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Self-Contained Self-Rescuer Long Term Field Evaluation Tenth Phase Results

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

NIOSH

Report of Investigations

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DEPARTMENT OF HEALTH AND HUMAN SERVICES
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June 2008

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Contents

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

breaths/min	breaths per minute
dB	decibel(s)
kg	kilogram(s)
L	liter(s)
L/breath	liter(s) per breath
L/min	liter(s) per minute
mL/min	milliliter(s) per minute
mm H_2O	millimeter(s) of water (pressure)
ppm	parts per million

Abstract

The National Personal Protective Technology Laboratory (NPPTL) of the National Institute for Occupational Safety and Health (NIOSH) has undertaken a collaborative study with the Mine Safety and Health Administration (MSHA) to determine how well self-contained self-rescuers (SCSRs), deployed in accordance with Federal regulations (30 CFR 75.1714), withstand the underground coal mining environment with regard to both physical damage and aging. Apparatus tested included the CSE SR-100, the Draeger OXY-K Plus, the MSA Life-Saver 60, and the Ocenco EBA 6.5 and M-20.

This report presents findings regarding laboratory-tested SCSRs in the tenth phase of testing, from July 2004 to March 2006. The SCSRs were tested on a breathing and metabolic simulator and on a human subject walking on a treadmill. The tests performed in this study are not the tests used for certification (Title 42 of the Code of Federal Regulations, Part 84). The tests performed in this study continue until the apparatus are empty to enable comparison of new versus deployed apparatus. The method for obtaining deployed SCSRs for this evaluation was not a random selection from the deployed population of SCSRs. We sought older apparatus with visible environmental impact rather than newer apparatus, and we attempted to sample a wide range of deployment modes. Although the results of these tests are useful for observing performance of the tested SCSRs, they are not representative of all deployed SCSRs. This report is the last of 10 report phases begun in 1982. Previous reports describe phases 1 through 9 [Kyriazi et al. 1986; Kyriazi and Shubilla 1992, 1994, 1996, 2000, 2002, 2004, 2006] A new evaluation protocol, with revised sampling strategies, test methods, and reporting procedures, is currently being designed to enhance the applicability of the results.

The results of these studies suggest that the large majority of SCSRs that pass their inspection criteria can be relied upon to provide a safe level of life support for mine escape purposes. However, the storage and handling in the mining environment seems to have caused performance degradation in some of the apparatus. In this phase, phase 10, we found some CSE SR-100s (93 tested) that exhibited high CO_2 levels, stuck-together breathing hoses, starter-O_2 failure, breathing hose punctures and tears, high breathing pressures, and loose particulates in the breathing hose. The loose particulates caused coughing in human-subject tests. One MSA Life-Saver 60 (20 tested) in this phase had a stuck-open relief valve. One Ocenco EBA 6.5 (50 tested) had an unattached O_2 supply hose. An unexplained phenomenon occurred with two Ocenco M-20s (20 tested): low O_2 flow rates preventing their successful use. Almost all of the failures noted involved units that failed their inspection criteria.

Introduction

On June 21, 1981, U.S. coal mine operators were required to make available to each underground coal miner a self-contained self-rescuer (SCSR). The regulations (30 CFR 75.1714) require that each person in an underground coal mine wear, carry, or have immediate access to a device that provides respiratory protection with an oxygen (O_2) source for at least 1 hour as approved according to the requirements found at Title 42, Code of Federal Regulations, Part 84 (42 CFR, Part 84). The SCSRs are sealed to protect them from the underground mining environment. The sealed case that protects the apparatus from environmental and physical damage also makes it difficult to inspect. No functional assessment can be made prior to actual use. In order to assure proper functioning in an emergency, NPPTL and MSHA are jointly conducting a long-term field evaluation (LTFE) of SCSRs deployed in underground coal mines. NPPTL and MSHA locate mines willing to participate in the study and trade deployed SCSRs for new ones; NPPTL then tests the deployed SCSRs. The objective of this program was to evaluate the in-mine operational durability of deployed SCSRs. Of utmost concern is the successful performance of any SCSR that passes its approved inspection criteria. Such apparatus must function successfully to enable a miner to escape safely during an emergency.

