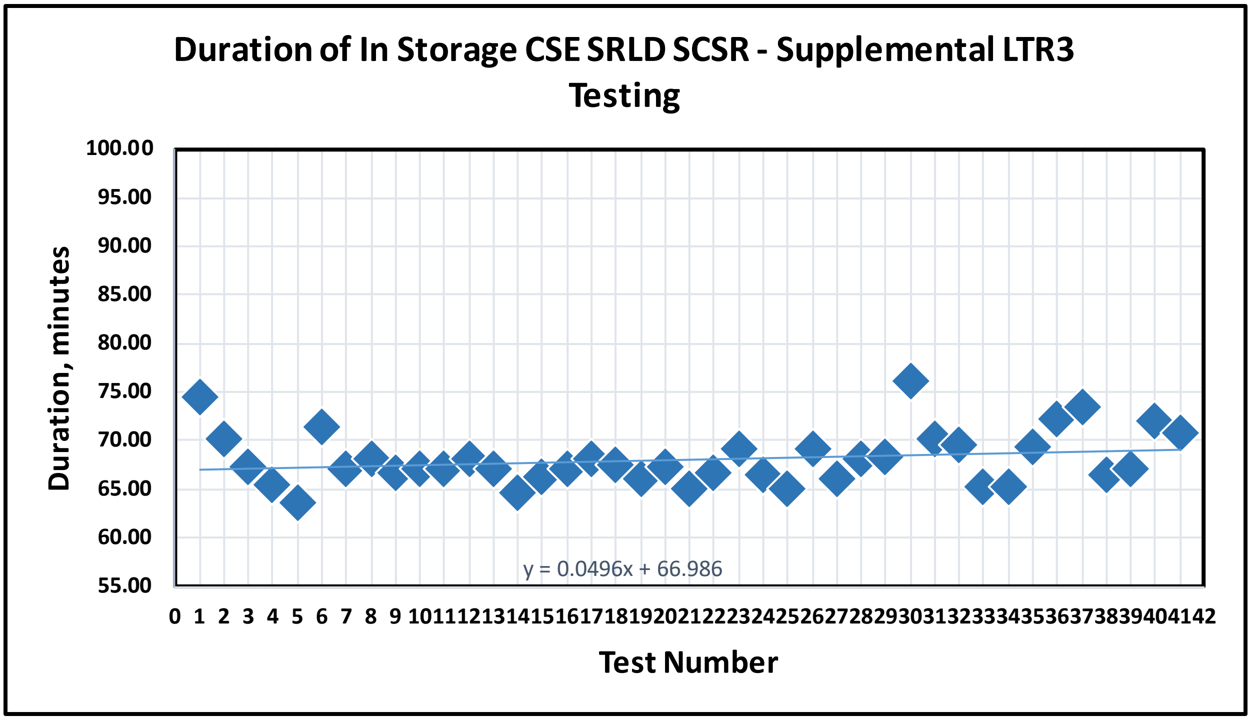

Figure 27. Duration of In Storage CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

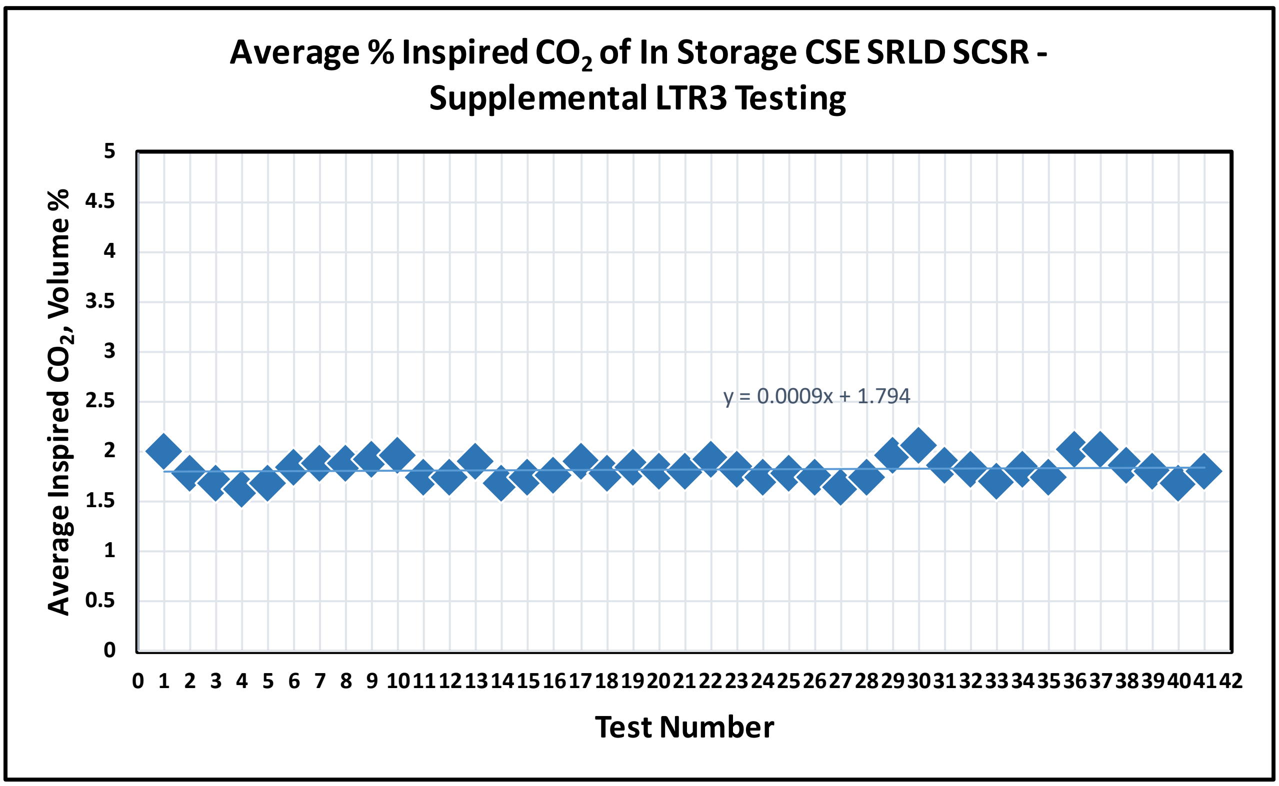

Figure 28. 60-Minute Average Percent Inspired Carbon Dioxide of In Storage CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

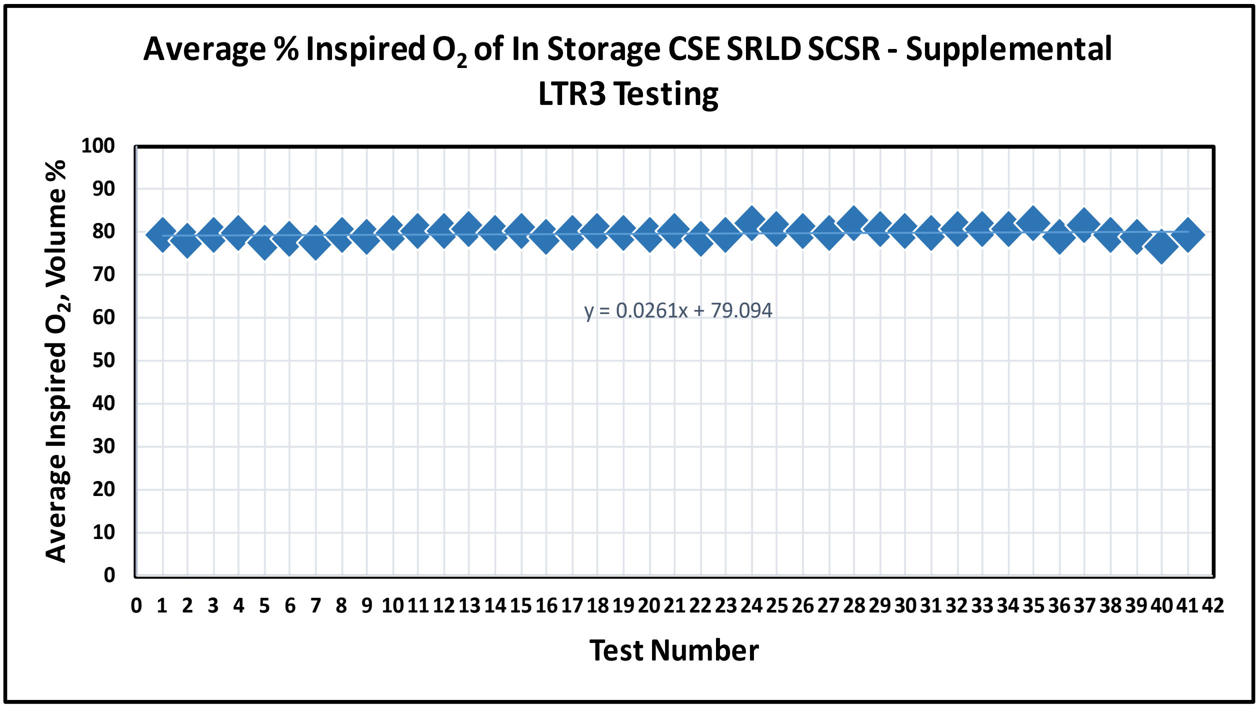

Figure 29. 60-Minute Average Percent Inspired Oxygen of In Storage CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

