Self-Contained Self-Rescuer
Long-Term Field Evaluation:
Second Phase Random Sampling Results
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ACRONYMS AND ABBREVIATIONS

ABMS  automated breathing and metabolic simulator
BMS   breathing and metabolic simulation
CO    carbon monoxide
CO₂   carbon dioxide
CPPIP certified product investigation process
FICO₂ mole fraction inspired carbon dioxide
FIO₂ mole fraction inspired oxygen
LTFE  long term field evaluation
LTR   long term random field evaluation
MSHA  Mine Safety and Health Administration
N₂    Nitrogen
NIOSH National Institute for Occupational Safety and Health
NPPTL National Personal Protective Technology Laboratory
O₂    oxygen
OSHA  Occupational Safety and Health Administration
QNT   quantitative leak test
PEPRS CMH20 peak expired pressure, centimeters of water
PIPRS CMH20 peak inspired pressure, centimeters of water
SCSR  self-contained self-rescuer
TAVGDB average dry bulb temperature over entire breath, °C
TLV   threshold limit value
VCO₂ volume of carbon dioxide
VO₂   volume of oxygen

UNIT OF MEASURE ABBREVIATIONS

breaths/min  breaths per minute
kgs          kilogram(s)
Ls           liter(s)
L/breath     liter(s) per breath
lbs          pound(s)
LPM          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
Acknowledgements

Thanks are extended to the Mine Safety and Health Administration, The United Mine Workers of America, Mine Operators, Manufacturers, Mine Workers, and NIOSH personnel that supported and continue to support the long-term field evaluation of SCSRs in U.S. underground coal mines. The authors gratefully acknowledge Courtney Neiderhiser, Nicholas Kyriazi, and John P. Shubilla who developed the initial draft of this document and for their contributions on the Long-Term Field Evaluation Project that include developing the sampling strategy, arranging the collection from the various mines, and testing of SCSRs.

Front cover photos courtesy of Dräger Safety, Ocenco Incorporated, and CSE Corporation.

1 Formerly of NIOSH, National Personal Protective Technology Laboratory
Self-Contained Self-Rescuer Long-Term Field Evaluation: Second Phase Random Sampling Results

Gary Walbert and Bill Monaghan

Abstract

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) in Pittsburgh, PA have undertaken a study to evaluate the long-term field performance and reliability of self-contained self-rescuer (SCSR) units deployed in U.S. underground coal mines in accordance with federal regulation 30 CFR § 75.1714. This ongoing project provides performance, reliability, and user maintenance compliance data on field deployed SCSR units.

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

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

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

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Introduction

Coal mine operators in the United States are required to make a self-contained self-rescuer (SCSR) available to each underground coal miner. Additional SCSRs are required to be cached on working settings and in outby escape ways. Title 30 Code of Federal Regulations (30 CFR) § 75.1714 requires that each person in an underground coal mine wear, carry, or have ready access to a device approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA). The device must provide respiratory protection with an oxygen (O₂) source for up to one hour. In some mines, shorter duration SCSRs are also available to reach caches for the 1-hour units. SCSRs are sealed for protection from the underground mining environment. The sealed case protects the apparatus from environmental and physical damage, but makes it difficult to inspect the unit for damage. Unlike open-circuit, self-contained breathing apparatus employed in fire services and general industry, no functional assessment can be made prior to actual use. For these reasons, the NIOSH National Personal Protective Technology Laboratory (NPPTL), in cooperation with MSHA, conducts an ongoing, long-term field evaluation (LTFE) of SCSRs deployed in underground coal mines to assess their reliability and performance.

The objective of the LTFE program is to evaluate how well SCSRs endure the underground coal mining environment with regard to both physical damage and the effects of aging. In order to protect miners’ safety, mines must conduct regular inspections of deployed units to ensure readiness. The criteria for these inspections are established by the manufacturers and include damage assessment of specific components by either visual inspection or non-destructive testing. Among the visual inspection criteria are evaluation of heat and humidity indicators or pressure gauges, verification of the service time date, assurance that the case seal is intact, and visual assessment of physical indications of wear or damage. All users must comply with the manufacturer’s specified conditions for storage and use. SCSRs failing inspection, or not in compliance with the conditions of storage and use, no longer meet the NIOSH/MSHA approval and must be removed from service. Beginning with the LTR1 collection phase, NIOSH subjected the SCSRs to strict visual inspections. The intent was to permit only units that passed the visual inspection into the study. The LTR2 portion of the program did not test any units that failed the subsequent NIOSH visual inspection at the NPPTL laboratory.