Mines must conduct regular inspections of deployed units to ensure SCSR readiness. The criteria for these inspections are established by the manufacturers and include damage assessments of specific components by either visual inspection or other non-destructive testing. Among the visual inspection criteria are evaluating the use indicators or gauges provided on the unit, checking the service life date, and visually assessing physical indications of wear. Users must comply with the manufacturer's specified conditions of use. SCSRs failing inspection or not complying with the conditions of use no longer meet the NIOSH/MSHA approval and should have been removed from service; however, we tested all units collected including some that we judged to fail inspection criteria since they were considered viable units by the users and were in service when collected. The test results and data analysis include all units tested.

The sampling strategy used in the initial 10 phases of the LTFE program has had some changes in the mines and in the numbers of units of each approved type sampled. At various phases sampling has concentrated on smaller mines, segregated mines by seam height, and the number of units collected has varied. The protocol followed in each of the earlier phases is noted in the report for that phase. The replacement of used units with new units from the same SCSR manufacturer likely introduced a sampling bias in the program, where an old or damaged unit from the mine could be replaced by a new unit from NIOSH.

Evaluation Procedure

194 SCSRs were tested in the tenth phase of the study, from July 2004 to March 2006. Previous reports describe phases 1 through 9 [Kyriazi et al. 1986; Kyriazi and Shubilla 1992, 1994, 1996, 2000, 2002, 2004, 2006]. Ninety percent of the apparatus were targeted to be tested on a breathing and metabolic simulator (BMS) (Figure 1) and 10% on human subjects on a treadmill (Figure 2). In this phase, however, due to the lack of trained subjects meeting Human Subject Review Board constraints, we had only one test subject and were able to conduct only seven treadmill tests.

Figure 1. Breathing and Metabolic Simulator

Figure 2. Treadmill Testing

The SCSRs tested were manufactured by CSE Corp., Dragerwerk AG, Mine Safety Appliances Co., Inc. (MSA), and Ocenco, Inc. The number collected for this phase is indicated in Table 1.

Table 1. – SCSRs collected for evaluation

Apparatus	Number Collected	Number Tested
CSE SR-100	93	93
Draeger OXY K-Plus .	22	21
MSA Life-Saver 60	20	20
Ocenco EBA 6.5.........	50	50
Ocenco M-20.............	14	14
Total	199	198

One OXY K-Plus test was aborted due to equipment malfunction.

Sampling Strategy

NIOSH selected the participating mines with regard to type of mining operation, coal bed height, and SCSR deployment mode in order to obtain a wide range of deployment impact. Deployment modes included permanent storage on the ground, on a man-trip or mining machine, daily carry-and-store, and belt-worn. At on-site visits, NIOSH staff, accompanied by MSHA inspectors, new units are exchanged for deployed units judged to meet the manufacturer's criteria, and the mines are advised to remove rejected units from service. Mines selected for participation in Phase 10 are identified in the Acknowledgements.

Figure 3. Uncased and Cased CSE SR-100 Self-rescuer

Figure 4. Cased and Uncased Draeger OXY K-Plus Self-rescuer

Figure 5. Cased and Uncased MSA Life-Saver 60 Self-rescuer

Figure 6. Cased and Uncased Ocenco EBA 6.5 Self-rescuer

Figure 7. Partially Uncased and Uncased Ocenco M-20 Self-rescuer

O_2 Constant-Flow Rate

The O_2 constant-flow rate is checked on the Ocenco EBA 6.5, a compressed-O_2 apparatus. The required flow rate is 1.5 L/min at ambient temperature and pressure, dry (ATPD).

