PPE CASE

Personal Protective Equipment Conformity Assessment Studies and Evaluations

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

Sample Period: May 2009 to July 2010

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Abstract

The National Personal Protective Technology Laboratory (NPPTL)[1] of the National Institute for Occupational Safety and Health (NIOSH) has undertaken a study to evaluate the long-term field performance and reliability of self-contained self-rescuers (SCSRs) deployed in U.S. underground coal mines in accordance with the use and location requirements of Title 30 Code of Federal Regulations (30 CFR) Part 75.1714. This ongoing project provides visual inspection data and performance data on field deployed SCSRs.

This report presents findings from the first phase of the SCSR Long-Term Field Evaluation Program (LTR1). The Mine Safety and Health Administration (MSHA) maintains a list of deployed SCSRs in the United States. From the MSHA list, NIOSH randomly selects 140 units each from four models to attempt a field collection of 100 SCSRs per model for laboratory testing. One hundred and forty units are chosen to allow for issues with obtaining specific units. The SCSRs that pass the manufacturer's recommended visual inspection at the mine are collected and further evaluated by NPPTL including a second visual inspection, leak testing, gas flow testing, and breathing and metabolic simulation (BMS) testing. The tests performed in this study are not respirator approval tests; however, poor performance during testing led to the opening of a certified product investigation process (CPIP) on one SCSR model. The data obtained for the one model that underwent the CPIP investigation was reported in a Department of Health and Human Services numbered document that is posted on the NIOSH website.

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**.

Overall, 85% of the SCSRs examined at NIOSH passed the visual inspection. The BMS test results indicate that 99% of SCSRs that pass the manufacturer's recommended visual inspection criteria demonstrated acceptable rated service life. Of the three SCSRs with unacceptable service lives, only one failed the visual inspection. Most of the respirators failing the visible inspection in this phase of the study would have met the BMS testing criteria or been removed from service, if the manufacturer's recommended cleaning, handling, and visual inspection had been performed properly. There were no discernible trends from BMS, leak tests, or flow tests that might indicate or predict an end-of-service-life for any SCSR model.

The most frequent limitations in the collection of SCSRs from the mines could be partially overcome through better communication with the mines and district offices, and by obtaining a more recent and expanded inventory list from the MSHA electronic SCSR inventory. This phase of the LTR1 study demonstrates the need to expand collection options to meet the quota of 100 SCSRs from each manufacturer, and ultimately retain the desired statistical validity of the study.

Introduction

U.S. coal mine operators are required to provide to each underground coal miner a SCSR. Additional SCSRs are required to be stored in caches on working sections and in outby escape ways. Title 30 Code of Federal Regulations (30 CFR) Part 75.1714 requires that each person in an underground coal mine wear, carry, or have ready access to a device that provides respiratory protection with an oxygen (O_2) source for at least one hour, as approved by the certifying agencies, NIOSH and MSHA. In some mines, shorter duration SCSRs are also available to reach caches of one-hour units. Together, the agencies conduct long-term field evaluations (LTFE) of SCSRs deployed in U.S. underground coal mines to assess the reliability and performance of the SCSRs.

In the first ten phases of the long-term field evaluation, referred to as LTFE 1 through 10, NIOSH targeted SCSRs deployed in underground coal mines for the longest period of time exhibiting signs of environmental impact for collection. Previous reports describe phases 1 through 10 (Kyriazi et al. 1986; Kyriazi and Shubilla 1992, 1994, 1996, 2000, 2002; NIOSH 2006, 2008). The LTFE phases 1 through 10 were successful at identifying performance and reliability issues, and resulted in SCSR product improvements; however, the sample size and criteria limited the results in statistical validity.

In 2009, the formation of a new sampling strategy allowed randomization of the SCSR population tested. The new sampling plan increases the statistical significance of observations made in the LTFE study. The new sampling plan is designed to result in a 98% chance of detecting a failing respirator when the true error rate is 1.5% or more. From 2009 forward, NIOSH referred to the collections as Long-Term Random Field Evaluation Phase 1 (LTR1), LTR2, et cetera to indicate the randomization of the sample and the phase of collection.

Beginning with the LTR1 collection, NIOSH subjects the respirators to strict visual inspection following the manufacturer's user instructions. This allows only units that should be in field use into the study and eliminates testing units that do not meet the manufacturer's visual inspection criteria for continued deployment. NIOSH bases LTR1 collection on a random sampling protocol negating the influence of different mining environments; such as coal seam height, size of the mine, and other environmental factors as a bias in the sample. The current LTR collection strategy targets the same number of each SCSR model approved for use in underground coal mines, regardless of market share.

Methods

Self-Contained Self-Rescuer Respirators

The SCSRs tested in this LTR1 phase were the Dräger Oxy K Plus, Ocenco EBA 6.5 and M-20 models (Figures 1 through 3), and the CSE SR-100 (Figure 4). The CSE SR-100 testing revealed that some units did not produce enough starter oxygen to allow for safe escape in the event of a mine emergency. NIOSH initiated an investigation into the sources of this problem. As a result, the NIOSH approval was rescinded and MSHA required the units to be removed from service no later than December 31, 2013. The results of the CSE SR-100 investigation are detailed elsewhere and are not discussed in this report (Ahlers, 2012).

Figure 1. Dräger Oxy K Plus SCSR

Figure 2. Ocenco EBA 6.5 SCSR

Figure 3. Ocenco M-20 SCSR

Figure 4. CSE SR-100 SCSR

The Dräger Oxy K Plus is a chemical oxygen producing SCSR that employs an oxygen starter apparatus for initial performance and is rated for a 60-minute service life. The Ocenco EBA 6.5 and M-20 are closed-circuit compressed oxygen SCSRs. The EBA 6.5 has a rated duration of 60 minutes; the M-20 has a rated duration of 10 minutes. All SCSRs included in the study utilize a chemical bed to keep carbon dioxide within acceptable limits for use.

Sampling Strategy

For this phase of the statistical analyses, NIOSH targets collection of 100 each of these NIOSH-approved SCSR models deployed in United States underground coal mines. NIOSH receives a list of SCSR serial numbers across all mining districts using the MSHA SCSR Inventory and Report. NIOSH uses this list to select units for future collections. From the MSHA list, NIOSH randomly selects 140 units of each model to allow for issues collecting units. Selecting 140 units increases the likelihood of a field collection of 100 SCSRs per model for laboratory testing.

Visual Inspection

NIOSH performs a visual inspection of each unit using the manufacturers' recommended visual inspection procedure upon receipt of each SCSR at the Pittsburgh facility. Most manufacturer's recommended visual inspections of SCSRs focus on the integrity of the case, latches, and indicators that are viewable without opening the respirator. If all visual inspections pass, the respirator should be safe for use.

Quantitative Leak Test

Respirators that pass visual inspection are subjected to the quantitative leak test (QLT) to assess breathing circuit integrity. This is an additional test which is not required by 42 CFR 84 for approval testing. The leak test uses a 300 mm of water (mm H_2O) vacuum and measures the inward leakage in milliliters per minute (mL/min). At maximal work rates, inhalation pressures should not exceed 300 mm H_2O or 500 mL/min of inward leakage to reasonably assure user protection for a period of 1 hour. The inward leakage threshold of 500 mL/min was developed using the one-hour threshold limit value (TLV) for carbon monoxide (CO) which is 200 ppm. An inward leakage rate of 500 ml/min in a 10% CO atmosphere at a peak inhalation rate of 250 liters per minute (L/min), which coincides with an oxygen consumption rate of 3.0 L/min, would lead to an inward leakage of 200 ppm CO, the one-hour TLV. Based on this reasoning, a quantitative leak measurement should be less than 500 ml/min.

Gas Flow Test

After assessing the breathing circuit integrity, NIOSH could only test the Ocenco EBA 6.5 model for maximum sustained oxygen flow rate because it uses compressed oxygen and is manufactured with valves to turn the oxygen flow on and off. This was performed by disconnecting the oxygen supply line from the breathing bag, connecting it to a flow meter, and fully opening its 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 using a wire tie.

This test is part of the approval process described in Title 42 Code of Federal Regulations, Part 84, §84.94, Gas flow test; closed-circuit apparatus (Code of Federal Regulations, 2014). For combination constant flow and on-demand SCSR units, this approval regulation 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. None of the Ocenco EBA 6.5 SCSR units tested at the NIOSH laboratory had maximum sustained oxygen flow rates below this limit.

Breathing and Metabolic Simulation (BMS) Test

SCSR performance is then evaluated using a BMS test. The computer-controlled BMS 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 BMS is an ideal device for evaluating inhaled CO_2 and O_2 concentrations in respirators due to its high degree of accuracy and repeatability in duplicating human CO_2 production and O_2 consumption. Also, the BMS continuously measures the inhalation air temperature (dry bulb and wet bulb) and inhalation and exhalation pressure resistance. By design, a BMS replicates breathing ventilation (respiratory frequency, tidal volume, flow, temperature, and humidity), O_2 consumption, and CO_2 production. A BMS produces human respiratory air qualities at approximately 33°C and saturated with water vapor. The computer uses a routine of energy expenditures (protocol) to make adjustments and provide measurements of respiratory gas concentrations, pressures, and temperatures (Figure 5).

The SCSR units tested in this phase were not certified using the BMS test. The units were certified 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 SCSRs. The BMS test was used as a surrogate for Man-test 4.

NIOSH tested the SCSRs on the BMS using a constant average metabolic work rate test (Table 1). The constant average work rate used is similar to the 50^{th} percentile miner (body weight of 87 kg or 192 lbs.) performing the one-hour Man-test 4 as described in 42 CFR 84, Subpart H. NIOSH programmed the BMS to run 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. Tests on the BMS were 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 below 15%. When these limits are exceeded, the BMS gas metabolism is compromised and further data are not acceptable for analysis. In this study, the BMS testing was deliberately conducted beyond the SCSR rated service life until the breathing gas supply was expended.