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

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

Breathing and Metabolic Simulation (BMS) tests performed for LTR2 focused on assessing the performance of in-service SCSRs retrieved from the mines during the LTR2 collection phase. The BMS machine test provides a reproducible measure for comparison. All tests were conducted to endpoints under constant BMS operating conditions to facilitate duration comparisons between NPPTL in-storage and deployed units. Sixty-minute and 10-minute test data averaging, consistent with service time, was subsequently used to eliminate the test duration variability effect in the determination of stressor levels. LTFE tests differ from the tests used in respirator approval and are consistent with SCSRs performing at a constant work rate in an underground escape scenario. The SCSR units collected and tested for the LTR2 phase were approved to be manufactured and sold in accordance with the requirements of 42 CFR, Part 84, Subpart H. NIOSH approval of SCSRs under Subpart H required the passing of a series of human subject tests where stressors were measured periodically by test administrators during the exercise routines performed. Although approval tests using human subjects and simulator testing using the ABMS can produce similar results, they are different tests, and the data reported from BMS testing cannot be considered equivalent to previous approval tests using human subjects. Therefore, test data from LTR2 testing should not be used to predict actual respirator performance for a miner in an emergency where work rates will vary based on escape route conditions, miner fitness level, etc.

**Methods**

**SCSRs Collected and Evaluated**

The SCSRs evaluated in the LTR2 study included units manufactured by Ocenco Incorporated and Dräger. The Ocenco EBA 6.5 and the Ocenco M-20 (Figures 1 and 2) are compressed oxygen-supplying SCSRs. The EBA 6.5 has a rated duration of 60 minutes; the
M-20 has a rated duration of 10 minutes. The Dräger Oxy K Plus (Figure 3) is a chemical oxygen-producing SCSR that employs an oxygen gas starter for initial operation while chemical oxygen generation is induced from the canister via the user’s exhaled breath. The Oxy K Plus SCSR has a rated duration of 60 minutes. All SCSRs included in the study utilize a chemical bed to reduce carbon dioxide (CO₂) to within acceptable limits.

CSE SR-100 SCSR units were not collected during this sampling period due to the Occupational Safety and Health Administration’s mandatory removal of these devices from service in

Sampling Strategy

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

Table 1. Summary of LTR2 SCSR Collection

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Number of units collected</th>
<th>Manufacture date range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dräger</td>
<td>Oxy K Plus</td>
<td>96</td>
<td>02/2006 – 01/2011</td>
</tr>
<tr>
<td>Ocenco</td>
<td>EBA 6.5</td>
<td>111</td>
<td>06/1997 – 08/2011</td>
</tr>
<tr>
<td>Ocenco</td>
<td>M20</td>
<td>105</td>
<td>11/2006 – 06/2012</td>
</tr>
</tbody>
</table>

Tests and Evaluations

The following tests and evaluations were conducted on each SCSR unit obtained: (1) visual inspection which miners are required to make before each shift; (2) phenolphthalein indicator check; (3) quantitative leak test; (4) oxygen flow test; and (5) breathing and metabolic simulation (BMS) test. In addition to the visual checks, the CSE and Dräger inspection manuals state that each SCSR utilizing a chemical bed to generate oxygen should be tested with the CSE acoustic solids movement detector (ASMD) every 90 days to field-check the condition of the chemical bed. NIOSH did not perform this test because the equipment necessary to conduct this test was not available. While the units were provided to NIOSH with the understanding that they should have passed the mine’s ASMD assessment, we acknowledge that unassessed, or even improperly assessed bed degradation could have had a negative impact on at least some of the results being reported herein.