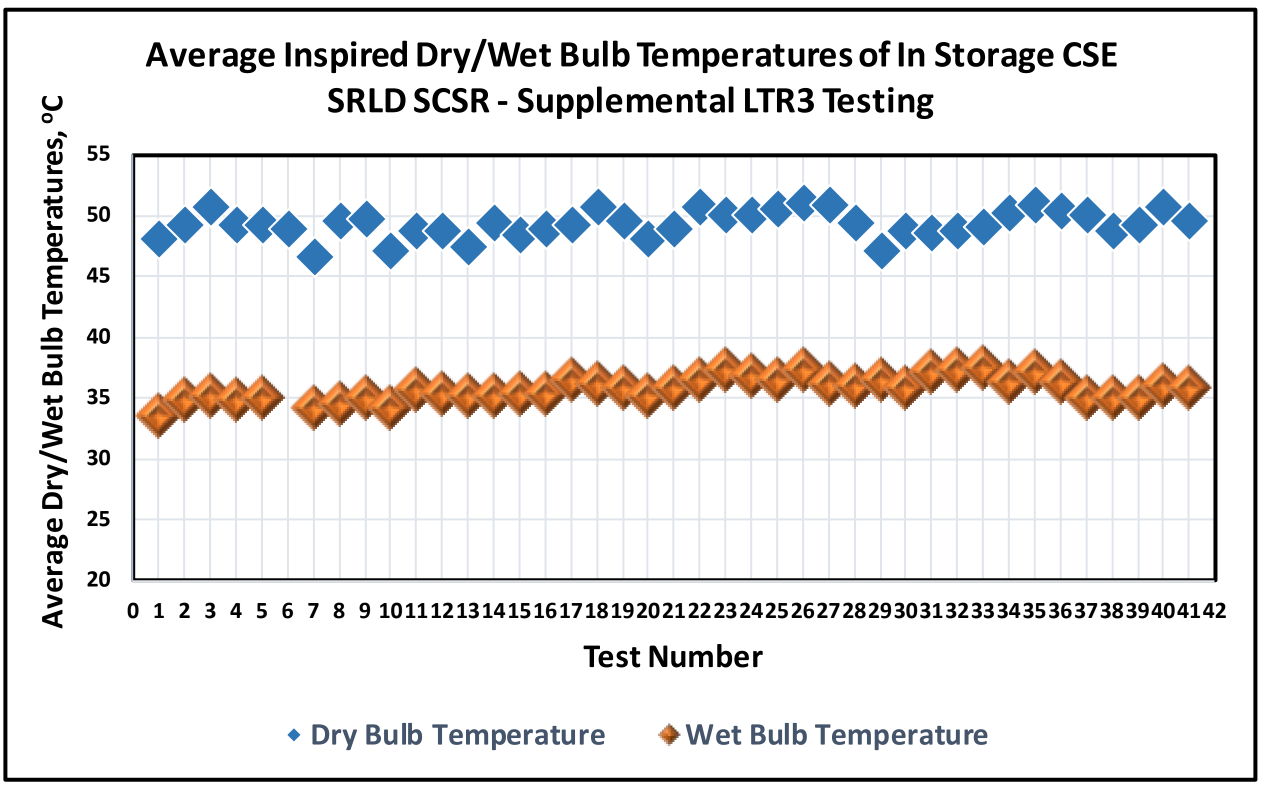

Figure 30. 60-Minute Average Dry/Wet-Bulb Temperatures of In Storage CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

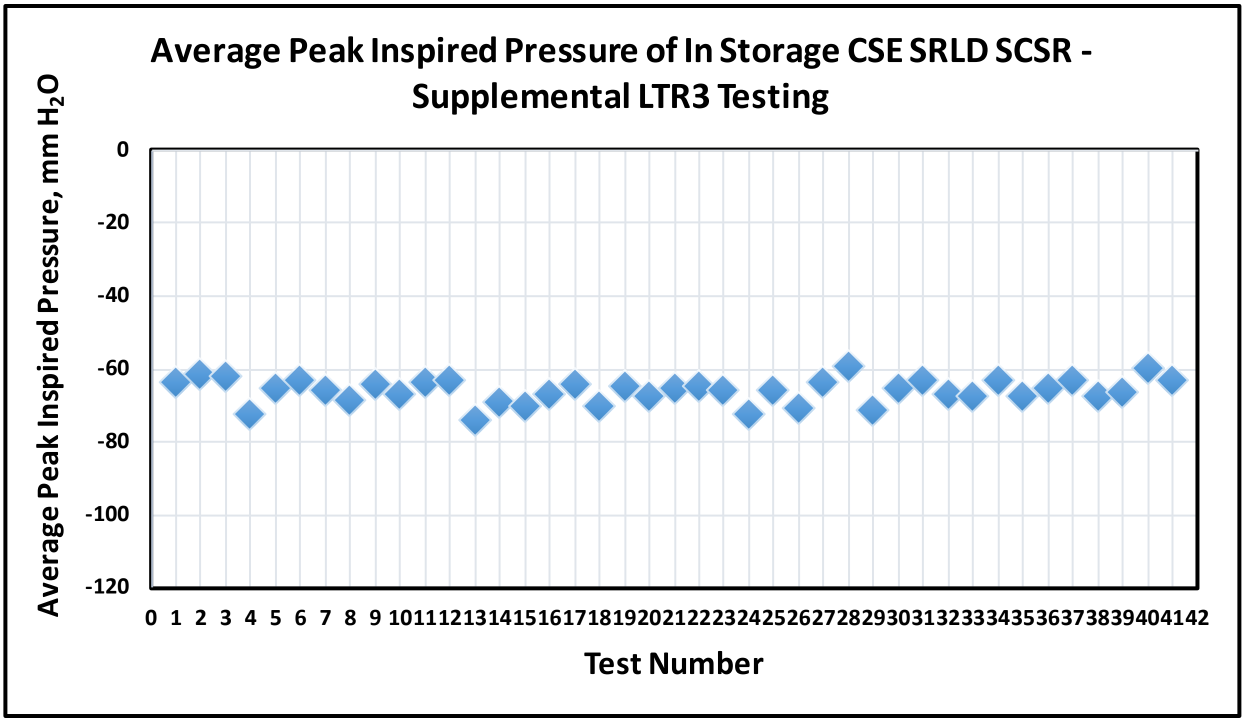

Figure 31. 60-Minute Average Peak Inspired Pressure of In Storage CSE SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

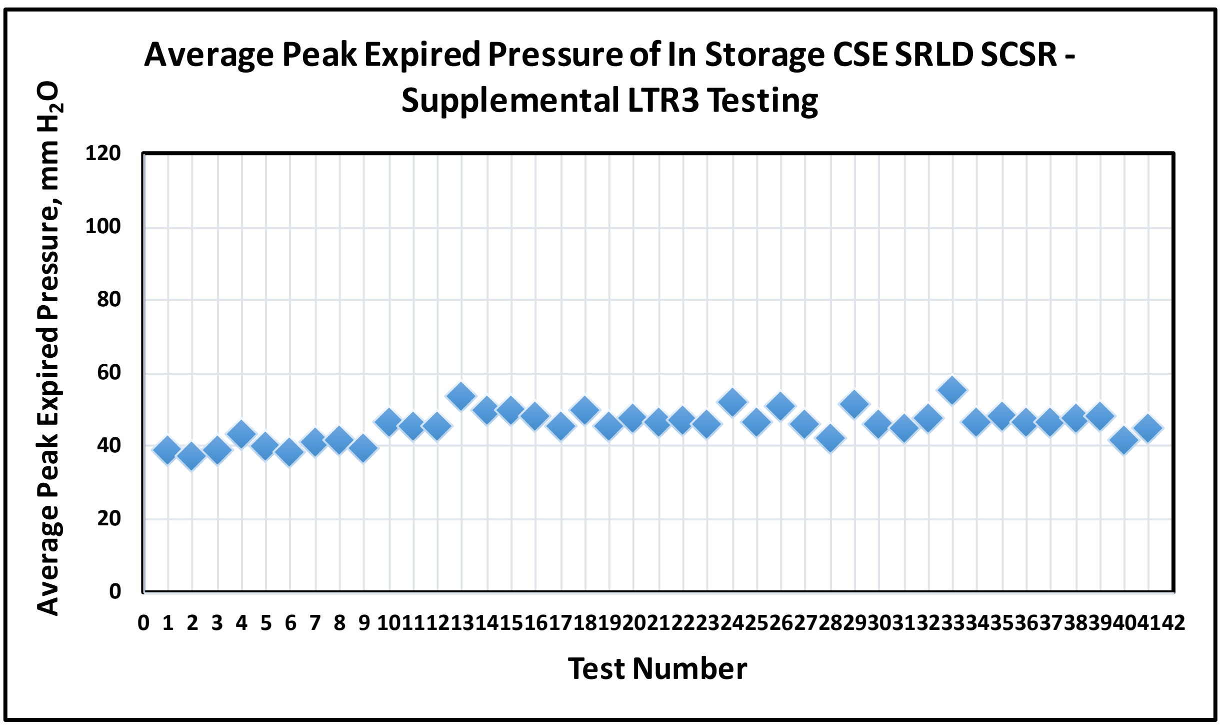

Figure 32. 60-Minute Average Peak Expired Pressure of In Storage SRLD Self-Contained Self-Rescuers – Supplemental LTR3 Testing