Although the average work rate is the same, the LTR testing is not equivalent to approval testing. Human subjects may differ from each other and from the BMS 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 the BMS tests, even though the O_2 consumption rate is the same. However, the BMS can be used to provide an indication of SCSR duration performance. Approval testing under 42 CFR 84, Subpart H using human subjects imposes high and low work rates that the average work rate used in the LTR does not. Also, the stressor levels are continuously monitored in the LTR, whereas the stressor levels are sampled only between work activities performed by the 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 1. 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

The performance requirements for the tests conducted during this evaluation are identified in Table 2.

Table 2. SCSR Performance Requirements

Parameter	Requirement
Quantitative Leak Test	< 500 ml/min
Gas Flow	≥ 1.5 L/min
Inhaled CO_2 Concentration*	< 1.5 %
Inhaled O_2 Concentration*	> 19.5%
Breathing Peak Pressure*	≤ 200 mm H_2O
Wet Bulb Temperature*	< 43°C

* 42 CFR 84.303 Acceptable Operating Minute Average

Units giving results not meeting the rated duration and those that fall under 42 CFR 84.41 regarding quality control plans had a report filed with the certified product investigation process (CPIP) coordinator for investigation into the cause of these results and to determine if any further action was warranted.

Results and Discussion

Sampling Results

In LTR1, as described previously, NIOSH randomly selected 560 units (140 of each of the four models) from the MSHA list. Of the 560 units selected, it was only feasible for NIOSH to collect 517 SCSRs from the mines for various reasons such as it is not economic to collect just one unit from a remote mine. Figure 6 depicts the status of the 560 SCSRs randomly selected in the LTR1 collection. Of the 517 SCSRs requested for collection, a total of 185 SCSRs were either missing, not available, or removed from service. This amounts to 35.8% of the respirators on the NIOSH random selection list. In order to improve future collection efforts, NIOSH will explore communication strategies for confirming SCSR status prior to collection and a means of reaching smaller mines that may only have one unit to collect. The NIOSH Pittsburgh facility received 332 SCSRs for testing, yielding a collection rate of 64.2%. However, four of the units received did not pass visual inspection at the mine and should not have been sent. Although the 64 collected CSE SR-100 units were BMS tested, the results are reported elsewhere (Ahlers, National Personal Protective Technology Laboratory, 2012) and are not included in this report. The BMS data from 12 tests was not usable; therefore, the results from the remaining 315 units were the basis of these findings.

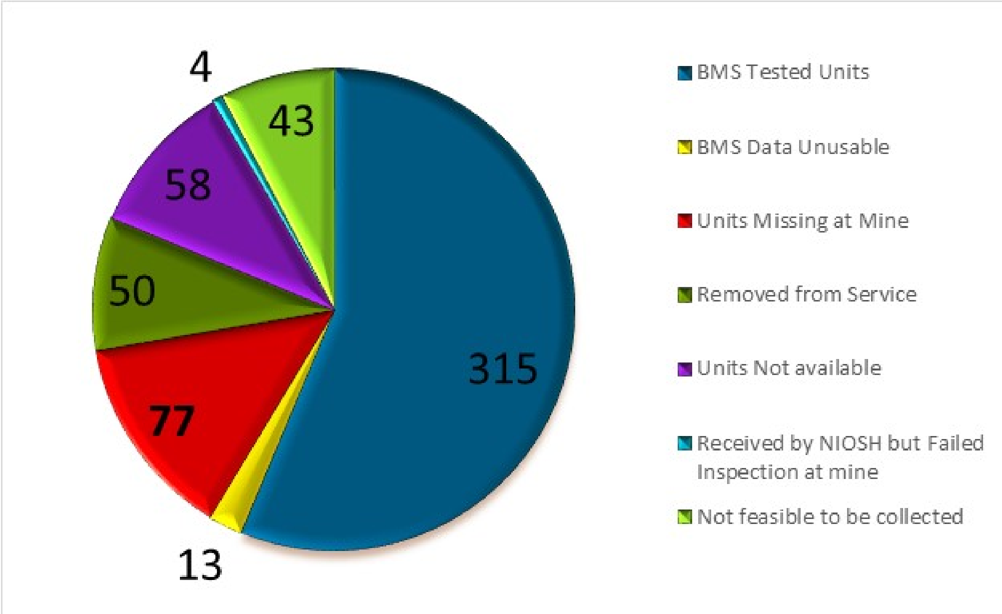

Figure 6. LTR1 Collection Dispersion

NIOSH attained 87 of the 140 Dräger Oxy K Plus SCSRs listed on the LTR1 targeted collection list, yielding a collection rate of 62%. Challenges affecting the collection of Dräger Oxy K Plus SCSRs include: the closure of mines leading to the unavailability of 21 SCSRs and communication issues within one of the mining districts which made 14 Dräger Oxy K Plus units unavailable. These two challenges alone resulted in 25% of the Dräger Oxy K Plus SCSRs on the targeted collection list being deemed unavailable.

NIOSH collected 103 of the 140 Ocenco EBA 6.5 SCSRs on the targeted LTR1 collection list, yielding a collection rate of 74%. Ocenco EBA 6.5 SCSRs were the most prevalent SCSR deployed in U.S. underground coal mines at the time of collection, holding roughly 60% of the market share. Therefore, this respirator model was easier to attain than other models in this study. LTR1 methods call for the collection of 100 EBA 6.5, but due to the shortfall in other collection areas, NIOSH accepted 103 units into the study.

NIOSH collected 61 of the 140 Ocenco M-20 SCSRs on the targeted LTR1 collection list, yielding a collection rate of 44%. Challenges affecting the collection of M-20 SCSRs include: the closure/non-production status of mines leading to the unavailability of 46 respirators and 28 M-20s reported as missing by the mine. This eliminates 53% of the targeted collection list for M-20 respirators in the LTR1 from collection.

As noted previously, NIOSH did collect CSE SR-100. Sixty-four of the 140 CSE SR-100 SCSRs on the targeted LTR1 collection list were collected, yielding a collection rate of 46%; however, as stated previously, further CSE SR-100 results are not presented in this report.

Visual Inspection

All units were inspected using the manufacturer's recommended visual inspection criteria after being cleaned. Despite having passed the inspection during collection, some collected units were judged to have failed the manufacturer's recommended visual inspection criteria once received in the laboratory as described below. In other words, these units should have been removed from service and not been available for the LTR1 tests. Failure could be attributed to differences in judgment as to the compliance with inspection criteria. This reflects the difficulty inspecting units deployed in the underground coal mine environment. Units can become encrusted with dirt, making a thorough inspection difficult. The test results and data analysis, therefore, include all units tested whether the units passed subsequent NIOSH laboratory visual inspection or not. Units that failed laboratory inspection are noted in the results.

Dräger Oxy K Plus

All 87 Dräger SCSRs passed cursory inspection done by the mine, but after cleaning the SCSRs of coal dust at NIOSH, five respirators failed the manufacturer's recommended visual inspection. This means that 94% (82 of 87) of the Oxy K Plus SCSRs collected passed visual inspection at NIOSH. Of the five units that failed inspection, three were missing the red plastic seals (Figure 7), and two had cracked moisture indicator windows (Figure 8). One of the cracked moisture indicators was also missing a circular band at its edge.

Figure 7. Areas of Visual Inspection Deficiency

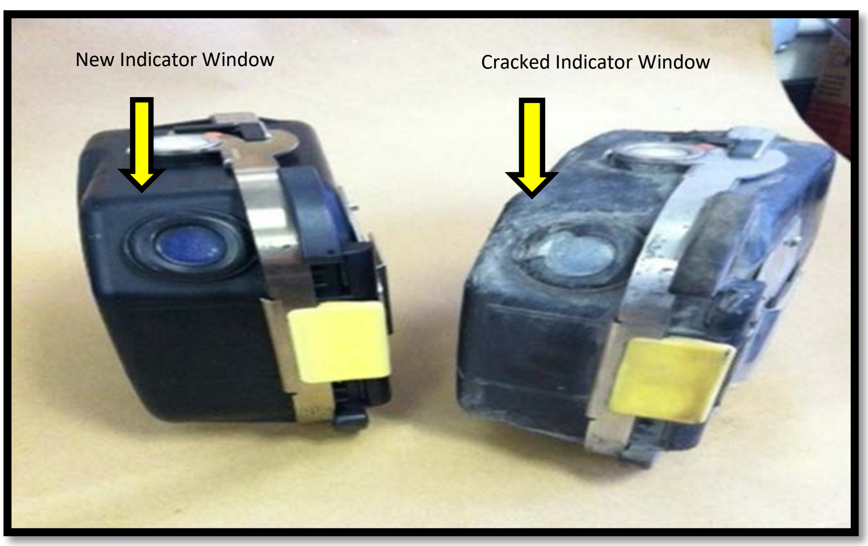

Figure 8. New Moisture Indicator and Cracked Indicator Found After Cleaning at NIOSH

Ocenco EBA 6.5

Of the 103 Ocenco EBA 6.5 SCSRs that NIOSH collected, 19 failed the manufacturer's recommended visual inspection criteria at NIOSH. The failures include outer cases cracked at the handle strap location (Figure 9), shifted cylinder bands with loose nuts, washers and/or brackets, scratched out serial numbers, crimped breathing hoses, and other signs of abuse (i.e., scuffs and hammer marks). NIOSH found one unit that passed the manufacturer's recommended visual inspection to have a cracked cap nut on the demand valve. All of these defects indicate that the SCSRs were exposed to excessive force through impact during mine deployment. This means that 82% of the EBA 6.5 SCSRs collected passed visual inspection at NIOSH.