Visual Inspection

Three-hundred seventy-nine SCSRs passed the manufacturer’s recommended visual inspections at the mine and were collected for further evaluation by NIOSH, including a second visual inspection at NPPTL prior to laboratory testing. Manufacturers’ recommended visual inspections focus on the integrity of the case, seal, latches, mouthpiece plug, and indicators
that are viewable without opening or activating the respirator. The case of the Dräger Oxy K
Plus chemical unit has moisture and heat indicators that signify water penetration or excessive
temperature exposure, respectively. Ocenco Incorporated oxygen units have pressure
indicators that measure oxygen cylinder pressure. Damage to the case, missing case latches,
broken seals allowing contaminant penetration, excessive heat exposure, moisture penetration
into the case, or low O₂ gauge pressures are reasons for a unit to fail the visual inspection. If all
visual inspections pass, the SCSR is safe for use. If a unit does not meet the manufacturer’s
prescribed limits for these indicators when inspected at the mine, it must be taken out of
service. SCSR units that failed the visual inspection at NPPTL were removed from the study. It
should be noted that NPPTL only performed the same visual inspections that a miner is
required to conduct prior to using the unit or taking it underground.

Phenolphthalein Indicator Check

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

Quantitative Leak Test

SCSRs that passed the visual inspection check proceeded to the quantitative (QNT) leak test.
This test assesses breathing circuit integrity but is not required for certification approval. The
leak test employs an exhaust blower to induce a vacuum of 300 mm H₂O within the SCSR
breathing circuit while measuring the inward leakage rate with a mass flow meter. At maximal
work rates, inhalation pressure/vacuum should not exceed +300 or -300 mm H₂O (Hodgson,
1993) and inward leakage rates should be less than 500 milliliters per minute (ml/min) to
reasonably assure user protection for a period equal to or greater than the rated service time.
The inward leakage threshold of 500 ml/min is a function of the 200-ppm, one-hour threshold
limit value (TLV) for carbon monoxide (CO). An inward leakage rate of 500 ml/min in a 10% CO
atmosphere at a peak inhalation rate of 250 liters per minute over one hour corresponds to a
CO volume fraction of 0.0002 or 200 ppm. Leakage rates were documented and SCSR units that
exceeded the 500 ml/min leakage rate continued with the remaining pre-test evaluations and
were subsequently tested.

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

**Oxygen Flow Test**

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

**BMS Test**

The SCSR units tested in this phase were not NIOSH-approved using the ABMS. The units were approved using man-test 4 for the stated service time (either 10 or 60 minutes), as described in 42 CFR Part 84, Subpart H. Due to resource constraints, it was not feasible to conduct man-test 4 on 400 SCSRs. The BMS test was used as a surrogate for man-test 4. The computer-controlled ABMS (Figure 4) produces CO2 and simulates O2 consumption at fixed breathing frequencies and tidal volumes to simulate human metabolic processes (Deno, 1984 and Kyriazi, 1986). The ABMS machine is an ideal device for evaluating inhaled CO2 and O2 concentrations in SCSRs due to its high degree of accuracy and repeatability in duplicating human CO2 production and O2 consumption. By design, an ABMS replicates breathing ventilation (respiratory frequency, tidal volume, flow, temperature, and humidity), O2 consumption, and CO2 production. An ABMS produces human respiratory air qualities at approximately 33ºC and saturated with water vapor. Due to its complexity, an ABMS is managed by a computer program. The computer uses a routine of energy expenditures (protocol) to make adjustments and provide measurements of respiratory gas concentrations, pressures, and temperatures.

NIOSH tested the SCSRs 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 VO2 of 1.35 L/min, VCO2 of 1.15 L/min, a ventilation rate of 30 L/min, and respiratory frequency of 18 breaths per minute. During testing, the ABMS monitored metabolic stressors which include inhaled levels of CO2 and O2, wet- and dry-bulb temperatures, and inhalation and exhalation breathing resistances (pressures) continuously until the test was terminated. Tests on the ABMS are terminated upon one of three endpoints: exhaustion of the O2 supply as indicated by inhalation pressures reaching -200 mm H2O, coinciding with an empty breathing bag; average inhaled CO2 levels exceeding 10%; or O2 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, LTR2 testing is not equivalent to 42 CFR, Part 84, Subpart H human subject certification testing. Human subjects may differ from each other and from the ABMS in terms of CO₂ 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 O₂ consumption rate is the same. However, the ABMS can be used to provide an indication of SCSR duration performance. Certification testing imposes high and low work rates that the average work rate used in LTR2 does not. Also, the stressor levels are continuously monitored during LTR2 testing, whereas they are sampled only between work activities in certification testing. In addition, LTR2 testing continued until the apparatus was empty or stressor levels exceed allowable parameters, whereas testing during certification ends at the rated duration, even if the capacity of the apparatus exceeds it.