Breathing Circuit Tightness

All apparatus in this study are checked for breathing circuit leak tightness after opening. The leak test used was developed by Draeger for its BG-174 rescue breathing apparatus. It is performed to determine how well the apparatus isolates the user from the environment, which may be irrespirable in an emergency. Passing this test is not a requirement of the current regulations for these apparatus, however. The test permits a decay in breathing circuit pressure from -70 to -60 mm H_2O in 1 minute. We have determined that just passing the test is equivalent to a leak rate of approximately 1 mL/min assuming an internal volume for both the apparatus and test stand of 1 L. To give this some perspective, an in-leakage rate of 87 mL/min in a 10% CO atmosphere at a peak inhalation flow rate of 250 L/min (all volumes in this report are given at standard temperature (0^o C) and pressure, dry, unless otherwise noted) will result in a CO in-leakage concentration of 35 ppm, the 8-hour threshold limit value (TLV). The 250 L/min peak inhalation flow rate is used because this occurs at roughly an 80 L/min ventilation rate, the highest likely such rate that can reasonably be expected of a user. At such a maximal work rate, inhalation pressure should not exceed -300 mm H_2O, the highest negative pressure tolerated by 80% of test subjects in a recent study [Hodgson 1993]. At the leak test pressure of -70 mm H_2O, the proportional in-leakage rate resulting in the 8-hour TLV would be 20 mL/min at a peak inhalation flow rate of 58 L/min. The Draeger leak test, therefore, can be considered to err on the safe side.

Metabolic Load

The BMS test consisted of the average metabolic work rate exhibited by the 50th-percentile miner weighing 87 kg while performing the 1-hour man-test 4 as described in 42 CFR 84. However, even though the average work rate is the same, LTFE testing is not equivalent to certification testing. The certification testing imposes high and low work rates that the average work rate, used in the LTFE, does not. Also, the stressor levels are continuously monitored in the LTFE, whereas they are sampled only between work activities in the certification testing. In addition, LTFE testing continues until the apparatus is empty, whereas testing during certification ends at a predetermined time—the rated duration—even though the capacity of the apparatus usually exceeds this. Therefore, an apparatus that fails LTFE testing would not necessarily fail certification, and vice versa. In the LTFE treadmill testing, the human subject walked at whatever speed and grade elicited an O_2 consumption rate of 1.35 L/min. The metabolic parameters for both BMS and the human subject are given in Table 2.

Table 2. – BMS and human-subject metabolic parameters

Metabolic workload		BMS	Human Subject
0_2 consumption rate	L/min.	1.35	1.35
CO_2 production rate	L/min.	1.15	1.15
Ventilation rate	L/minute.	30.0	29
Tidal volume	L/breath.	1.68	1.93
Respiratory frequency	breaths/min.	17.9	15
Peak respiratory flow rate:			
Inhalation	L/minute	89	Not measured
Exhalation	L/minute	71	Not measured

Monitored Stressors

In both the BMS and treadmill testing, the stressors monitored were inhaled levels of CO_2 and O_2, end-of-inhalation wet- and dry-bulb temperatures, and peak inhalation and exhalation breathing pressures. In the BMS testing, however, *average* inhaled values of gas concentration were measured as opposed to the *minimum* levels of CO_2 and *maximum* levels of O_2 in the treadmill testing. *Average* inhaled gas values include the effect of apparatus dead space, whereas *minimum* levels of CO_2, for example, are only the lowest level of gas concentration during inhalation. The BMS measures average inhaled values by electronically summing all of the CO_2 and O_2 over each inhalation cycle, weighted by the instantaneous flow rate. The BMS also measures minimum inhaled CO_2 levels.

Test Termination Criteria

Tests on the BMS were terminated upon exhaustion of the O_2 supply as indicated by inhalation pressures reaching -200 mm H_2O; coinciding with an empty breathing bag. If average inhaled CO_2 values exceed 10% or O_2 values fall below 10%, the accuracy of the metabolism of the BMS becomes questionable. Tests were, therefore, terminated at those points or shortly thereafter. In addition, if pressures exceed the range of the pressure transducer (approximately 500 mm H_2O) the accuracy of the gas analyzers is affected providing another reason for test termination. Treadmill tests were terminated when the O_2 supply was exhausted, if minimum inhaled CO_2 exceeded 4%, if maximum inhaled O_2 fell below 15%, or if the test subject stopped because of subjectively high breathing pressures or temperatures.