Appendix D: BMS Testing of the Dräger Oxy K Plus SCSRs Stressors

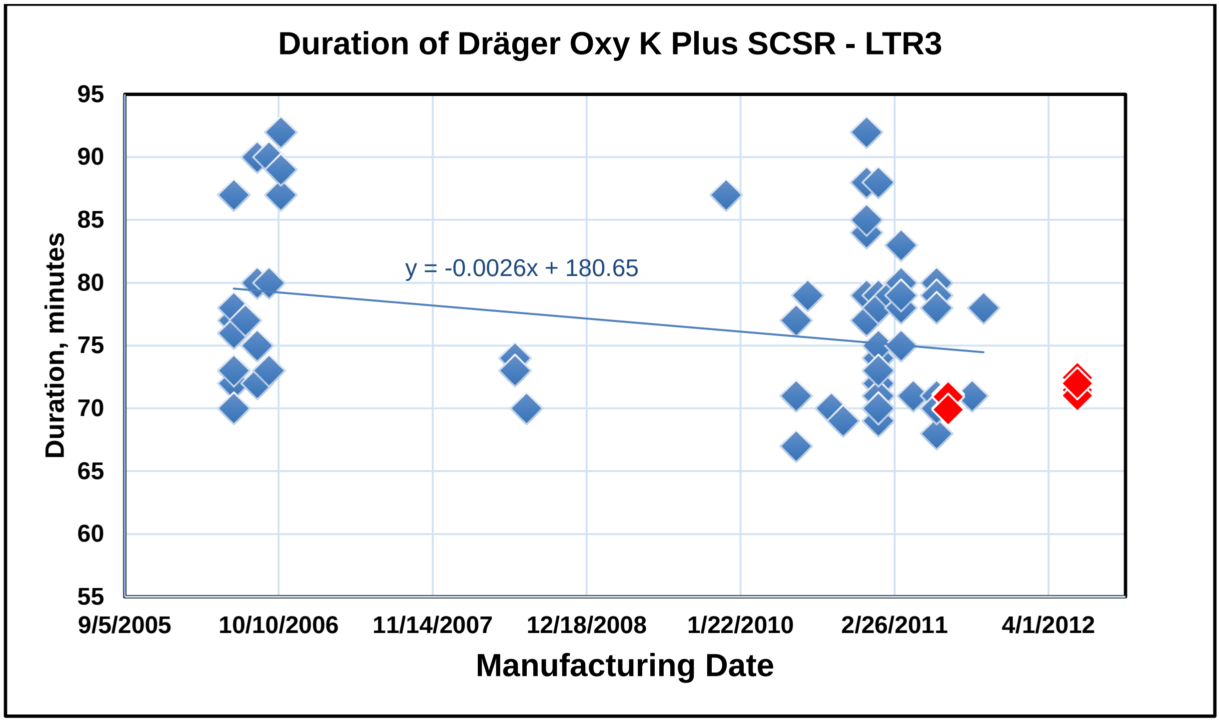

Figure 33. Duration of Field Deployed and New Dräger Oxy K Plus Self-Contained Self-Rescuers

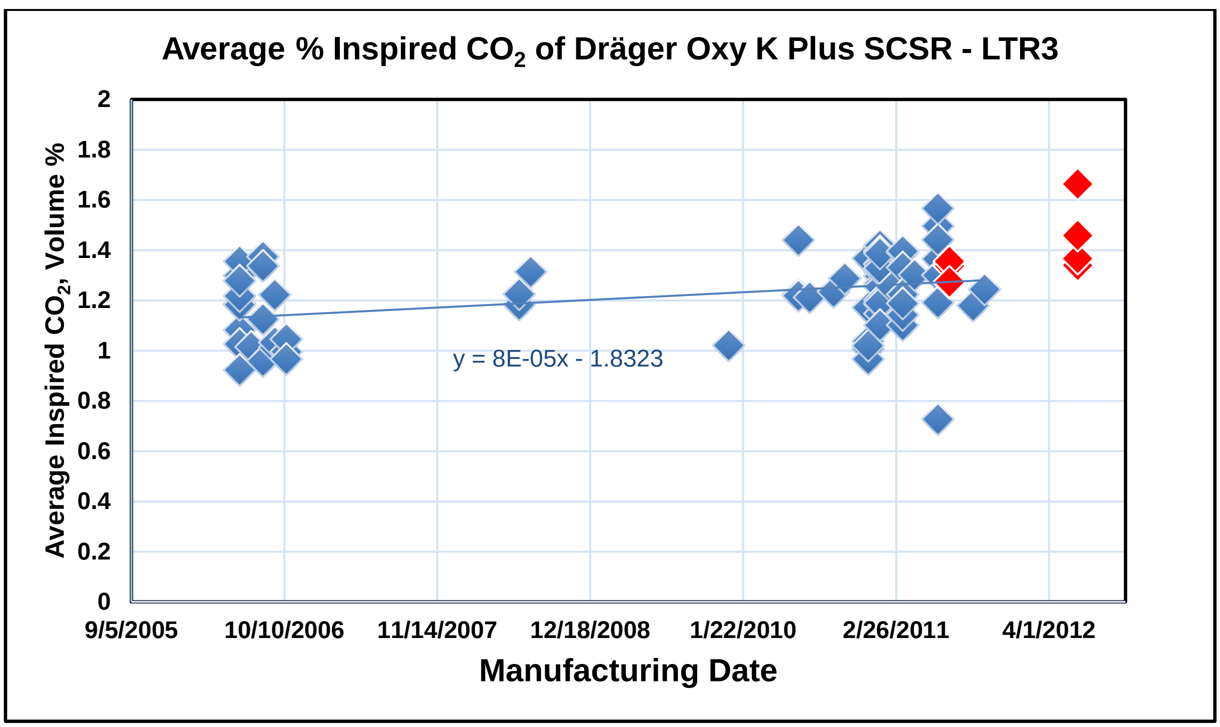

Figure 34. 60-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Dräger Oxy K Plus Self-Contained Self-Rescuers

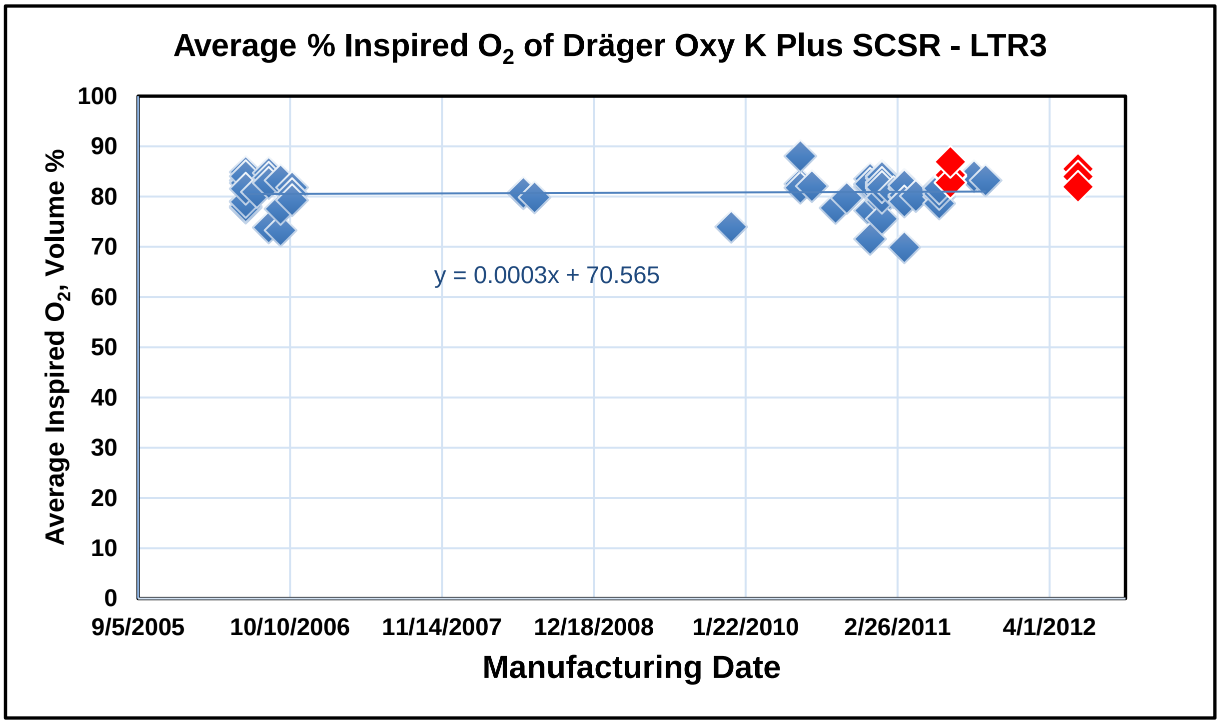

Figure 35. 60-Minute Average Percent Inspired Oxygen of Field Deployed and New Dräger Oxy K Plus Self-Contained Self-Rescuers