![Photo by NIOSH](image)

**Figure 4. Automated Breathing and Metabolic Simulator**

**Table 2. Constant Average Metabolic Work Rate**

<table>
<thead>
<tr>
<th>Metabolic workload</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ Consumption</td>
<td>1.35 L/min</td>
</tr>
<tr>
<td>CO₂ Production Rate</td>
<td>1.15 L/min</td>
</tr>
<tr>
<td>Ventilation Rate</td>
<td>30 L/min</td>
</tr>
<tr>
<td>Tidal Volume</td>
<td>1.68 l/breath</td>
</tr>
<tr>
<td>Respiratory Frequency</td>
<td>17.9 breaths/min</td>
</tr>
<tr>
<td>Peak Respiratory Flow Rate:</td>
<td></td>
</tr>
<tr>
<td>Peak Inhalation</td>
<td>89 L/min</td>
</tr>
</tbody>
</table>
Units not passing the manufacturer’s recommended visual inspection, not meeting the requirements of 42 CFR Part 84.41, Quality Control Plans, or not meeting the rated duration are referred to the certified product investigation process (CPIP) coordinator for investigation into the cause of these results and to determine if any further action is warranted. None of the LTR2 SCSRs referred to the CPIP coordinator for review required further action.

**SCSR Stressor Test Data**

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

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

**RESULTS AND DISCUSSION**

**SCSR Collection**

NIOSH targeted 536 units deployed in United States underground coal mines for collection for LTR2. On the randomly generated collection lists, approximately 137 units represented Ocenco EBA 6.5, 176 units represented Ocenco M-20, and 223 units represented Dräger Oxy K Plus/Oxy K Plus S models. Of the 536 units targeted, NIOSH collected 386 SCSR units at the mine. After identifying 7 visual inspection failures, NIOSH returned 379 SCSRs to NPPTL for testing, yielding a collection rate of 70.7%. Figure 5 depicts the status of the 536 SCSRs targeted in the LTR2 collection. A total of 150 SCSRs were either missing or not available for various reasons including mine closure, removed from service, and not feasible to be collected (Figure 5). This amounts to 28.0% of the SCSRs on the targeted collection list.
From the collection of 379 SCSRs, two units failed the visual inspection at NPPTL leaving 377 units that qualified for BMS testing. The SCSRs that qualified for BMS testing included: 163 Dräger Oxy-K Plus/Oxy K Plus S SCSRs, 109 Ocenco EBA 6.5, and 105 Ocenco M-20 SCSRs (Figure 6).

When LTR2 collection and testing began in January, 2012, NIOSH decided to collect all SCSRs that the mines and MSHA District Offices deemed as passing visual inspection. Of the 386 SCSRs
(Table 3) that were collected at the mines, seven (1.3%) failed mine visual inspection due to either damage to the unit, an open case, or a missing security seal. Out of 379 SCSRs collected and transported to NIOSH, an additional two SCSRs (0.4%) failed visual inspection when applying the manufacturer’s criteria upon test initiation in the laboratory. From the 377 qualifying SCSRs, NIOSH obtained 358 valid sets of data.

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

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

Dräger Oxy K Plus/Oxy K Plus S SCSR

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

All 163 Dräger Oxy K Plus/Oxy K Plus S SCSRs tested passed the manufacturer’s visual inspection at the NIOSH laboratory (Figure 7). Valid test data was obtained for 93 of the 96 Dräger Oxy K Plus and all Dräger Oxy K Plus S SCSRs. The three invalid tests were due to ABMS operational issues. None of the Dräger Oxy K Plus/Oxy K Plus S SCSR units returned to the NIOSH laboratory for testing failed the phenolphthalein indicator test.
The breathing circuit integrity check of the Dräger Oxy K Plus SCSR using the QNT leak test procedure showed that 91 of 93 SCSR units for which valid data was obtained had a leak rate less than 100 ml/min and all had leak rates less than 500 ml/min. The breathing circuit integrity check of the Dräger Oxy K Plus S SCSR using the QNT test procedure showed that 63 of the 67 units tested had a leak rate less than 100 ml/min and 66 of 67 SCSR units had a leak rate less than 500 ml/min.