Figure 9. Ocenco EBA 6.5 with Case Crack

Ocenco M-20

Of the 61 Ocenco M-20 SCSRs that NIOSH collected, 10 failed the manufacturer's recommended visual inspection criteria at NIOSH. The failures include a missing ball in the yellow security latch, loose and missing bottom bumpers on the case, coal dust or a white powder inside in the case, gashes, and visible cracks in the top lid (Figures 10 and 11). After opening the SCSR with the cracked lid, researchers found dirt within the case. This means that 84% (51 of 61) of the M-20 SCSRs collected passed visual inspection at NIOSH.

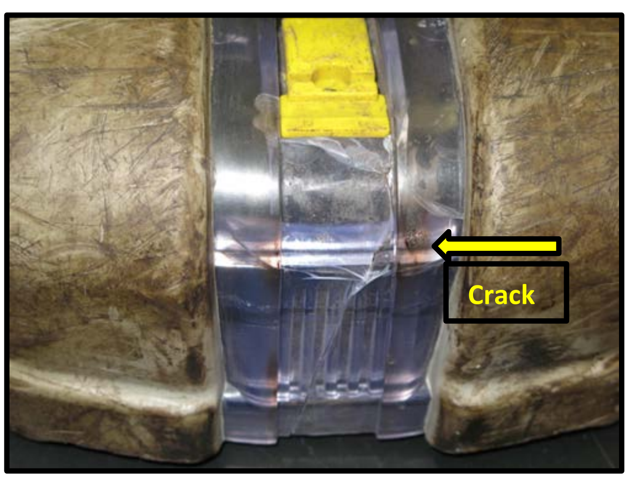

Figure 10. Ocenco M-20 with Cracks in Top Lid

Figure 11. Ocenco M-20 Security Latch

Out of 252 SCSRs collected by NIOSH, 34 SCSRs (13%) failed visual inspection when applying the manufacturer's criteria at NIOSH.

Quantitative Leak Test

All units, regardless of whether or not the units passed the NIOSH laboratory visual inspection, were leak tested.

Dräger Oxy K Plus

After checking the breathing circuit integrity of the Dräger Oxy K Plus SCSRs using the quantitative leak test (QLT), 99% (86 of 87) of the units had a leak rate less than 500 mL/min.

Ocenco EBA 6.5

When NIOSH performed the QLT to assess breathing circuit integrity, 85% of the EBA 6.5 SCSRs (87 out of 103) had a leak rate of less than 500 mL/min. Sixteen units had leakage rates greater than or equal to 500 mL/min, possibly at the juncture of the plastic valve frame and the mouthpiece or due to leakage through the relief valve (Figures 12 and 13). These units were included in the BMS testing and found to meet the duration requirement.

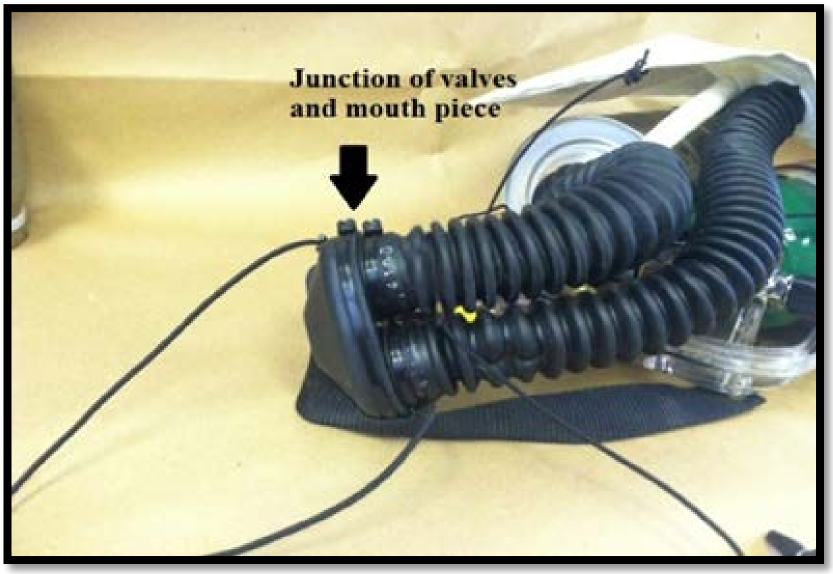

Figure 12. Ocenco EBA 6.5 Junction of Plastic Valves at Mouthpiece

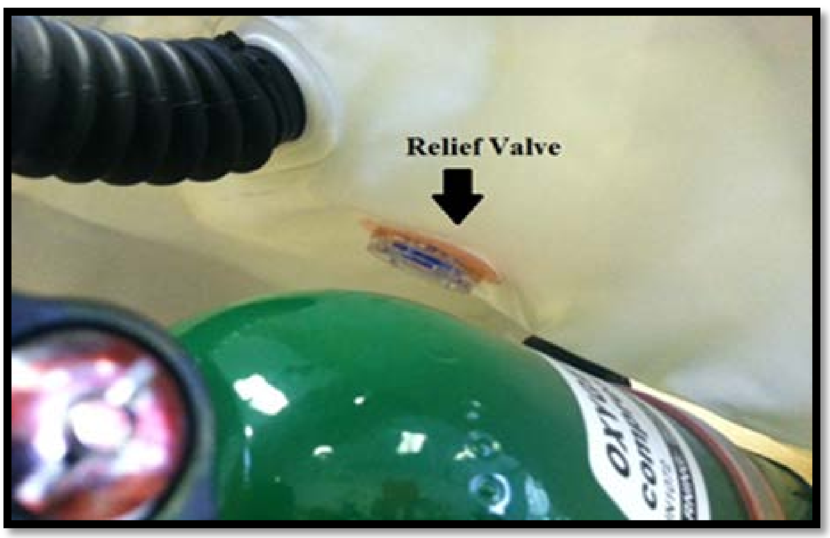

Figure 13. Ocenco EBA 6.5 Relief Valve on Breathing Bag

Ocenco M-20

When NIOSH evaluated the breathing circuit integrity using the QLT, all 61 of the Ocenco M-20 respirators had leakages <500 mL/min.

Gas Flow Test

Ocenco EBA 6.5

After testing the oxygen regulator flow rates, the average ranged from 1.63-2.15 liters per minute (L/min) at ambient temperature and pressure. Certification tests require a minimum constant flow of 1.5 L/min; therefore, all 103 Ocenco EBA 6.5 respirators passed the oxygen flow test.

Breathing and Metabolic Simulation (BMS) Test

From the 251 collected SCSRs (not counting the 64 CSE SR-100 units), all units qualified for testing with the BMS: 87 Dräger Oxy-K Plus, 103 Ocenco EBA 6.5, and 61 Ocenco M-20 respirators (Figure 14). When LTR1 collection and testing began in May of 2009, NIOSH decided to test all respirators that the mines and MSHA District Offices deemed as passing visual inspection.

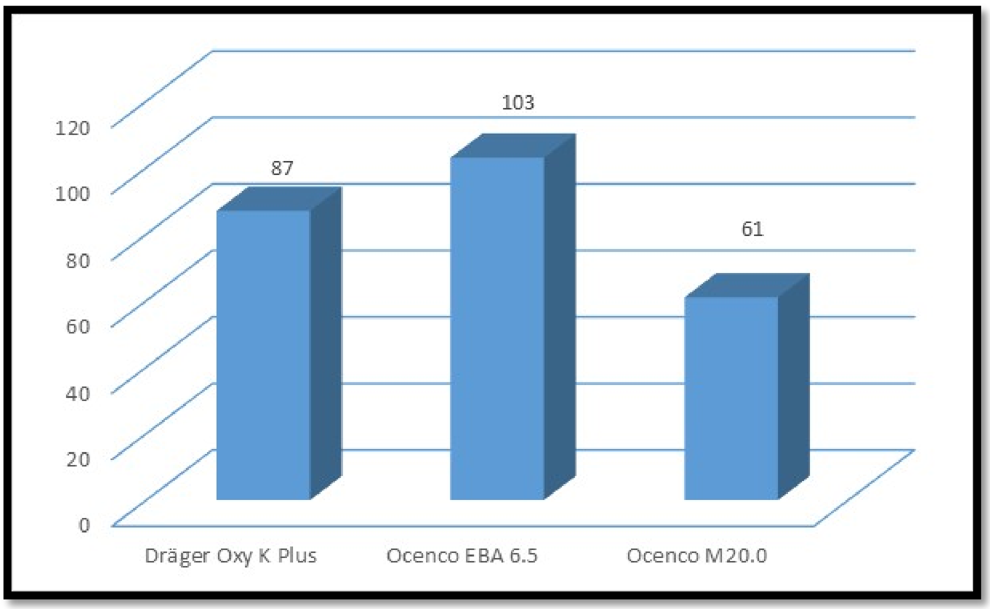

Figure 14. Dispersion of Respirators Qualified for BMS Testing

Dräger Oxy K Plus

Of the 87 Dräger Oxy K Plus SCSRs that NIOSH tested on the BMS, there were two units which exceeded the maximum average inhaled CO_2 requirement of 1.5% during the rated service life. These results were only slightly above 1.5% (1.7% and 1.9%, see Figure 16). These levels did not exceed the 4% inspired CO_2 breakthrough level which could cause impairment. Overall, 99% of the respirators that passed visual inspection at NIOSH also passed BMS testing. Eighty percent (80%) of the respirators that failed visual inspection also passed BMS testing. The average duration time for the BMS testing was 85.4 minutes. All of the Dräger Oxy K Plus SCSRs passed the wet bulb, peak breathing pressure, and inhaled O_2 performance requirements. The following BMS performance test results are graphically provided in Appendix A:

- Duration of Dräger Oxy K SCSR (Figure 15)
- Average Percent Inspired CO_2 of Dräger Oxy K SCSR (Figure 16)