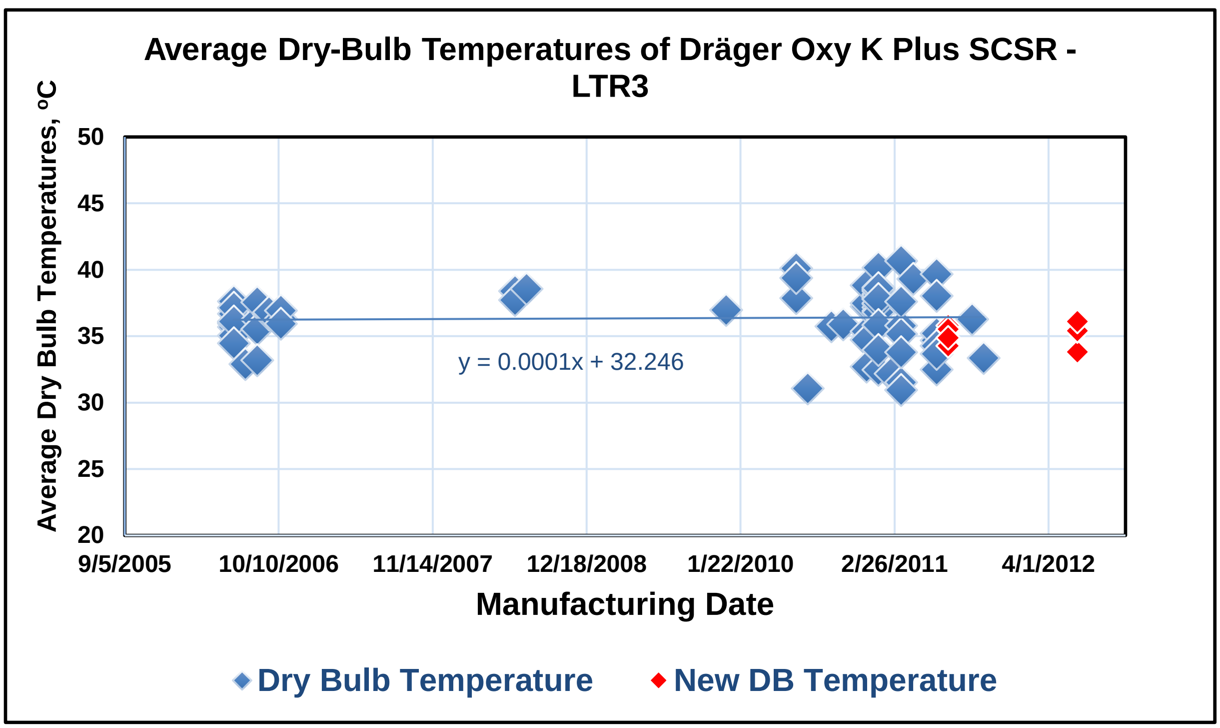

Figure 36. 60-Minute Average Dry-Bulb Temperatures of Field Deployed and New Dräger Oxy K Plus Self-Contained Self-Rescuers

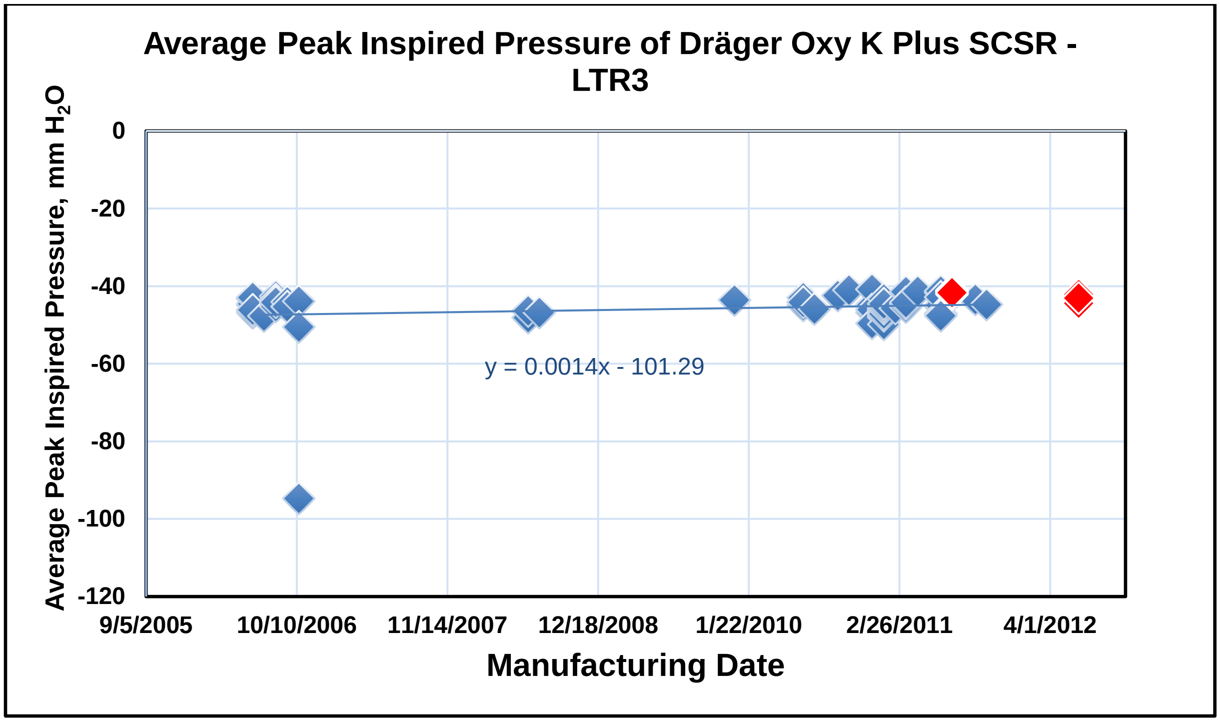

Figure 37. 60-Minute Average Peak Inspired Pressure of Field Deployed and New Dräger Oxy K Plus Self-Contained Self-Rescuers

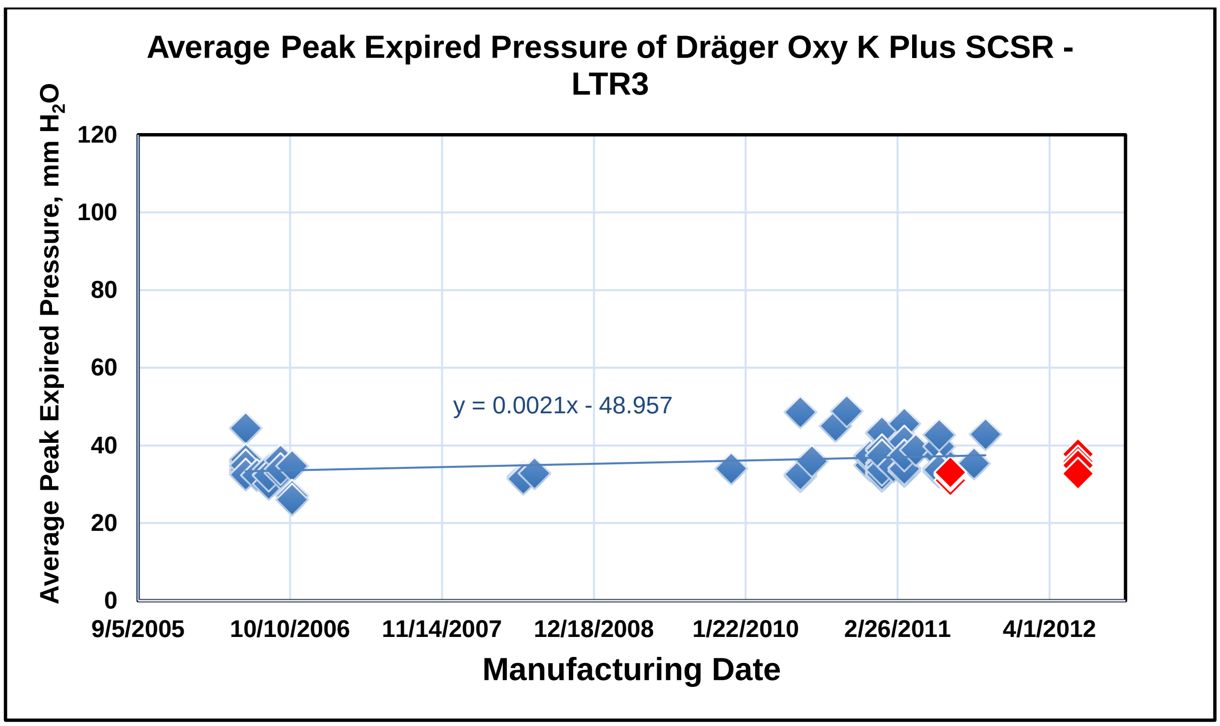

Figure 38. 60-Minute Average Peak Expired Pressure of Field Deployed and New Dräger Oxy K Plus Self-Contained Self-Rescuers

