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

Sample Period: January 2012 to June 2013

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Introduction

Catastrophic underground coal mine events such as a fire or explosion may create a mine atmosphere that is immediately dangerous to life or health. Therefore, the Mine Safety and Health Administration (MSHA)\(^1\) requires that all underground coal mine workers be provided with a closed-circuit escape respirator known as self-contained self-rescuer (SCSR). To support the multi-hour, physiologically demanding task of mine escape, MSHA also requires the operator to cache additional devices along the escape routes to replace devices prior to the O\(_2\) source being depleted during escape. MSHA and the National Institute for Occupational Safety and Health (NIOSH) serve as joint approvers for SCSRs with both agencies defining performance requirements. NIOSH oversees device testing, evaluation, and sets quality assurance requirements with both agencies jointly approving when a manufacturer’s device meets performance and quality requirements. NIOSH’s post-market activities for SCSRs include a cooperative effort with MSHA where point-of-use assessments are conducted to ensure that operators are adhering to manufacturer specifications and to verify that SCSRs remain protective under use conditions, which includes both physical damage and the effects of aging. These NIOSH-conducted point-of-use assessments are critical, because it is not possible for the mine operator to conduct a

\(^{1}\) A list of acronyms and abbreviations is available in Appendix A.
functional assessment of its SCSRs as this would destroy the unit itself. This report provides the results and conclusions from NIOSH’s SCSR point-of-use assessments, conducted from January, 2012 to June, 2013 on all SCSR devices that were NIOSH/MSHA-approved during that time frame.

**Sampling Strategy**

For statistical analysis purposes, NIOSH attempted to obtain at least 100 of each NIOSH-approved SCSR model deployed in United States underground coal mines for this post-market point-of-use assessment study. This included units manufactured by Ocenco Incorporated (EBA 6.5 and M-20 models) and Dräger (Oxy K Plus and Oxy K Plus S models) ([Figure 1](#)). 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 accordance with the NIOSH Respirator User Notice “Loss of Start-Up Oxygen in CSE SR-100 Self-Contained Self-Rescuers” of April 26, 2012.

![A) Ocenco EBA 6.5, B) Ocenco M-20, and C) Dräger Oxy K Plus S self-rescuer models (Photo Credit: NIOSH). D) The only difference between the Oxy K Plus (top) and Oxy K Plus S (bottom) models is the opening mechanism (Photo Credit: Dräger).](#)

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 the 11 U.S. mining districts², 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. For example, a mine may be unable to locate a particular unit, may have already

² Units were obtained from Districts 2 thru 12 as there is no District 1 ([http://arlweb.msha.gov/DISTRICT/COALHOME.htm](http://arlweb.msha.gov/DISTRICT/COALHOME.htm); accessed December 22, 2016).
removed the unit for failing the visual inspection, or the unit may have failed when NIOSH conducted the visual inspection. In the latter case, the SCSR was removed from the remainder of this study because the NIOSH/MSHA approval was invalidated and no additional testing was necessary to determine if it met approval criteria.

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
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’s 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 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 documented as not meeting approval requirements and were, therefore, not subject to any additional tests.

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 (QNT) Leak Test
The QNT leak test assesses breathing circuit integrity of the SCSR unit prior to testing but is not required for certification approval. This test is performed on the bench to identify leaks in the closed-circuit portion of the SCSR or the mouthpiece connector prior to connection to the ABMS. This process isolates leaks in the ABMS breathing circuit once connection to the trachea is made. 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. NIOSH documented leakage rates and SCSR units that exceeded the 500 ml/min leakage rate continued with the remaining pre-test evaluations and were subsequently tested. Additional information regarding the QNT leak test protocol may be reviewed in Appendix B.

**Oxygen Flow Test**
NIOSH tested each Ocenco EBA 6.5 SCSR for maximum sustained oxygen flow rate as it is an oxygen-supplying closed-circuit apparatus supplying breathable oxygen from a compressed gas cylinder. The Ocenco M-20 10-minute SCSR cannot be flow tested because its oxygen supply valve cannot be closed once it is opened. The Dräger Oxy K Plus and Oxy K Plus S SCSR devices are chemical oxygen generators and, therefore, not subject to this test. The Ocenco EBA 6.5 was flow tested 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 for combination constant flow and on-demand SCRs. If the maximum sustained oxygen flow rate is greater than or equal to 1.5 L/min, the unit meets this test requirement.