- Average Percent Inspired O_2 of Dräger Oxy K SCSR (Figure 17)
- Average Dry/Wet Bulb Temperature of Dräger Oxy K SCSR (Figure 18)
- Average Peak Inspired Pressure of Dräger Oxy K SCSR (Figure 19)
- Average Peak Expired Pressure of Dräger Oxy K SCSR (Figure 20)

Ocenco EBA 6.5

Of the 103 Ocenco EBA 6.5 SCSRs that NIOSH tested on the BMS, there were no failures during the 60 minute rated service life. There were 19 SCSRs that failed visual inspection, but each unit passed the BMS testing. The average duration time was 99.5 minutes. On one unit, the damaged cap nut caused oxygen to leak upon opening the cylinder valve which resulted in a shorter duration time of 70 minutes than the average BMS test time. The following BMS performance test results are graphically provided in Appendix B:

- Duration of Ocenco EBA 6.5 SCSR (Figure 21)
- Average Percent Inspired CO_2 of Ocenco EBA 6.5 SCSR (Figure 22)
- Average Percent Inspired O_2 of Ocenco EBA 6.5 SCSR (Figure 23)
- Average Dry/Wet Bulb Temperature of Ocenco EBA 6.5 SCSR (Figure 24)
- Average Peak Inspired Pressure of Ocenco EBA 6.5 SCSR (Figure 25)
- Average Peak Expired Pressure of Ocenco EBA 6.5 SCSR (Figure 26)

Ocenco M-20

Of the 61 Ocenco M-20 SCSRs that NIOSH tested on the BMS, there was one failure during the 10 minute rated service life. This unit had an average inhaled CO_2 of 2.0% but had a duration time of 14 minutes. Overall, 98% of the respirators that passed visual inspection at NIOSH also passed BMS testing. The average duration time for the BMS testing was 17.6 minutes. All of the Ocenco M-20 SCSRs passed the wet bulb, peak breathing pressure, and inhaled O_2 performance requirements. The following BMS performance test results are graphically provided in Appendix C:

- Duration of Ocenco M-20 SCSR (Figure 27)
- Average Percent Inspired CO_2 of Ocenco M-20 SCSR (Figure 28)
- Average Percent Inspired O_2 of Ocenco M-20 SCSR (Figure 29)
- Average Dry/Wet Bulb Temperature of Ocenco M-20 SCSR (Figure 30)
- Average Peak Inspired Pressure of Ocenco M-20 SCSR (Figure 31)
- Average Peak Expired Pressure of Ocenco M-20 SCSR (Figure 32)

Test Data Summary

Table 3 is a summary of the results for the SCSR models.

Table 3. Test Summary for SCSRs Passing Visual Inspection at the Mine and MSHA District Office

SCSR Models	Dräger OXY K Plus	Ocenco EBA 6.5	Ocenco M-20	Total
Units tested on BMS	87	103	61	251
Met rated service life on BMS	85	103	60	248
Did not meet rated service life on BMS	2	0	1	3

Failed visual inspection at NIOSH	5	19	10	34
Failed visual inspection at NIOSH, and did not met rated service on BMS	1	0	0	1
Failed visual inspection at NIOSH, but met rated service on BMS	4	19	10	33
Did not meet breathing circuit integrity requirement	1	16	0	17
Did not meet oxygen flow test requirement	N/A	0	N/A	0

Conclusions

All but three of the Ocenco and Dräger SCSRs tested on the BMS demonstrated an acceptable rated service life. Of the three with unacceptable service lives, only one failed visual inspection. Overall, about 85% of the SCSRs examined at NIOSH passed visual inspection as well. There were no discernible trends from BMS, leak tests, or flow tests that might indicate or predict an end of service life for any SCSR model. Most of the respirators failing visible inspection in this phase of the study would have met the BMS testing criteria or been removed from service, if the manufacturer recommended cleaning, handling, and visual inspection had been performed properly. A loose chemical bed or lack of starter oxygen can be the product of rough handling, missed inspection, or a manufacturing defect. A proper visual inspection of a cleaned respirator case and indicators could have identified respirators that required removal from service. These preventative measures along with following the manufacturer's prescribed 90 day and periodic service can identify respirators that have reached the end-of-service-life in the mining environment.

The most frequent limitations in the collection of SCSRs from the mines could be partially overcome through better communication with the mines and district offices, and by obtaining a more recent and expanded inventory list from the MSHA electronic SCSR inventory. This phase of the LTR1 study demonstrated the need to expand collection options to meet the quota of 100 SCSRs from each manufacturer, and ultimately retain the desired statistical validity of the study.

Appendix A: Acronyms and Abbreviations

Acronyms and Abbreviations

ASM	Acoustic Solid Movement
BMS	Breathing and Metabolic Simulation
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPIP	Certified Product Investigation Process
LTFE	Long-Term Field Evaluation
LTR	Long-Term Random Field Evaluation
MSHA	Mine Safety and Health Administration
NIOSH	National Institute for Occupational Safety and Health
NPPTL	National Personal Protective Technology Laboratory
O_2	Oxygen
OSHA	Occupational Safety and Health Administration
QLT	Quantitative Leak Test
SCSR	Self-Contained Self-Rescuer
TLV	Threshold Limit Value
VCO_2	Volume of Carbon Dioxide
VO_2	Volume of Oxygen

Unit of Measure Abbreviations

breaths/min	breaths per minute
dB	decibel(s)
kg	kilogram(s)
L	liter(s)
L/breath	liter(s) per breath
lb	pound(s)
L/min	liter(s) per minute
mL/min	milliliter(s) per minute
mm	millimeter(s)
mm H2O	millimeter(s) of water pressure
%	percent
ppm	parts per million