Appendix E: BMS Testing of the Ocenco EBA 6.5 SCSRs Stressors

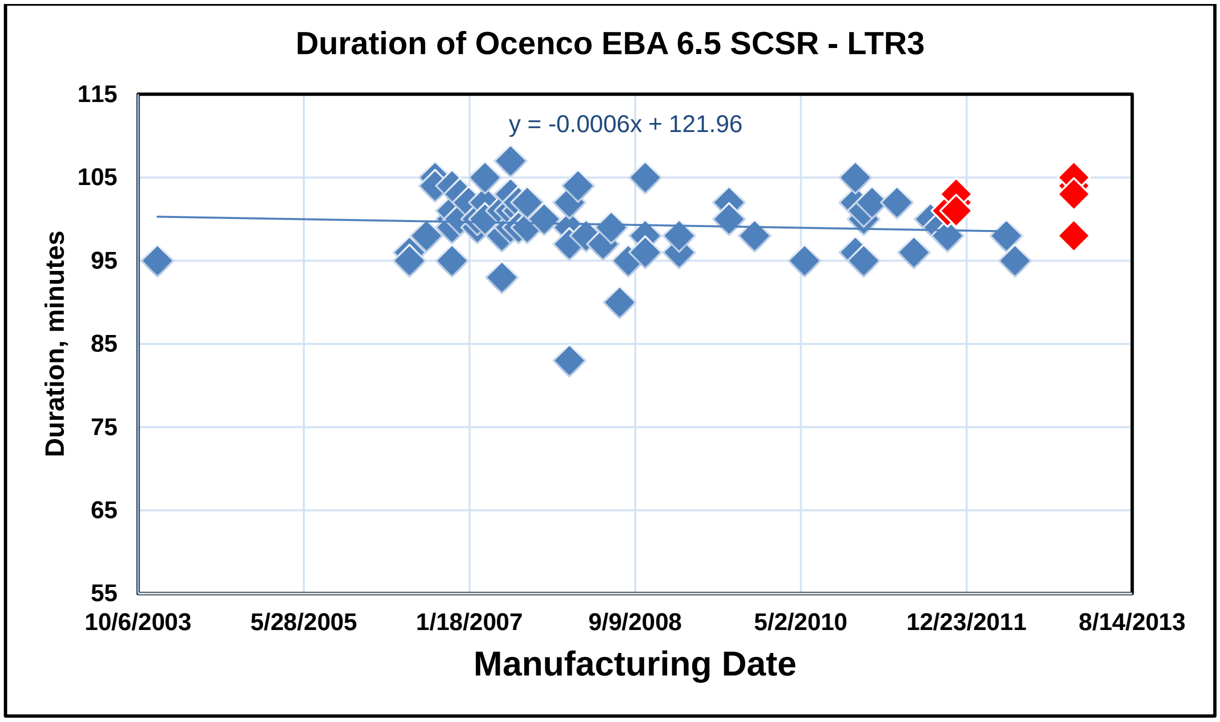

Figure 39. Duration of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

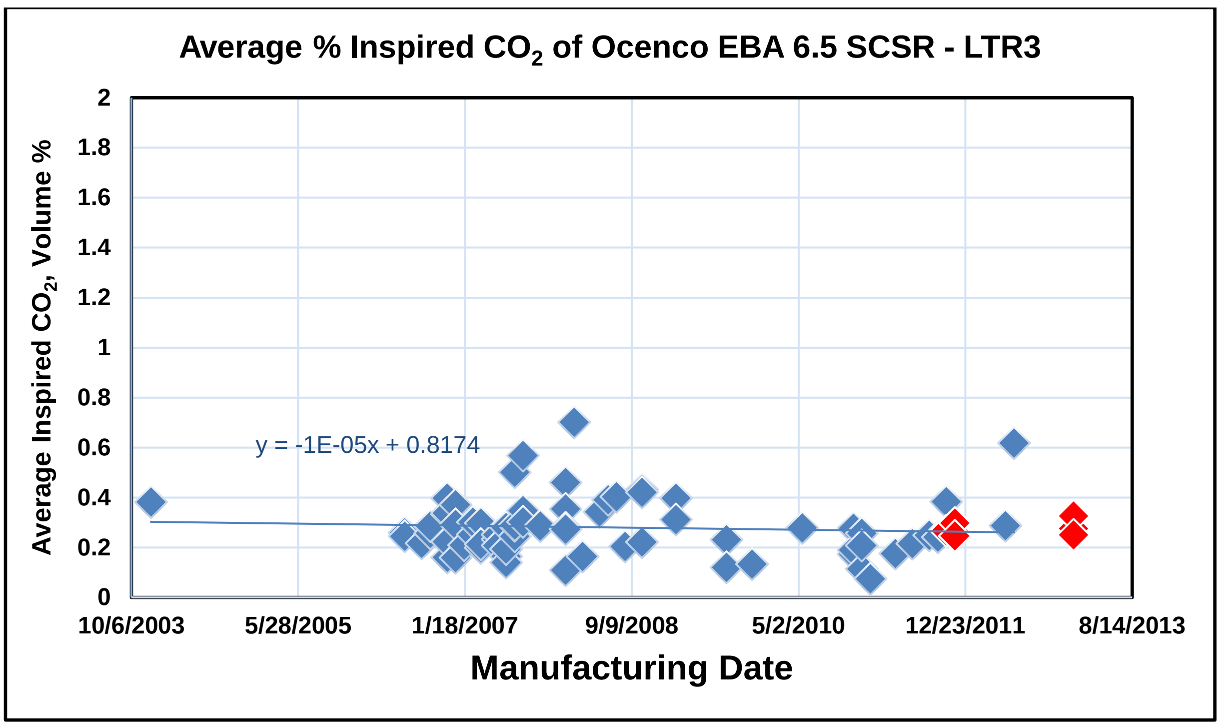

Figure 40. 60-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

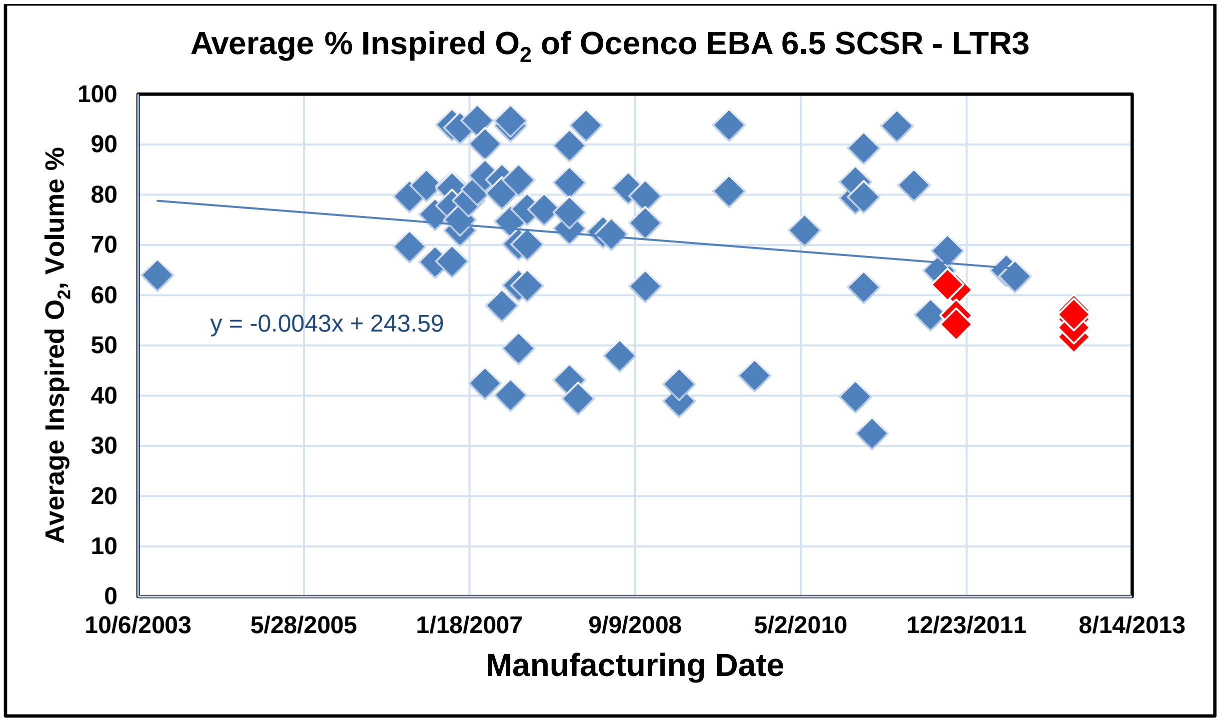

Figure 41. 60-Minute Average Percent Inspired Oxygen of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