**Breathing and Metabolic Simulation (BMS) Test**
As part of 42 CFR Part 84, Subpart H requires that SCSR devices undergo man-test 4 for the stated service time of the device (either 10 or 60 minutes). However, replicating this test for the nearly 400 SCSR units collected as part of this point-of-use assessment is unnecessarily resource-intensive. For initial approval, it is critical that devices meet performance requirements that support the physiological demands of a worker; however, point-of-use assessments are merely seeking to identify any indication that use conditions may be altering device performance such that it may no longer meet approval requirements. For this point-of-use assessment it was, therefore, deemed appropriate to use a computer-controlled automated breathing and metabolic simulator (ABMS) as a surrogate for the man-test 4.

The ABMS ([Figure 2](#)) produces CO\(_2\) and simulates O\(_2\) consumption at fixed breathing frequencies and tidal volumes to simulate human metabolic processes (Kamon, Deno, and Vercruyssen, 1984 and Kyriazi, 1986). The ABMS machine is an ideal device for evaluating inhaled CO\(_2\) and O\(_2\) concentrations in SCRs due to its high degree of accuracy and repeatability in duplicating human CO\(_2\) production and O\(_2\) consumption. By design, an ABMS replicates breathing ventilation (respiratory frequency, tidal volume, flow, temperature, and humidity), O\(_2\) consumption, and CO\(_2\) production. An ABMS produces human respiratory air qualities at approximately 33°C and saturated with water vapor. The ABMS uses a routine of energy expenditures (protocol) to make adjustments and provide measurements of respiratory gas concentrations, pressures, and temperatures. Additional information regarding the ABMS protocol may be reviewed in Appendix B.

Units that did not meet the rated duration requirements using the ABMS were referred to NIOSH’s Certified Product Investigation Process.
SCSR Stressor Test
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.

NIOSH averaged all stressor data from the testing of deployed units 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
Sampling and Visual Inspection
Of the 536 units targeted, NIOSH collected 386 SCSR units at the mines. A total of 150 units were either missing or not available for various reasons including mine closure, removed from service, and not feasible to be collected (Figure 3). This amounts to 28.0% of the units on the targeted collection list. Additionally, seven visual inspection failures were identified while 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 units collected at the mine. Thus, NIOSH collected 379 units for testing at its facilities, yielding a collection rate of 70.7%.
Collectively, this resulted in the following dispersion of units across the four SCSR models of interest: 96 Dräger Oxy K Plus; 67 Dräger Oxy K Plus S; 111 Ocenco EBA 6.5; and 105 Ocenco M-20 SCSRs (Table 1). Table 1 describes those units that were tested—i.e., passed the visual inspection criteria.

**Table 1. Summary of SCSRs collected for this study including number of units that were tested and their manufacture date range.**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Number of units collected and passing visual inspection</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>M-20</td>
<td>105</td>
<td>11/2006 – 06/2012</td>
</tr>
</tbody>
</table>

**QNT, Oxygen Flow, ABMS, and Stressor Tests**

Of the 111 Ocenco EBA 6.5 units collected, two units were not able to be tested due to excessive inward leakage during handling for QNT testing. The leakage occurred at the collar connected to the mouthpiece for one unit and the breathing hose ripping during handling for the other unit. Therefore, only 109 of the 111 units that passed visual inspection were ultimately tested. For all four SCSR models, the number of units where NIOSH obtained valid test data is illustrated in Table 2.
Table 2. 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>111</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>
<td>96</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>536</strong></td>
<td><strong>386</strong></td>
<td><strong>379</strong></td>
<td><strong>377</strong></td>
<td><strong>377</strong></td>
<td><strong>358</strong></td>
</tr>
</tbody>
</table>

**Dräger Oxy K Plus and Oxy K Plus S SCSR Units**

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 SCSR units had a leak rate 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 4 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 all Dräger Oxy K Plus and 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 were graphically interpreted. NIOSH chose sixty-minute data averaging, consistent with service time, to eliminate the test duration variability effect in the determination of stressor levels. The deployed Dräger Oxy K Plus/Oxy K Plus S SCSR units’ stressor results were sorted within each composite graph by manufacturing dates. 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. NIOSH found no major trends in measured stressors that could be attributed to deployment time.