Appendix B: BMS Testing of the Dräger OXY K PLUS SCSRs Stressors

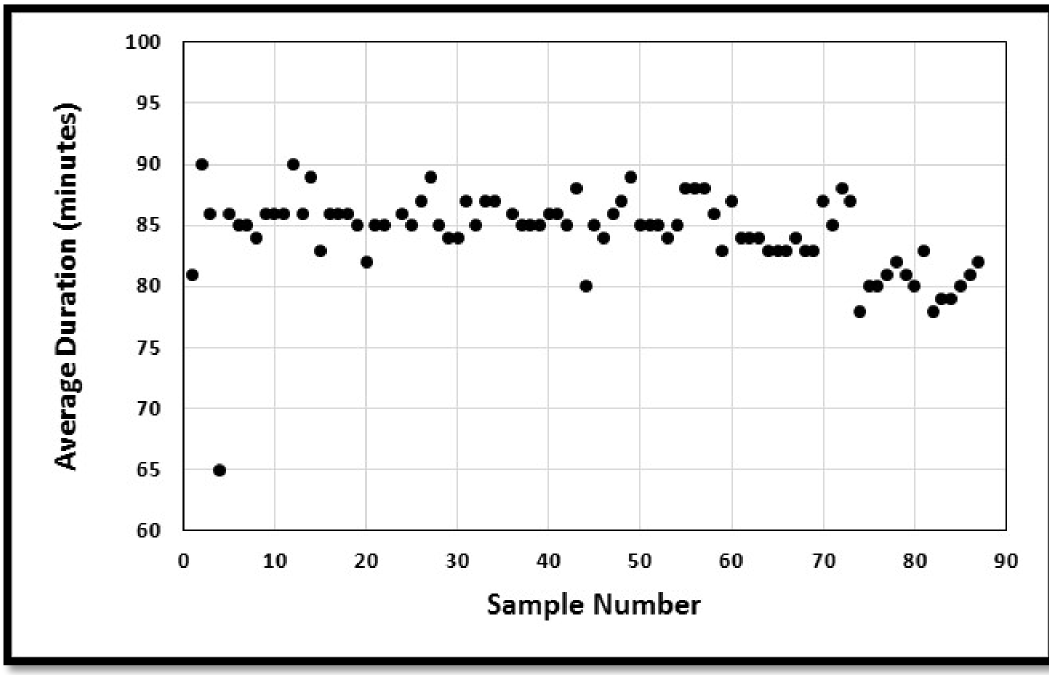

Figure 15. Average Duration of Dräger Oxy K Plus SCSRs

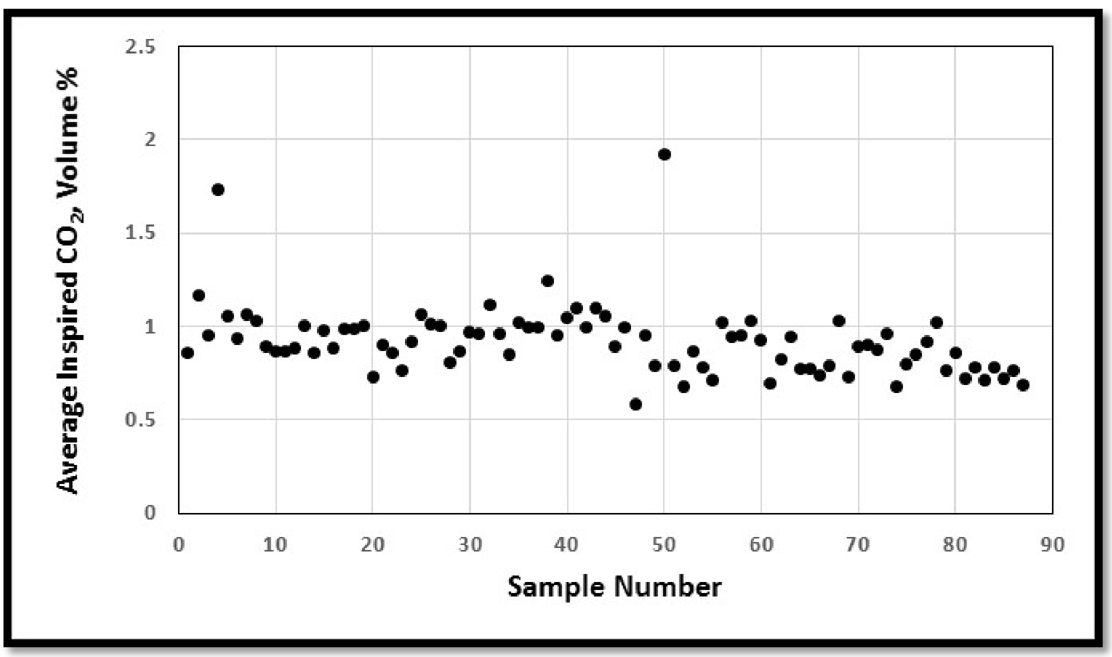

Figure 16. Average Percent Carbon Dioxide of Dräger Oxy K Plus SCSRs

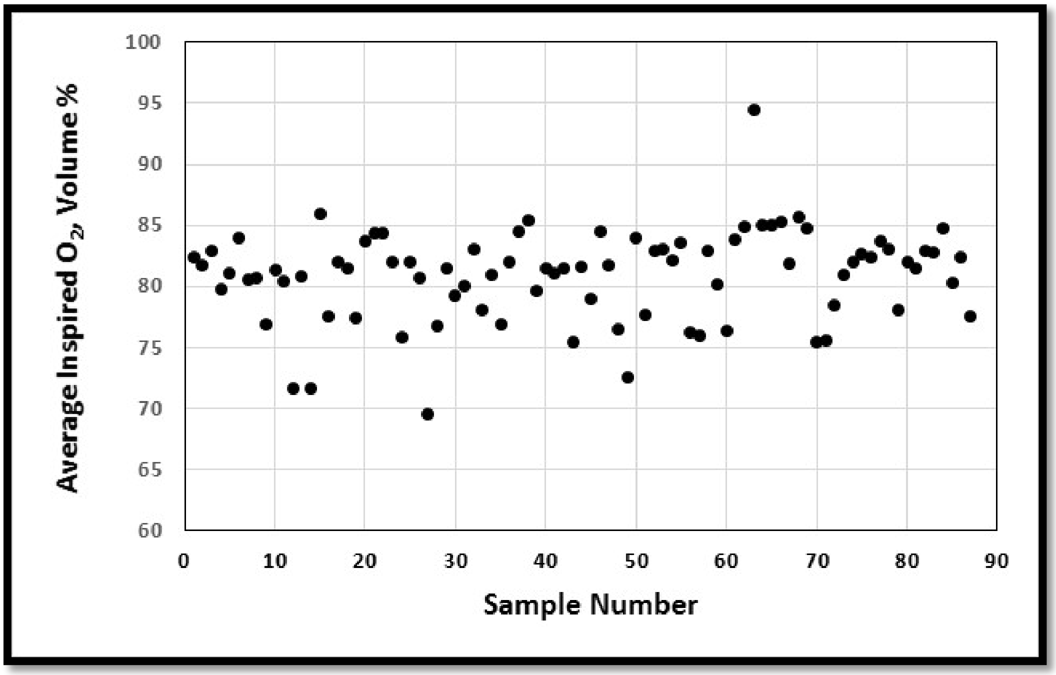

Figure 17. Average Percent Oxygen of Dräger Oxy K Plus SCSRs

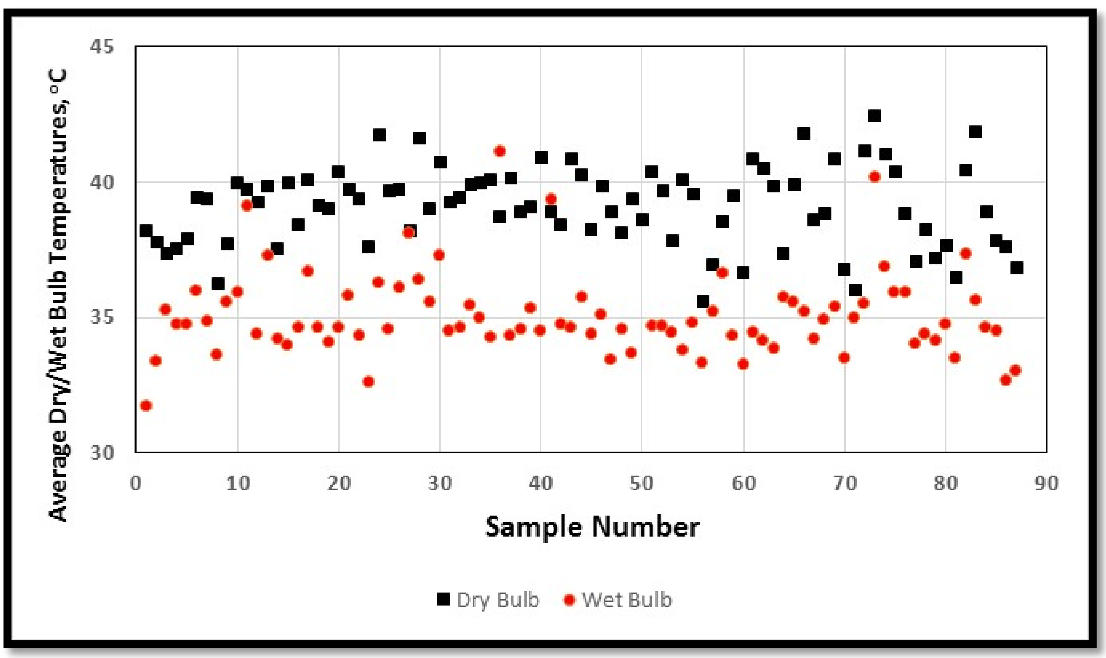

Figure 18. Average Dry Bulb/Wet Bulb Temperature of Dräger Oxy K Plus SCSRs

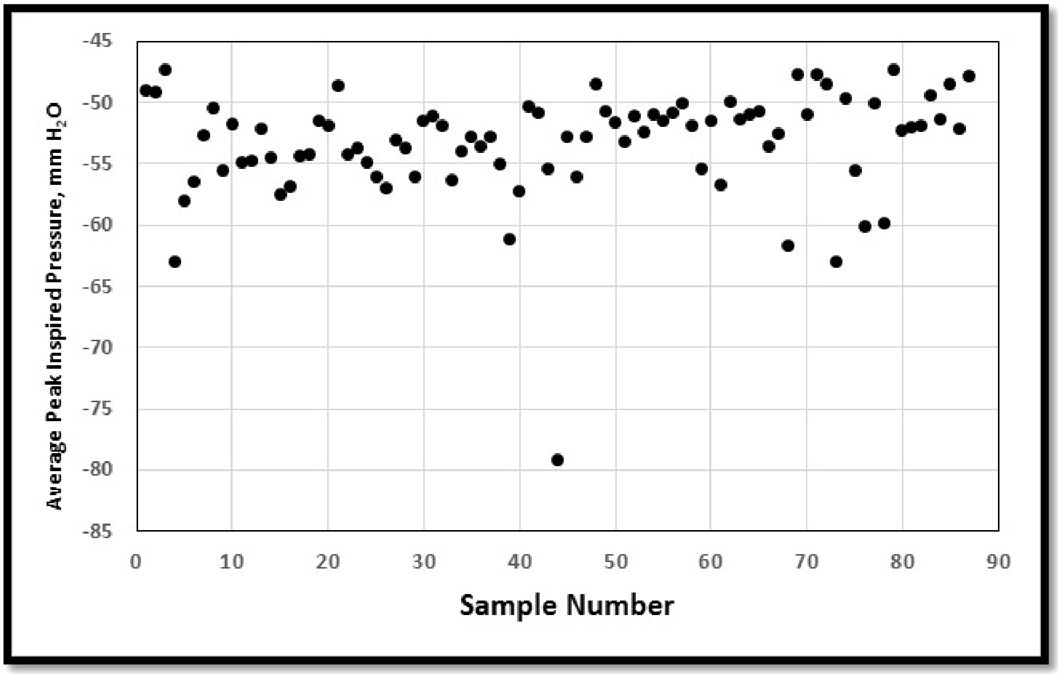