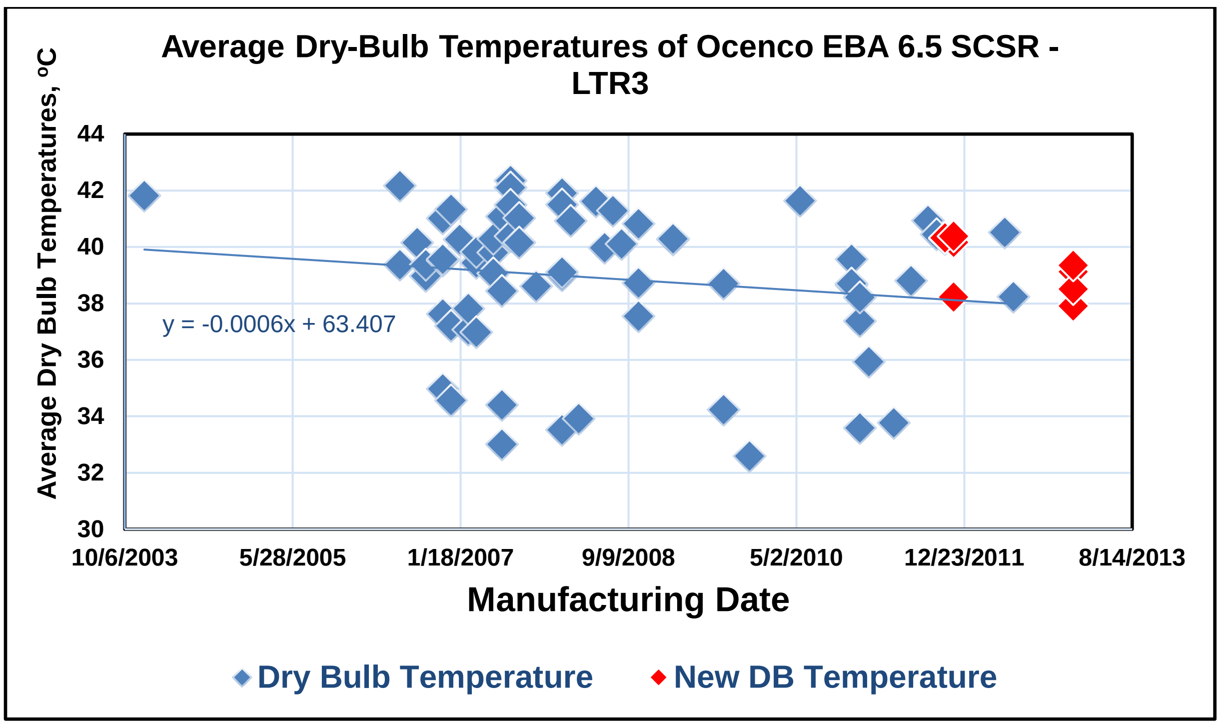

Figure 42. 60-Minute Average Dry-Bulb Temperatures of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

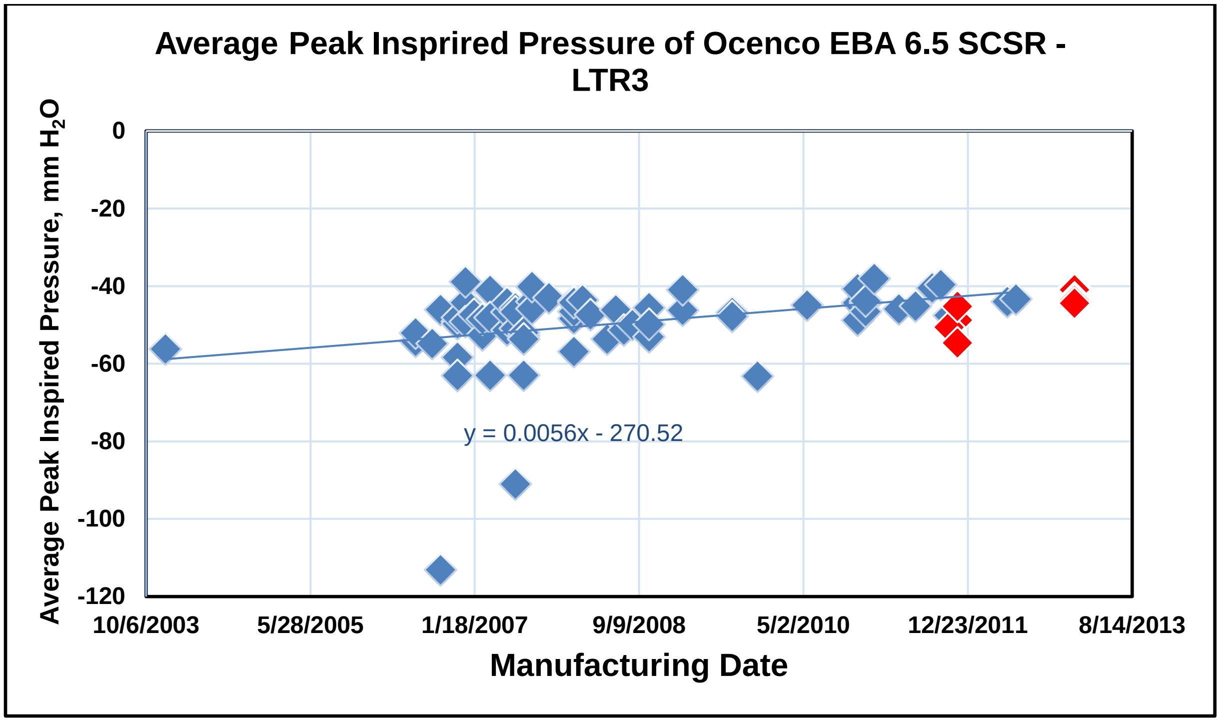

Figure 43. 60-Minute Average Peak Inspired Pressure of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

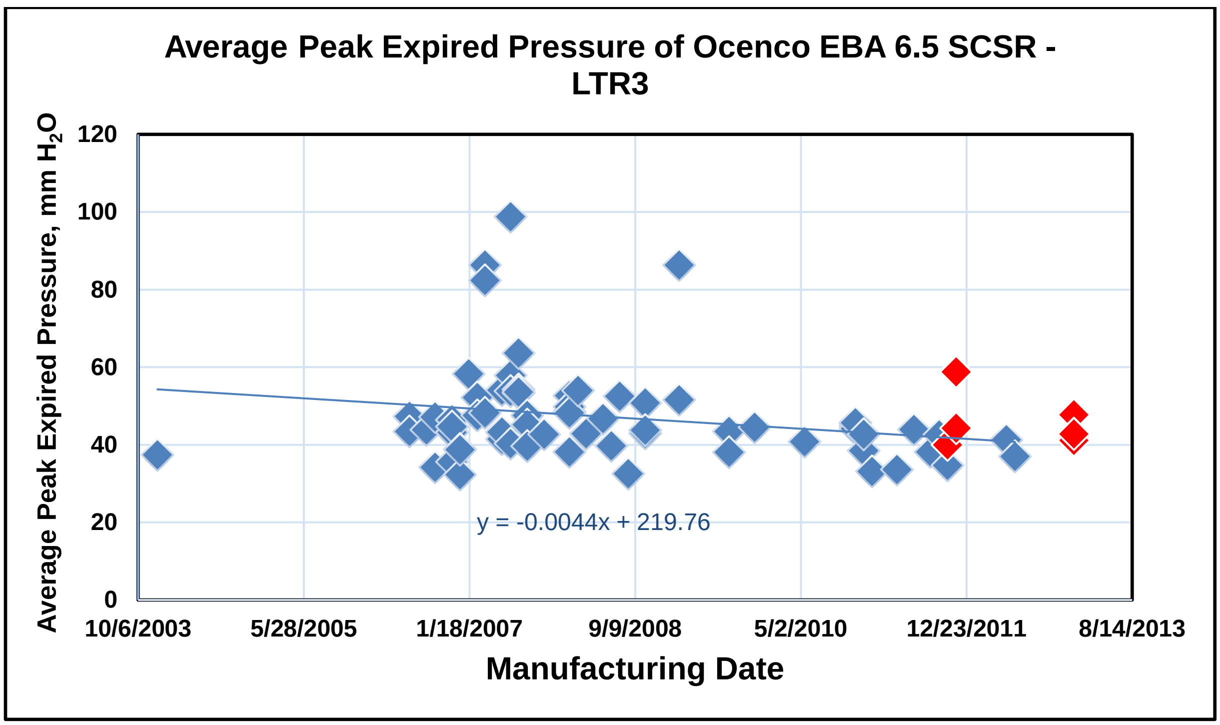

Figure 44. 60-Minute Average Peak Expired Pressure of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