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 3. The Dräger Oxy K Plus and Oxy K Plus S SCSR are functionally identical except for the opening procedure. As would be expected, average stressor levels measured for the Oxy K Plus and Oxy K Plus S SCSR were very similar.
Table 3. Dräger Oxy K Plus and Oxy K Plus S Deployed SCSR Unit Duration and Composite Mean Stressor Levels

<table>
<thead>
<tr>
<th></th>
<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><strong>Oxy K Plus Deployed Unit Data (93 tests)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>54</td>
<td>0.6936</td>
<td>0.0070</td>
<td>34.04</td>
<td>-76.98</td>
<td>36.24</td>
</tr>
<tr>
<td>MAX</td>
<td>90</td>
<td>0.8950</td>
<td>0.0203</td>
<td>55.98</td>
<td>-43.03</td>
<td>41.85</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>84.8</td>
<td>0.8403</td>
<td>0.0089</td>
<td>40.20</td>
<td>-50.65</td>
<td>39.22</td>
</tr>
<tr>
<td><strong>Oxy K Plus S Deployed Unit Data (67 tests)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>68</td>
<td>0.7120</td>
<td>0.0066</td>
<td>31.48</td>
<td>-60.31</td>
<td>30.67</td>
</tr>
<tr>
<td>MAX</td>
<td>89</td>
<td>0.8613</td>
<td>0.0139</td>
<td>56.55</td>
<td>-39.88</td>
<td>41.94</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>84.8</td>
<td>0.8262</td>
<td>0.0094</td>
<td>38.91</td>
<td>-49.07</td>
<td>38.22</td>
</tr>
</tbody>
</table>

Ocenco EBA 6.5 SCSR

NIOSH obtained valid test data for 102 of the 109 Ocenco EBA 6.5 SCSRs 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. NIOSH evaluated all Ocenco EBA 6.5 SCSRs 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 were interpreted graphically. NIOSH chose sixty-minute data averaging, consistent with service time, 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 date. A linear regression was fit to each stressor plotted from SCSR testing to draw out the effects of deployment time. It was determined that 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 4.

Table 4. Ocenco EBA 6.5 Deployed SCSR Unit Duration and Composite Mean Stressor Levels

<table>
<thead>
<tr>
<th></th>
<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><strong>M-20 Deployed Unit Data (102 tests)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN</td>
<td>74</td>
<td>0.3236</td>
<td>0.0011</td>
<td>35.03</td>
<td>-87.98</td>
<td>38.20</td>
</tr>
<tr>
<td>MAX</td>
<td>110</td>
<td>0.9270</td>
<td>0.0068</td>
<td>71.87</td>
<td>-38.33</td>
<td>43.99</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>102.1</td>
<td>0.5364</td>
<td>0.0030</td>
<td>45.50</td>
<td>-47.47</td>
<td>41.02</td>
</tr>
</tbody>
</table>
Ocenco M-20 SCSR

NIOSH obtained valid test data 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 ninth invalid test was due to data acquisition system issues. None of the Ocenco M-20 SCSR units returned to the NIOSH laboratory for testing failed the phenolphthalein indicator test. The breathing circuit integrity check of the Ocenco M-20 SCSR units using the QNT leak test procedure showed that 71 of 96 SCSR units tested had a leak rate less than 100 ml/min and 94 of 96 SCSR units had a leak rate of less than 500 ml/min.

After test initiation on the ABMS, all but one Ocenco M-20 SCSR continued operating until the breathing gas supply was exhausted. Testing of this one unit was stopped after seven minutes because the breathing bag was empty and the inspired \(O_2\) level decreased to less than 7.0%. All but one M-20 SCSR 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% \(CO_2\) prior to oxygen expenditure. However, none of these 40 exceeded 4% \(CO_2\) before the 10-minute service time was reached. On average, the breakthrough times for these 40 units was 16.53±1.80 (mean±SD) with a minimum breakthrough time of 10 minutes.

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. NIOSH chose 10-minute data averaging, consistent with service time, 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 the Ocenco M-20 units tested to draw out the effects of deployment time. NIOSH found no major trends in measured stressors that could be attributed to deployment time.

Test duration and composite average mean stressor levels, including \(FIO_2\), \(FICO_2\), \(PEPRS\), \(PIPRS\), and \(TAVGDB\), are shown for the new and deployed Ocenco M-20 SCSR units in Table 5.

| Table 5. Ocenco M-20 Deployed SCSR Unit Duration and Composite Mean Stressor Levels |
|----------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                       | DURATION | \(FIO_2\) | \(FICO_2\) | \(PEPRS\) | \(CMH_2O\) | \(PIPRS\) | \(CMH_2O\) | \(TAVGDB\) |
| M-20 Deployed Unit Data (96 tests)   |          |          |          |          |            |            |            |            |
| MIN                                   | 7        | 0.2285   | 0.0018   | 23.67    | -112.31    | 38.99       |            |            |
| MAX                                   | 21       | 0.8092   | 0.0155   | 53.33    | -20.61     | 44.84       |            |            |
| AVERAGE                               | 17.6     | 0.4441   | 0.0069   | 32.21    | -58.18     | 42.34       |            |            |