Figure 19. Average Peak Inspired Pressure of Dräger Oxy K SCSR

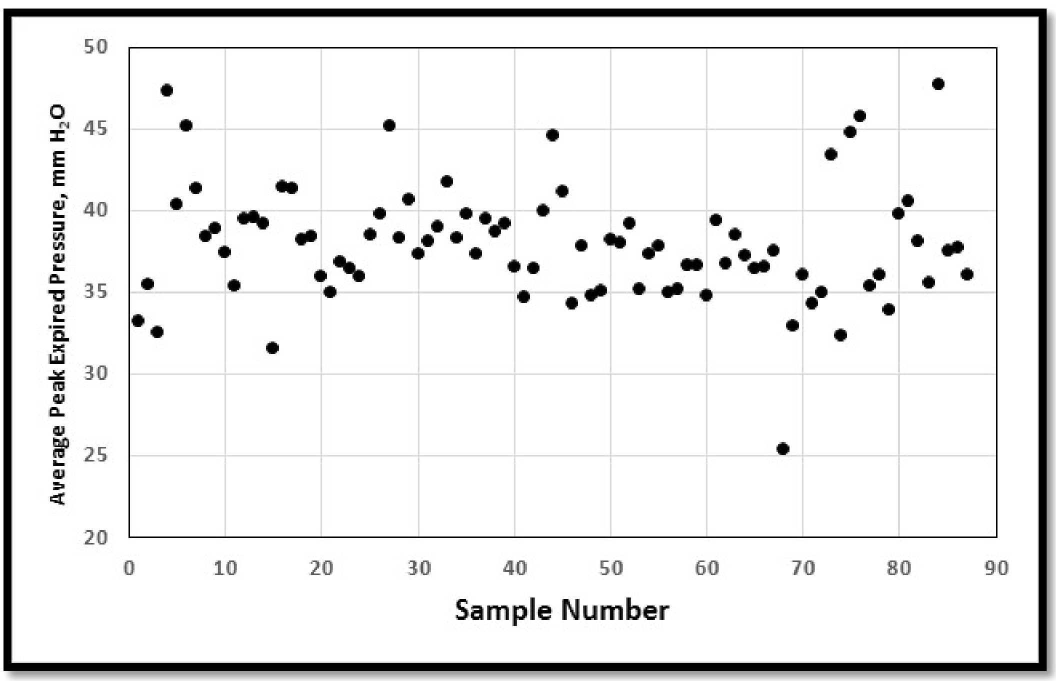

Figure 20. Average Peak Expired Pressure of Dräger Oxy Plus K SCSR

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

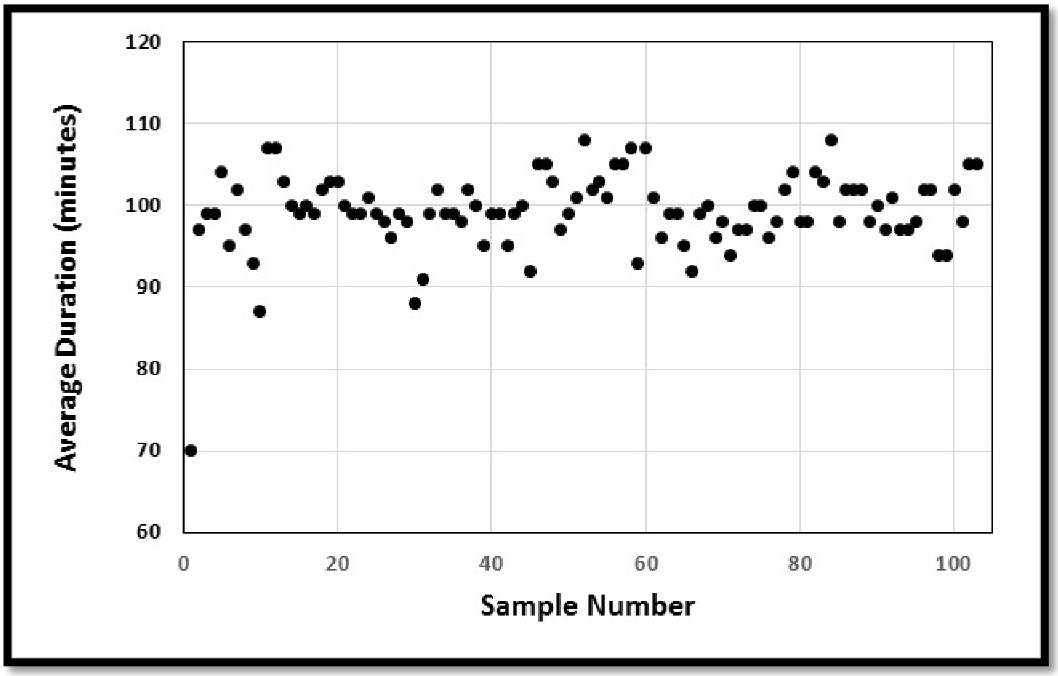

Figure 21. Average Duration of Ocenco EBA 6.5 SCSR

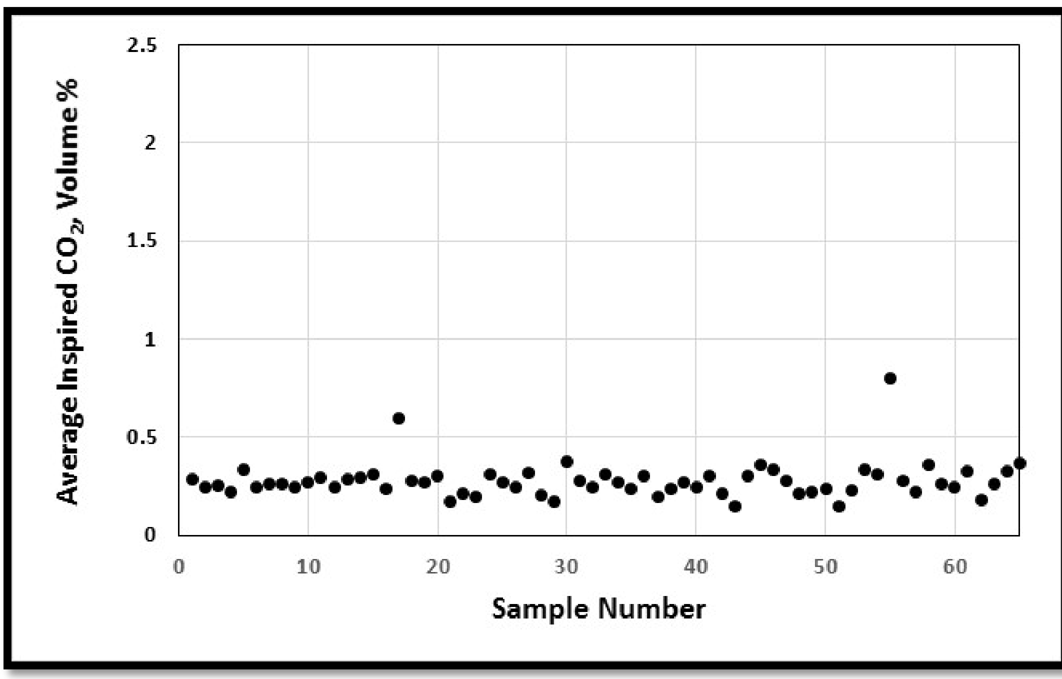

Figure 22. Average Percent Carbon Dioxide of Ocenco EBA 6.5 SCSR

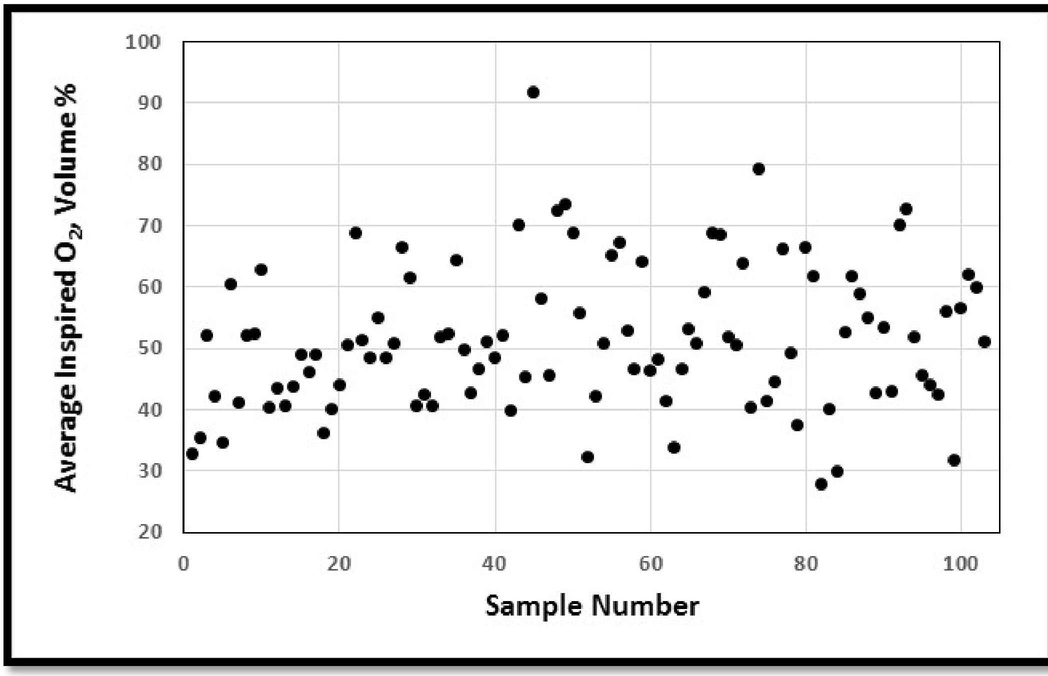

Figure 23. Average Percent Oxygen of Ocenco EBA 6.5 SCSR