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

NIOSH personnel averaged the minute-average values of the stressors monitored during BMS testing of the Dräger Oxy K Plus/Oxy K Plus S SCSRs over the first 60 minutes of the test and the results are presented graphically in Appendix A (Figures 18 through 23). Sixty minute data averaging, consistent with service time, was chosen to eliminate the test duration variability effect in the determination of stressor levels. The deployed Dräger Oxy K Plus/Oxy K Plus S SCSR unit stressor results were sorted within each composite graph by manufacturing dates which ranged in age from oldest to newest, left to right. A linear regression was fit to each stressor plotted from Dräger Oxy K Plus/Oxy K Plus S SCSR testing to draw out the effects of deployment time. No major trends in measured stressors that could be attributed to deployment time were identified.
Test Duration and composite mean stressor levels, including FIO2 (mole fraction inspired oxygen), FICO2 (mole fraction inspired carbon dioxide), PEPRS (peak expired pressure), PIPRS (peak inspired pressure), and TAVGDB (average dry bulb temperature), are shown for the deployed Dräger Oxy K Plus/Oxy K Plus S SCSR units in Table 4. Dräger Oxy K Plus and Oxy K Plus S SCSRs are functionally identical except for the opening procedure. As would be expected, average stressor levels measured for the Oxy K Plus and Oxy K Plus S SCSRs were very similar.

<table>
<thead>
<tr>
<th></th>
<th>Oxy K Plus Deployed Unit Data (93 tests)</th>
<th>Oxy K Plus S Deployed Unit Data (67 tests)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DURATION</td>
<td>FIO2</td>
</tr>
<tr>
<td>MIN</td>
<td>54</td>
<td>0.6936</td>
</tr>
<tr>
<td>MAX</td>
<td>90</td>
<td>0.8950</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>84.8</td>
<td>0.8403</td>
</tr>
</tbody>
</table>

Ocenco EBA 6.5 SCSR

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

All but two of the 111 Ocenco EBA 6.5 SCSRs returned for testing passed the manufacturer’s visual inspection at the NIOSH laboratory. The failures were due to excessive in-leakage observed at the collar connected to the mouthpiece and the breathing hose ripping during handling during QNT leak tests. This means that 98.2% of the EBA 6.5 SCSRs that passed the manufacturer’s visual inspection at the mine also passed visual inspection at NIOSH. Valid test data was obtained for 102 of the 109 Ocenco EBA 6.5 SCSRs that were tested. The invalid tests were due to ABMS operational issues. None of the Ocenco EBA 6.5 SCSR units returned to the NIOSH laboratory for testing failed the phenolphthalein indicator test.
The breathing circuit integrity check of the Ocenco EBA 6.5 using the QNT leak test procedure showed that 64 of 102 SCSR units tested had a leak rate less than 100 ml/min and 95 of 102 SCSR units had a leak rate of less than 500 ml/min.

After test initiation on the ABMS, all SCSRs continued operating until the breathing gas supply was expended. All SCSRs 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 102 minutes.

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

NIOSH averaged the minute-average values of the stressors monitored during BMS testing of the Ocenco EBA 6.5 SCSRs over the first 60 minutes of the test and the results are presented graphically in Appendix B (Figures 24 through 29). Sixty minute data averaging, consistent with service time, was chosen to eliminate the test duration variability effect in the determination of stressor levels. NIOSH sorted the deployed Ocenco EBA 6.5 SCSR unit stressor results within each composite graph by manufacturing dates which range in age from oldest to newest, left to right. A linear regression was fit to each stressor plotted from SCSR testing to draw out the effects of deployment time. As can be seen in Figures 28 and 29, breathing resistance increased slightly as a function of deployment time for the Ocenco EBA 6.5 SCSR.

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

| Table 5. Ocenco EBA 6.5 Deployed SCSR Unit Duration and Composite Mean Stressor Levels |
|----------------------------------------|------------------|------------------|-------------------|-------------------|------------------|------------------|
| DURATION | FIO2 | FICO2 | PEPRS | CMH2O | PIPRS | CMH2O | TAVGDB |
| MIN | 74 | 0.3236 | 0.0011 | 35.03 | -87.98 | 38.20 |
| MAX | 110 | 0.9270 | 0.0068 | 71.87 | -38.33 | 43.99 |
| AVERAGE | 102.1 | 0.5364 | 0.0030 | 45.50 | -47.47 | 41.02 |