Discussion and Action Items

Mine Operator Compliance with Manufacturer-Specified Requirements

Closed-circuit devices such as SCSRs cannot undergo a performance assessment without destroying the unit itself. This is unlike open-circuit devices such as a self-contained breathing apparatus, which are used in the fire service and general industry, where employers may evaluate the device performance routinely as part of its respiratory protection program. Without the option to routinely assess the performance of SCSRs, mine operators must be extremely diligent in their adherence to manufacturer-specified storage and visual inspection.
practices, and it is essential that SCSRs failing the visual inspection are immediately removed from service. In this study of nearly 400 SCRS collected from mine operators that span 11 of MSHA’s 12 mining districts, visual inspection failures amounted to only 2.3% of the SCSR units collected at the mine. This is an indication that mine operators are adhering to manufacturer-specified visual inspection requirements. This is a critical finding, because the joint NIOSH/MSHA approval is considered invalid for any units where the mine operator did not adhere to the manufacturer-specified storage and visual inspection requirements are not followed. Therefore, data from this study suggests that mine operators are compliant with manufacturer-specified requirements and that MSHA’s current resource investment for enforcement activities associated with SCSR storage and visual inspection is adequate.

**Ability of Manufactured Products to Withstand Mining Use Conditions**

Overall, NIOSH observed only slight degradation in SCSR performance due to deployment time in the mines. The inspired breathing resistance of one manufacturer’s SCSR increased slightly as a function of mine deployment time, but this increase was of no physiological significance. NIOSH found no definite trends in other stressors as a function of deployment time for any other manufacturer’s SCSR units. This is an indication that the designs, approaches to hardening the devices, and storage practices for the SCSR devices evaluated in this study were sufficiently able to withstand mining use conditions.

**NIOSH Point-of-Use Assessment Test Methodology for SCSRs**

The data from the ABMS tests demonstrated a high degree of variability in inhaled O2 levels for all but one manufacturer’s SCSR. Because inhaled O2 levels are sensitive to N2 imbalances, inward leakage of air into the ABMS breathing circuit, and inaccuracies in the exhaust, CO2, and N2 metabolic valve flow rates, this wide range of inhaled O2 levels may be attributable to these sensitivities. NIOSH will consult and work with the ABMS manufacturer and ABMS control software application designer to resolve these issues.

**NIOSH SCGR Performance Requirements**

During BMS testing, one manufacturer’s SCSR model exceeded 4% CO2 prior to oxygen expenditure, but not until after the service life was reached. For this one model, this finding occurred for 40 of the 96 units test, or 42%. These findings have identified the possibility for a mine worker to be receiving oxygen while under apparatus and suddenly experience CO2 levels that exceed a physiologically acceptable level. Recognizing this hazard, NIOSH addressed this issue in the new 42 CFR, Part 84 Subpart O regulations for all SCSRs sold after January 4, 2017, which prohibits approval of any SCSR device that is capable of operating with inspired CO2 levels above 4.0%. Under the new regulation, SCSRs may not be certified as meeting performance requirements if, from test start-up to oxygen depletion, the one-minute average inspired CO2 > 4.0%.
Appendix A: Acronyms and Abbreviations

ABMS automated breathing and metabolic simulator
BMS breathing and metabolic simulation
CO carbon monoxide
$\text{CO}_2$ carbon dioxide
CPIP certified product investigation process
FICO2 mole fraction inspired carbon dioxide
FIQ2 mole fraction inspired oxygen
LTFE long-term field evaluation
LTR long-term random field evaluation
MSHA Mine Safety and Health Administration
$\text{N}_2$ 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
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 $\text{H}_2\text{O}$ millimeter(s) of water pressure
% percent
ppm parts per million
Appendix B: Additional ABMS Protocol Information

QNT Leak Test
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.

BMS Test
NIOSH tested the SCSRs on the ABMS using a constant average metabolic work rate test (Table 6). 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.

Table 6. 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>
<tr>
<td>Peak Exhalation</td>
<td>71 L/min</td>
</tr>
</tbody>
</table>

Although the average work rate is the same, NIOSH’s point-of-use assessment using the ABMS 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 this point-of-use assessment study does not. Also, the stressor levels are continuously monitored during the point-of-use assessment testing in this study, whereas they are
sampled only between work activities in certification testing. In addition, point-of-use assessment 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.

**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\(^3\), Nicholas Kyriazi\(^3\), and John P. Shubilla\(^1\) 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.

**References**


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

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