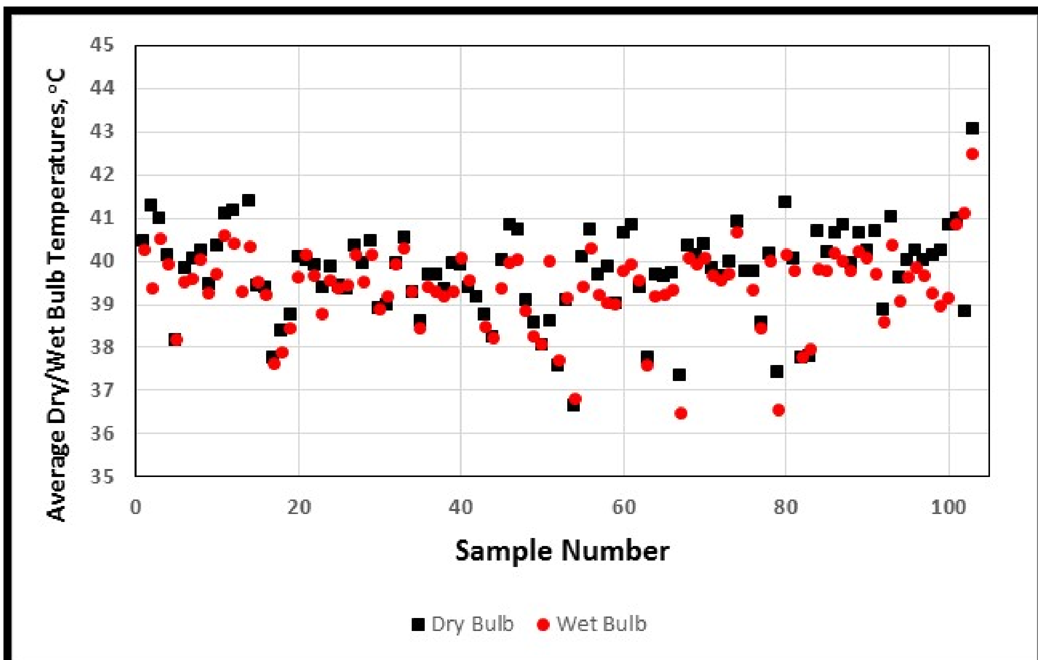

Figure 24. Average Dry/Wet Bulb Temperature of Ocenco EBA 6.5 SCSR

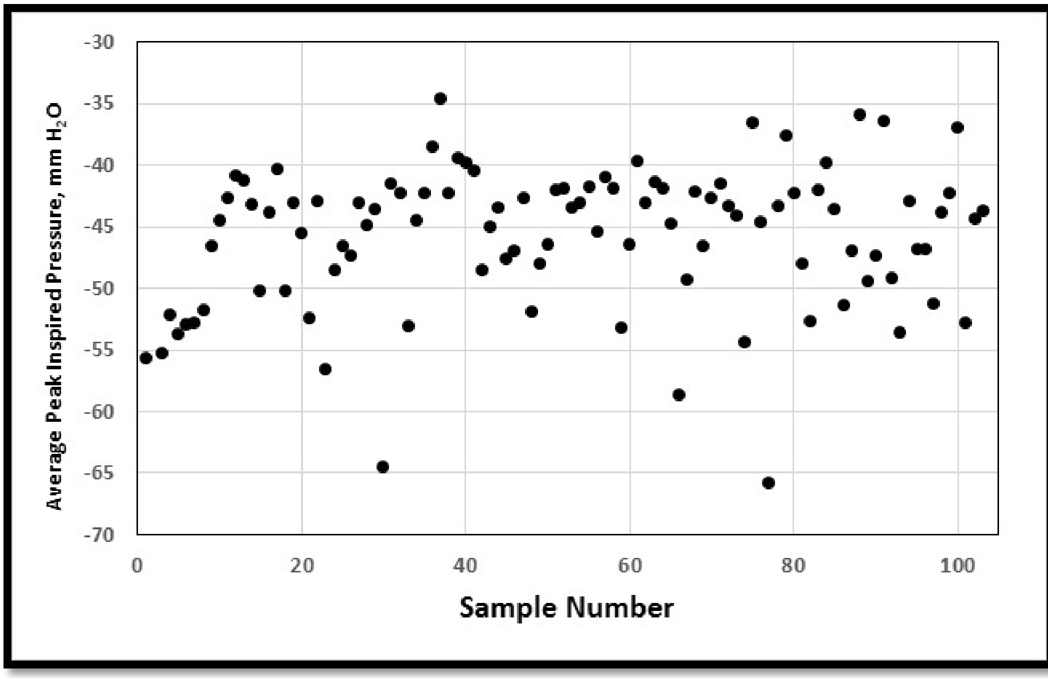

Figure 25. Average Peak Inspired Pressure of Ocenco EBA 6.5 SCSR

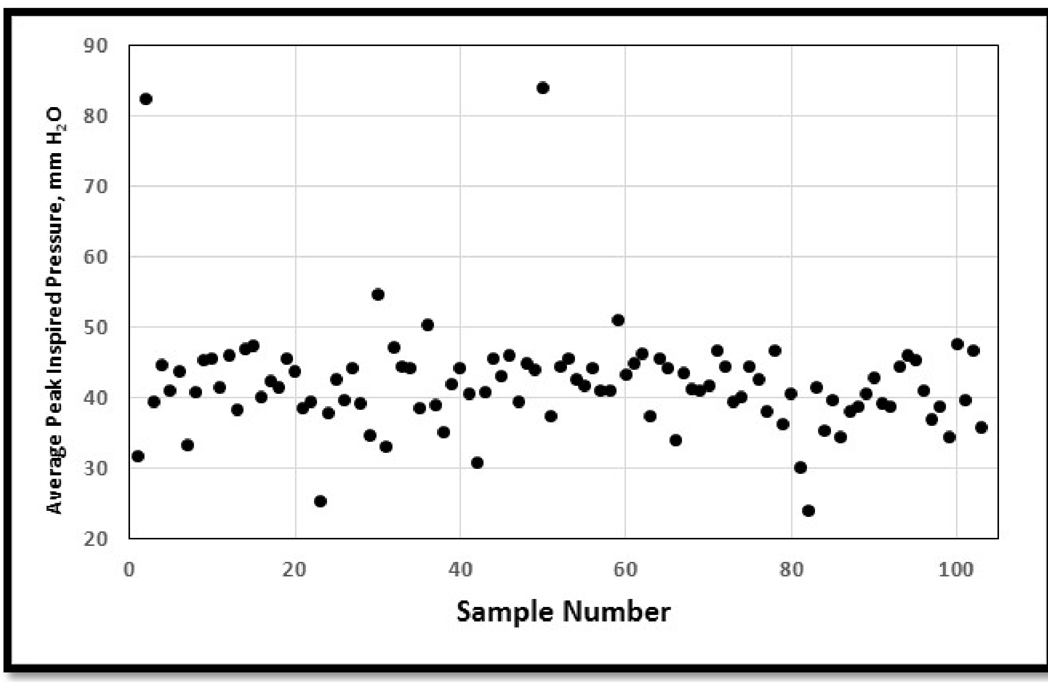

Figure 26. Average Peak Expired Pressure of Ocenco EBA 6.5 SCSR

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

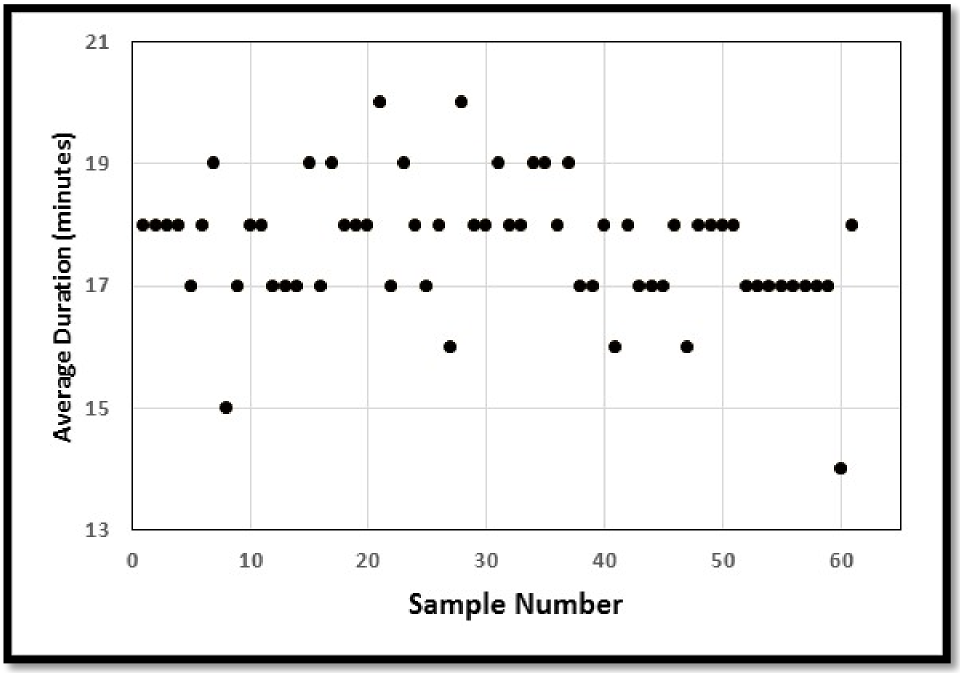

Figure 27. Average Duration of Ocenco M-20 SCSR

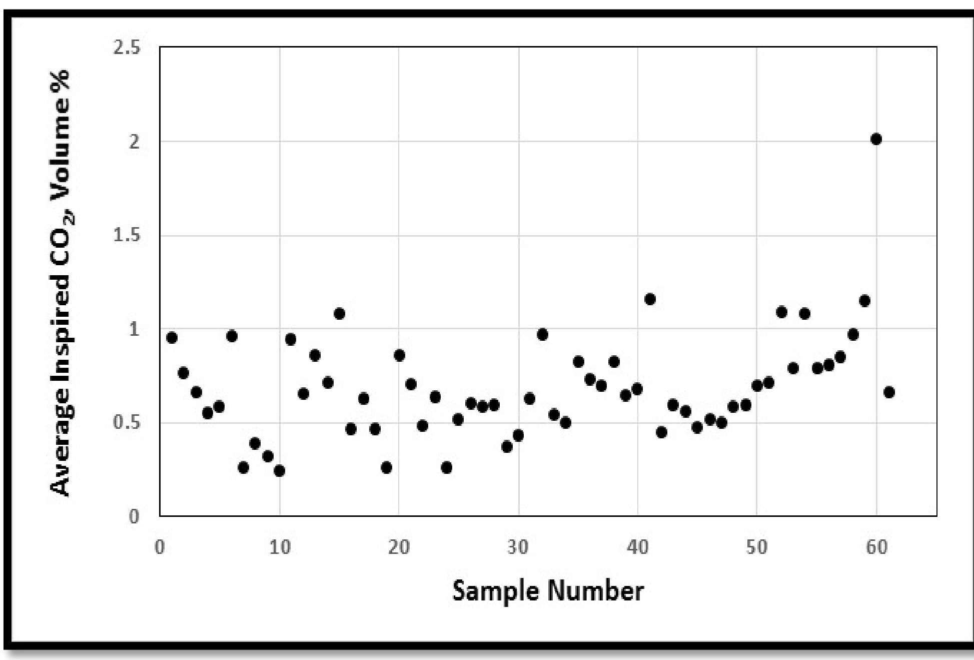

Figure 28. Average Percent Carbon Dioxide of Ocenco M-20 SCSR