Appendix F: BMS Testing of the Ocenco M-20 SCSRs Stressors

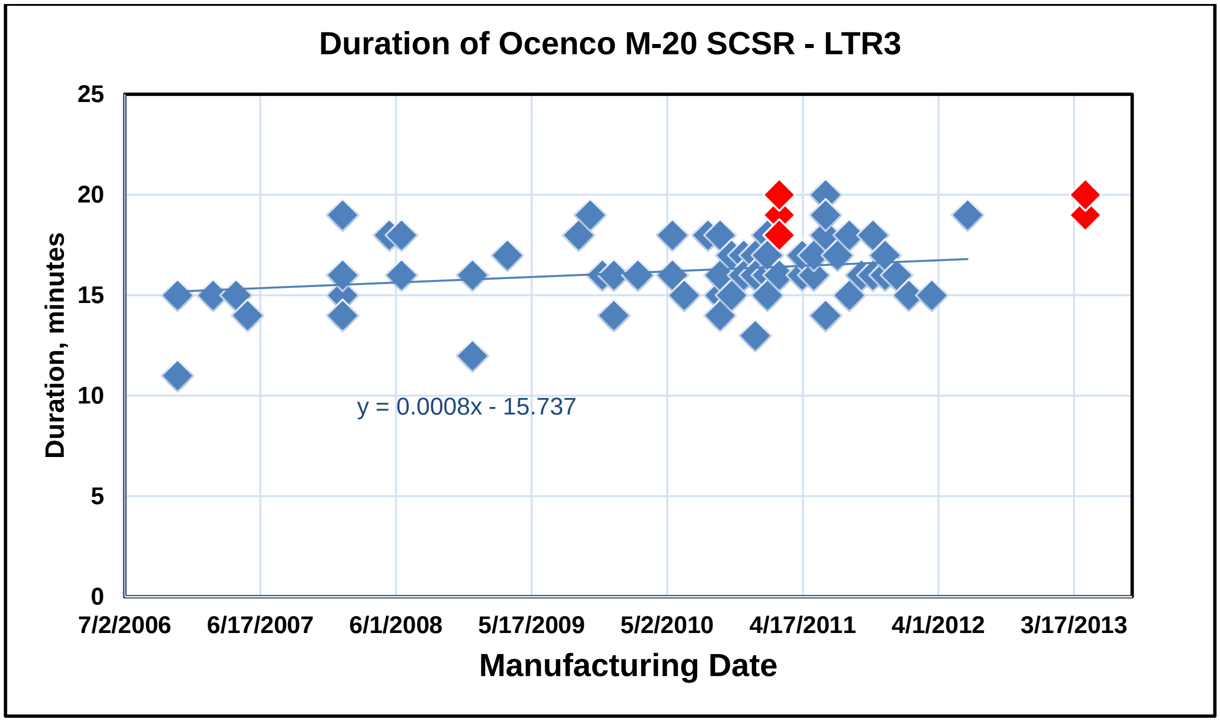

Figure 45. Duration of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

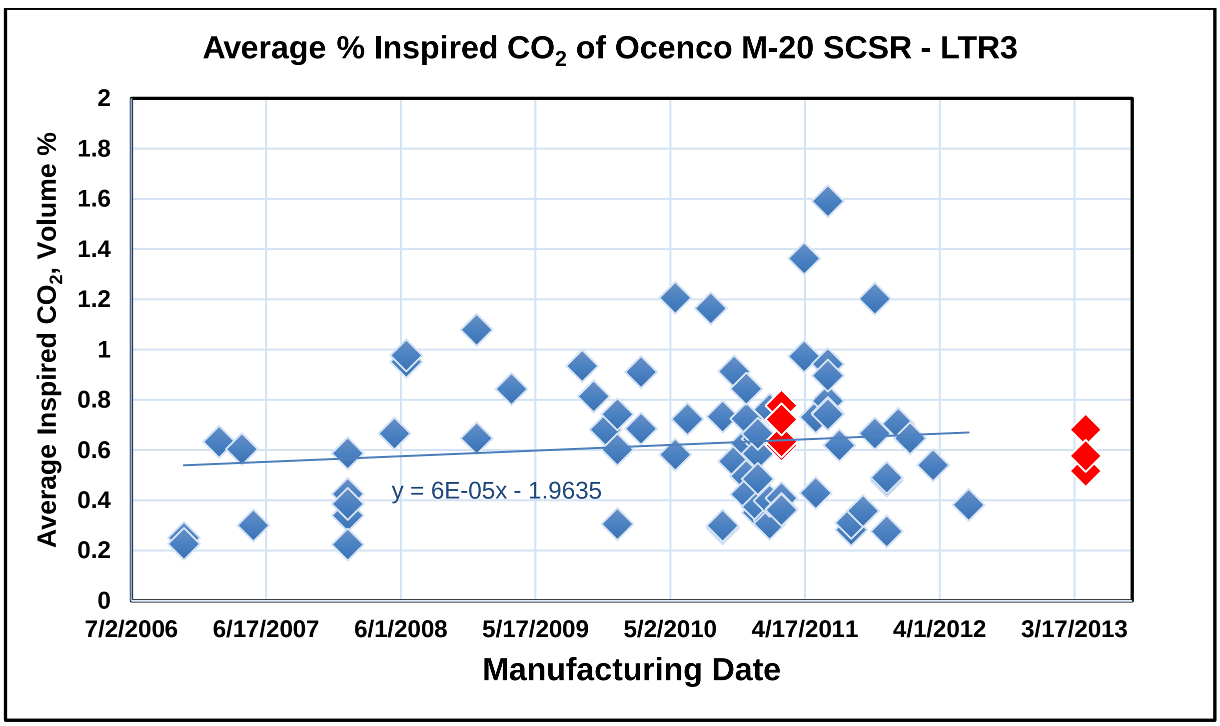

Figure 46. 10-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

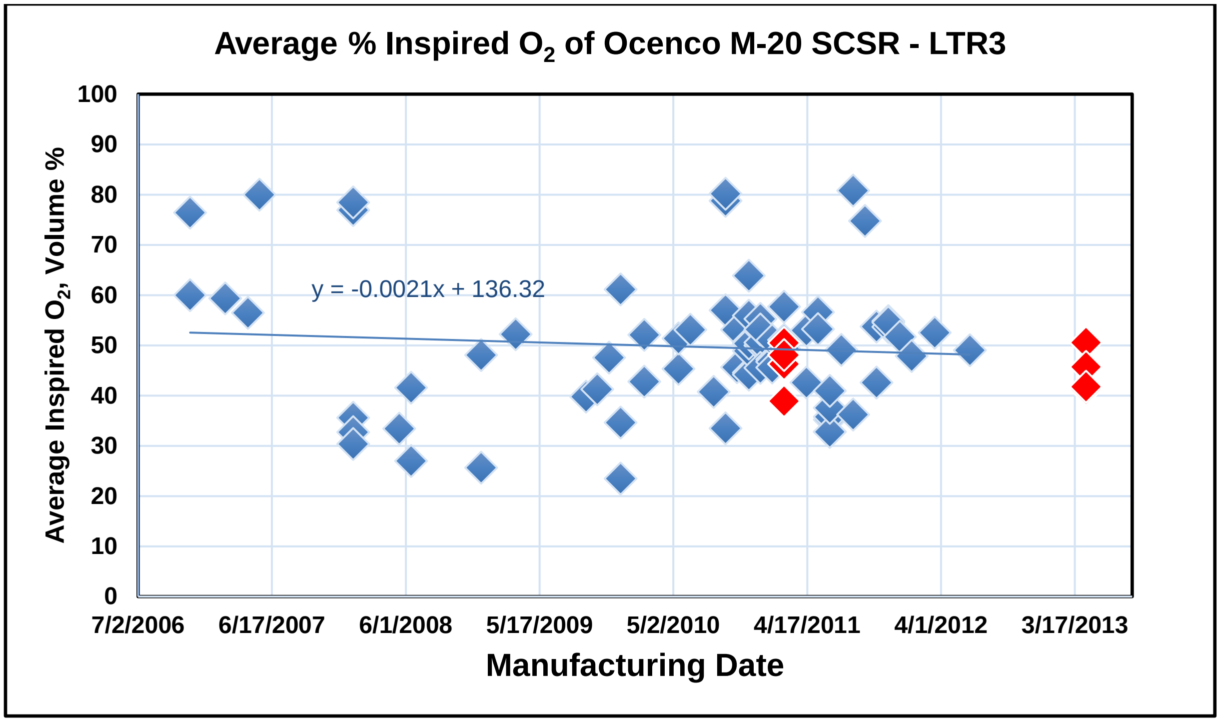

Figure 47. 10-Minute Average Percent Inspired Oxygen of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