Ocenco M-20 SCSR

One-hundred five of the 176 Ocenco M-20 SCSRs listed on the LTR2 targeted collection list were returned to NIOSH. This yielded a collection rate of 105% when compared to LTR2 methods calling for the collection of 100 units. Challenges affecting the collection of Ocenco M-20 SCSRs included: insufficient communications with mines (10) and 42 missing units. These two challenges alone resulted in 29.5% of Ocenco M-20 SCSRs on our targeted collection list being unavailable. The remaining units were not collected and returned for reasons listed as removed from service (6), no record (4), unavailable (3), out for repair (3), mine closed/abandoned (2), and failed visual inspection at mine (1).
All of the 105 Ocenco M-20 SCSRs that were returned for testing passed the manufacturer’s visual inspection at the NIOSH laboratory. Valid test data was obtained for 96 of the 105 Ocenco M-20 SCSRs tested. Eight of the nine tests were deemed to be invalid due to ABMS operational issues. The 9th invalid test was due to data acquisition system issues. None of the Ocenco M-20 SCSR units returned to the NIOSH laboratory for testing failed the phenolphthalein indicator test.

The breathing circuit integrity check of the Ocenco M-20 SCSR units using the QNT leak test procedure showed that 71 of 96 SCSR units tested had a leak rate less than 100 ml/min and 94 of 96 SCSR units had a leak rate of less than 500 ml/min.

After test initiation on the ABMS, all but one Ocenco M-20 SCSR continued operating until the breathing gas supply was exhausted. Testing of this one unit was stopped after 7 minutes because the breathing bag was empty and the inspired O₂ level decreased to less than 7.0%. All but one M-20 SCSR exceeded their NIOSH-approved 10 minute service time. The average duration for all Ocenco M-20 SCSRs was 17.6 minutes.

During BMS testing, NIOSH noted that 40 of the 96 M-20 SCSRs tested exceeded 4% CO₂ prior to oxygen expenditure (Table 6). However, none of these 40 exceeded 4% CO₂ before the 10-minute service time was reached.

<table>
<thead>
<tr>
<th>4% CO₂ Breakthrough Time, minutes</th>
<th>Test Duration, minutes</th>
<th>Maximum CO₂, Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>15</td>
<td>10.1</td>
</tr>
<tr>
<td>13</td>
<td>17</td>
<td>7.1</td>
</tr>
<tr>
<td>14</td>
<td>18</td>
<td>5.63</td>
</tr>
<tr>
<td>15</td>
<td>18</td>
<td>5.59</td>
</tr>
<tr>
<td>15</td>
<td>19</td>
<td>7.11</td>
</tr>
<tr>
<td>15</td>
<td>18</td>
<td>5.38</td>
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<tr>
<td>15</td>
<td>15</td>
<td>4.76</td>
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<tr>
<td>15</td>
<td>15</td>
<td>4.09</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
<td>4.85</td>
</tr>
<tr>
<td>15</td>
<td>17</td>
<td>6.24</td>
</tr>
<tr>
<td>16</td>
<td>18</td>
<td>5.03</td>
</tr>
<tr>
<td>16</td>
<td>20</td>
<td>7.96</td>
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<tr>
<td>16</td>
<td>17</td>
<td>4.83</td>
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<td>16</td>
<td>18</td>
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<td>4.37</td>
</tr>
<tr>
<td>17</td>
<td>18</td>
<td>4.33</td>
</tr>
</tbody>
</table>
NIOSH averaged the minute-average values of the stressors monitored during BMS testing of the Ocenco M-20 SCSRs over the first 10 minutes of the test. The results appear graphically in Appendix C (Figures 30 through 35). Ten minute data averaging, consistent with service time, was chosen to eliminate the test duration variability effect in the determination of stressor levels. NIOSH sorted the deployed Ocenco M-20 SCSR unit stressor results within each composite graph by manufacturing dates which range in age from oldest to newest, left to right. A linear regression was fit to each stressor plotted from Ocenco M-20 SCSR testing to draw out the effects of deployment time. No major trends in measured stressors that could be attributed to deployment time were identified.