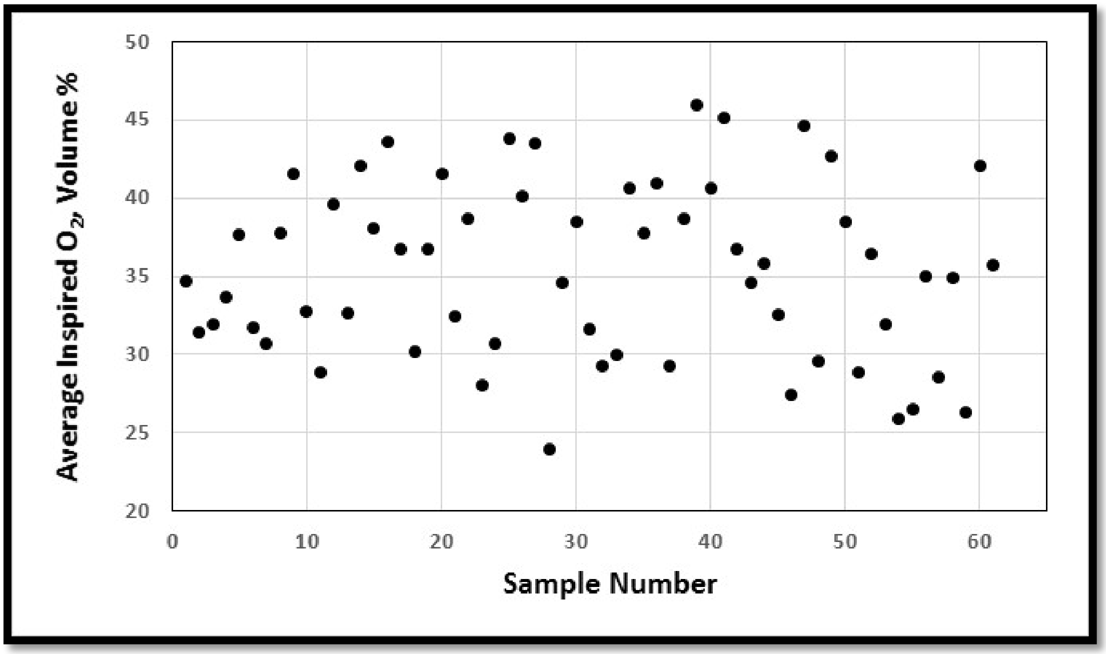

Figure 29. Average Percent Oxygen of Ocenco M-20 SCSR

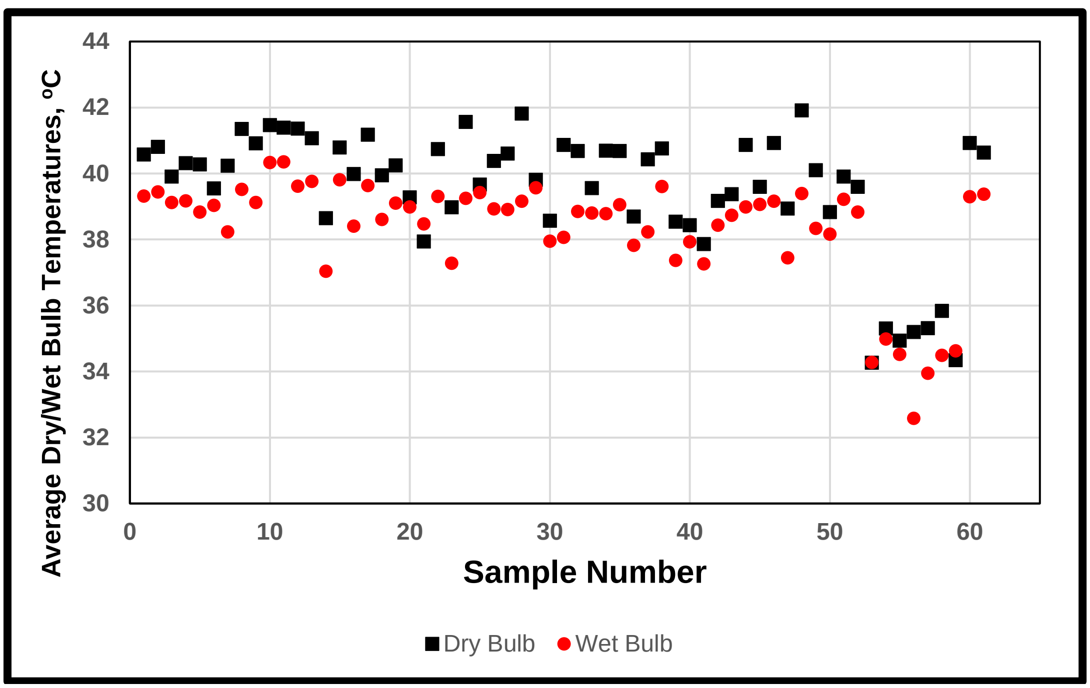

Figure 30. Average Dry/Wet Bulb Temperature of Ocenco M-20 SCSR

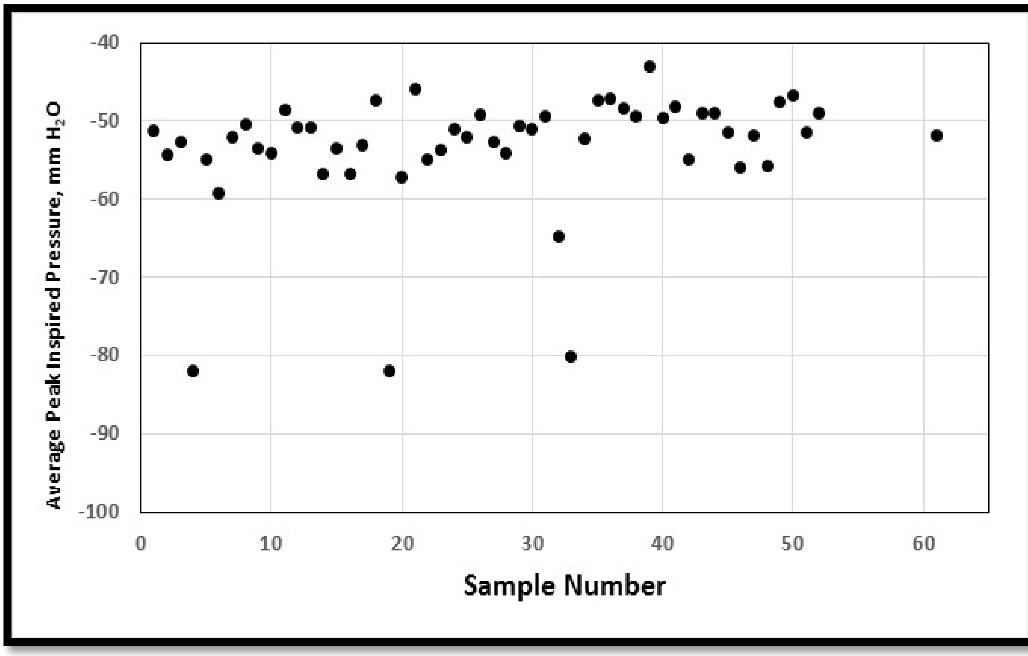

Figure 31. Average Peak Inspired Pressure of Ocenco M-20 SCSR

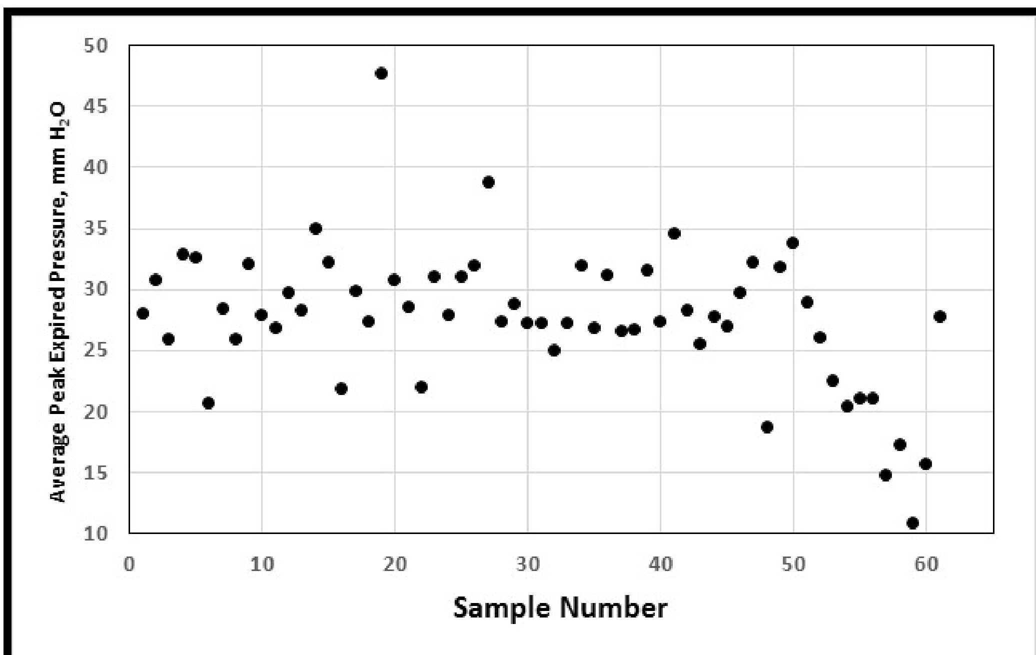

Figure 32. Average Peak Expired Pressure of Ocenco M-20 SCSRs

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

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