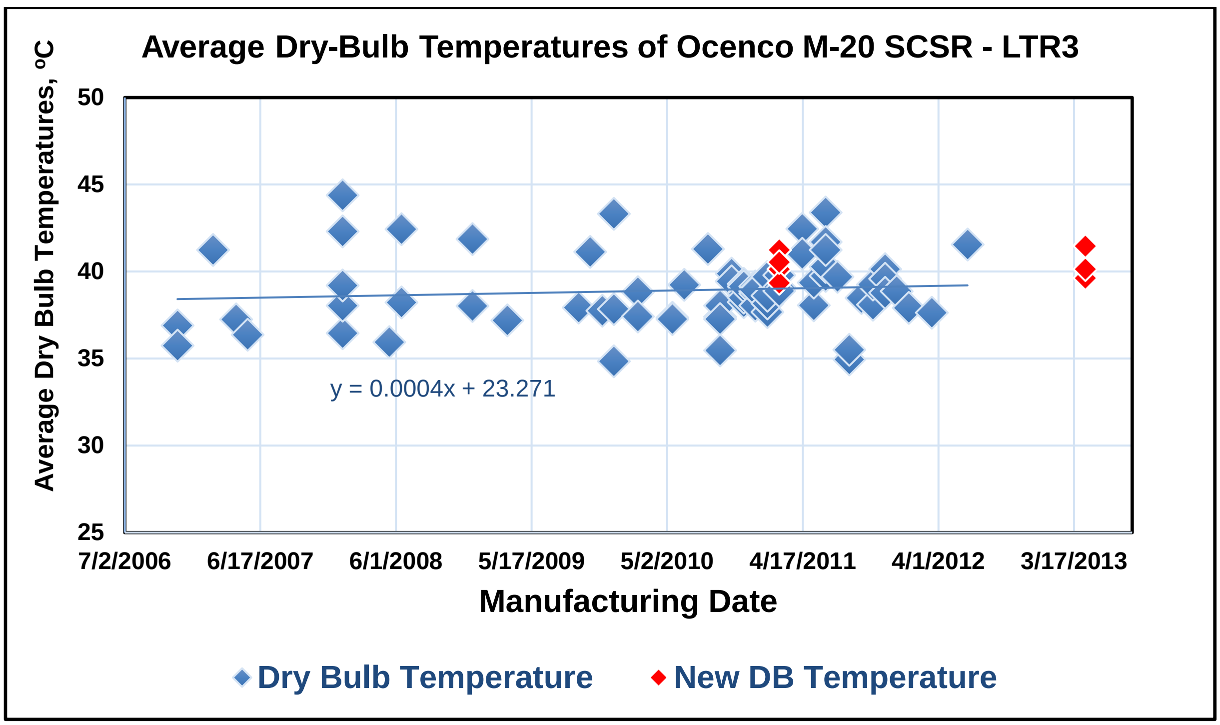

Figure 48. 10-Minute Average Dry-Bulb Temperatures of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

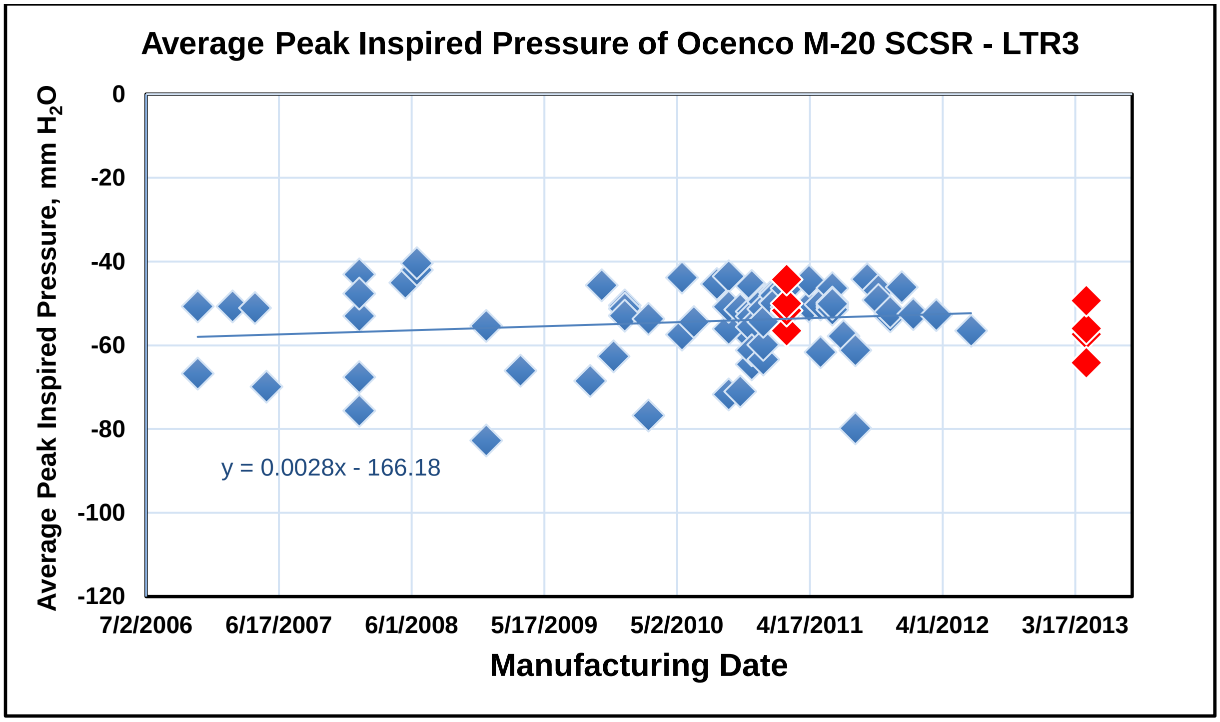

Figure 49. 10-Minute Average Peak Inspired Pressure of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

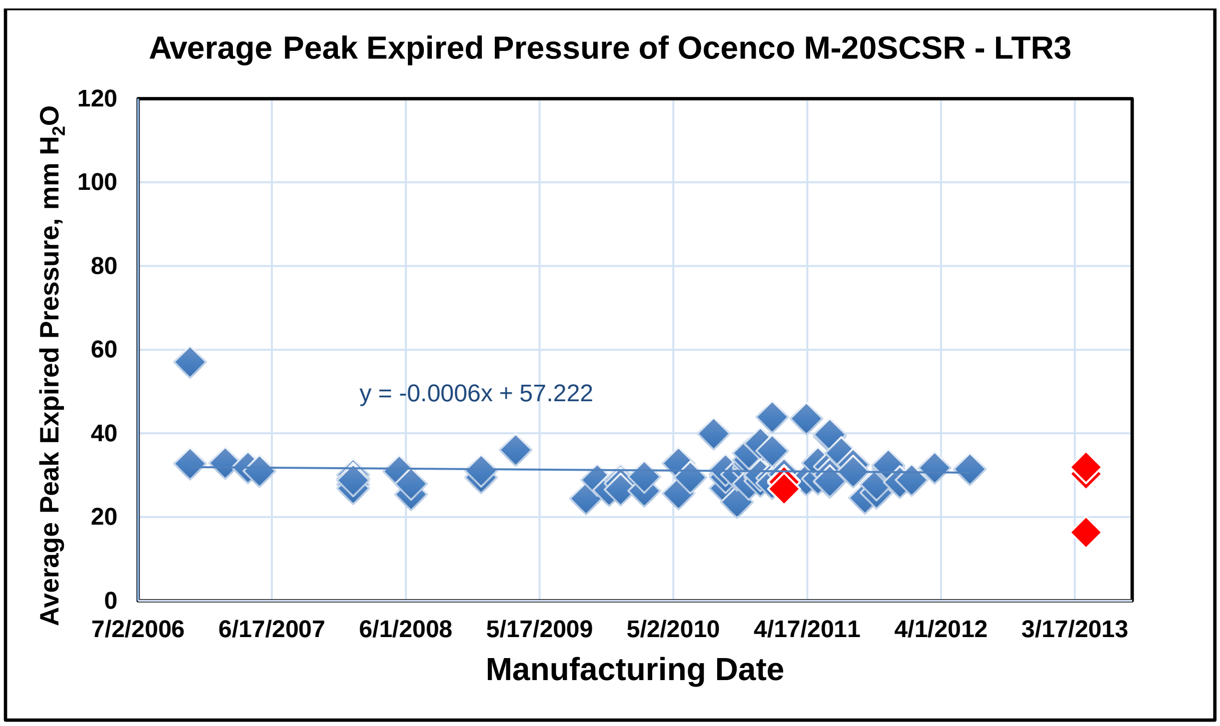

Figure 50. 10-Minute Average Peak Expired Pressure of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

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

For more information related to personal protective equipment, visit the NIOSH website https://www.cdc.gov/niosh/npptl

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