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

<table>
<thead>
<tr>
<th>DURATION</th>
<th>FIO2</th>
<th>FICO2</th>
<th>PEPRS CMH2O</th>
<th>PIPRS CMH2O</th>
<th>TAVGDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>7</td>
<td>0.2285</td>
<td>0.0018</td>
<td>23.67</td>
<td>-112.31</td>
</tr>
<tr>
<td>MAX</td>
<td>21</td>
<td>0.8092</td>
<td>0.0155</td>
<td>53.33</td>
<td>-20.61</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>17.6</td>
<td>0.4441</td>
<td>0.0069</td>
<td>32.21</td>
<td>-58.18</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**
All 358 SCSRs for which valid test data was obtained provided sufficiently high inhaled O₂ levels to sustain life over the course of the manufacturers’ specified service time. A high degree of variability was observed in inhaled O₂ levels for all but one manufacturer’s SCSR. Inhaled O₂ levels are sensitive to N₂ imbalances in and in-leakage of air into the ABMS breathing circuit. The wide range of inhaled O₂ levels measured for all deployed unit tests may be attributable to these sensitivities.

All 358 SCSRs for which valid test data was obtained provided sufficiently low inhaled CO₂ levels to sustain life over the course of the manufacturers’ specified service time. During BMS testing, 40 of 96 of one manufacturer’s SCSR units tested exceeded 4% CO₂ prior to oxygen expenditure. None of these 40 exceeded 4% CO₂, however, before the service time was reached. NIOSH recognized this potential hazard and new 42 CFR, Part 84 Subpart O regulations for all SCSRs sold after January 4, 2018 prohibit approval of apparatus that operate with inspired CO₂ levels above 4.0%. SCSRs fail this test and certification approval if from test start-up to oxygen depletion the one-minute average inspired CO₂ ≥ 4.0%.

Peak breathing pressures of -300 and +200 mm H₂O have been identified as the outer limits of what is humanly tolerable based on research conducted at Penn State’s Noll Laboratory. Breathing resistances measured for all SCSRs tested were well within these limits.

Only two of 379 SCSRs returned for testing failed the visual inspection at NIOSH. These SCSRs were subsequently removed from testing. One failure was due to excessive in-leakage at the collar connected to the mouthpiece. The second failure was due to the breathing hose ripping during handling for the QNT leak test. Seven SCSR units failed the visual inspection at the mine due to either damage to the unit, an open case, or a missing security seal. The visual inspection failures amount to only 2.3% of the SCSR units collected at the mine. This is an indication that the SCSR units targeted by NIOSH for collection in LTR2 were, for the most part, being properly maintained.

Overall, only slight degradation in SCSR performance due to deployment time in the mines was observed. The inspired breathing resistance of one manufacturer’s SCSR increased slightly as a function of mine deployment time. No definite trends in other stressors as a function of deployment time for any other manufacturer’ SCSR units were identified. This is an indication that the SCSR units targeted for collection in LTR2 were mainly not affected by deployment time.
References


Appendix A – BMS Testing of the Dräger Oxy K Plus/Oxy K Plus S SCSRs Stressors

Figure 8. Duration of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

Figure 9. 60-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers
Figure 10. 60-Minute Average Percent Inspired Oxygen of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

Figure 11. 60-Minute Average Dry-Bulb Temperatures of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers
Figure 12. 60-Minute Average Peak Inspired Pressure of Field Deployed and New Dräger Oxy K Plus/Oxy K Plus S Self-Contained Self-Rescuers

\[ y = 0.0008x - 82.581 \]

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

\[ y = 0.0018x - 30.716 \]
Figure 14. Duration of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

\[ y = -0.0005x + 119.62 \]

Figure 15. 60-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

\[ y = -3E-05x + 1.4262 \]
Figure 16. 60-Minute Average Percent Inspired Oxygen of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

Figure 17. 60-Minute Average Dry Bulb Temperatures of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers
Figure 18. 60-Minute Average Peak Inspired Pressure of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers

Figure 19. 60-Minute Average Peak Expired Pressure of Field Deployed and New Ocenco EBA 6.5 Self-Contained Self-Rescuers
Appendix C – BMS Testing of the Ocenco M-20 SCSRs Stressors

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

Figure 21. 10-Minute Average Percent Inspired Carbon Dioxide of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers
Figure 22. 10-Minute Average Percent Inspired Oxygen of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

Figure 23. 10-Minute Average Dry-Bulb Temperatures of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers
Figure 24. 10-Minute Average Peak Inspired Pressure of Field Deployed and New Ocenco M-20 Self-Contained Self-Rescuers

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