Wilcoxon Rank-Sum Test

The Wilcoxon rank-sum test was performed for each monitored stressor to determine whether or not the deployed units behaved differently from new units. The test evaluates the hypothesis that the two samples are from populations with the same mean. The values from both samples are ranked in ascending order of magnitude. If the sum of the ranks of the smaller sample (T) (in this case, new units) falls within the acceptable range for the given sample sizes, then there is not sufficient evidence at the specified probability level ($\alpha = 0.05$, two-sided) to say that the means of the two samples differ. The rank-sum test does not rely upon the assumptions that either the new- or deployed-unit data are normal distributions or that they have identical variances, as does the t-test for two populations of independent samples. One limitation of the Wilcoxon rank-sum test is that it does not distinguish between large and small differences in values. The results of the $\alpha = 0.05$, two-sided, Wilcoxon rank-sum tests are presented in Table 3. The probability of T falling outside the given range is 0.05 if the populations have the same mean.

Table 3. – Wilcoxon rank sum test results

Apparatus	Duration		Average inhaled CO_2		Average inhaled O_2		Wet-bulb temperature		Dry-bulb temperature		Inhalation pressure		Exhalation pressure	
	Range	T	Range	T	Range	T	Range	T	Range	T	Range	T	Range	T
SR-100	101-211	138	101-211	131	101-211	154	96-200	236	101-211	242	101-211	174	101-211	160
OXY K-Plus	45-105	72	42-96	86	44-100	64	44-100	84	45-105	107	45-105	70	45-105	84
Life-Saver 60	58-124	92	45-105	64	58-124	98	54-114	79	58-124	100	58-124	123	58-124	92
EBA 6.5	29-91	48	29-91	40	29-91	69	28-88	87	28-88	88	29-91	78	29-91	40
M-20	17-51	52	17-51	46	17-51	34	17-51	50	17-51	54	17-51	50	17-51	26

T = Sum of the ranks of the smaller sample (new units).

CSE Induced Noise Test

CSE developed a test to identify apparatus that have sustained internal damage, based on a correlation between loose particles in the chemical bed and CO_2 breakthrough during the last rest interval of a 1-hour Man Test #4. This was established by testing SR-100s on the CSE breathing simulator performing NIOSH variable-work rate certification tests. The Acoustic Solids Movement Detector (ASMD) analyzes the noise induced in the unit by shaking it in a controlled manner. The noise produced by the SCSR when shaken is used as an indicator of shock and vibration damage incurred by the chemical bed within the SCSR. In the field, this assessment is made using a hand-held instrument provided by CSE. A laboratory version of the ASMD test involves rotating the SR-100 in an anechoic chamber to measure the noise levels in decibels (dB). Various frequency ranges are weighted differently and result in a composite dB rating for each apparatus. A unit with a composite rating of higher than 60 dB fails the test. NIOSH performs the laboratory version of the ASMD test as part of the LTFE inspection. Excessive noise as evaluated by either of the test instruments is an indication of chemical-bed damage that may adversely affect the performance of the SCSR. SCSRs failing the ASMD test must be removed from service.

Problem Investigation Procedure

Any problems encountered with SCSRs, such as hidden damage or anomalous performance, were reported for investigation under the Certified Product Investigation Program (CPIP). These investigations and their outcomes are reported in Appendix 1.

Results and Discussion

Experience with each model of apparatus is discussed separately. The minute-average values of the monitored stressors were averaged over the entire test duration and are presented graphically (Figures 8-12) for each apparatus by stressor. The values for new units tested on the BMS can be compared with those for deployed units also tested on the BMS. To some extent, they may also be compared with those for deployed units tested on the human subject on a treadmill. Because the human subject differs from the BMS in respiratory frequency, treadmill tests cannot be considered equivalent to the BMS tests even though the O_2 consumption rate is the same. Missing data points indicate test equipment malfunction or inability to instrument apparatus.

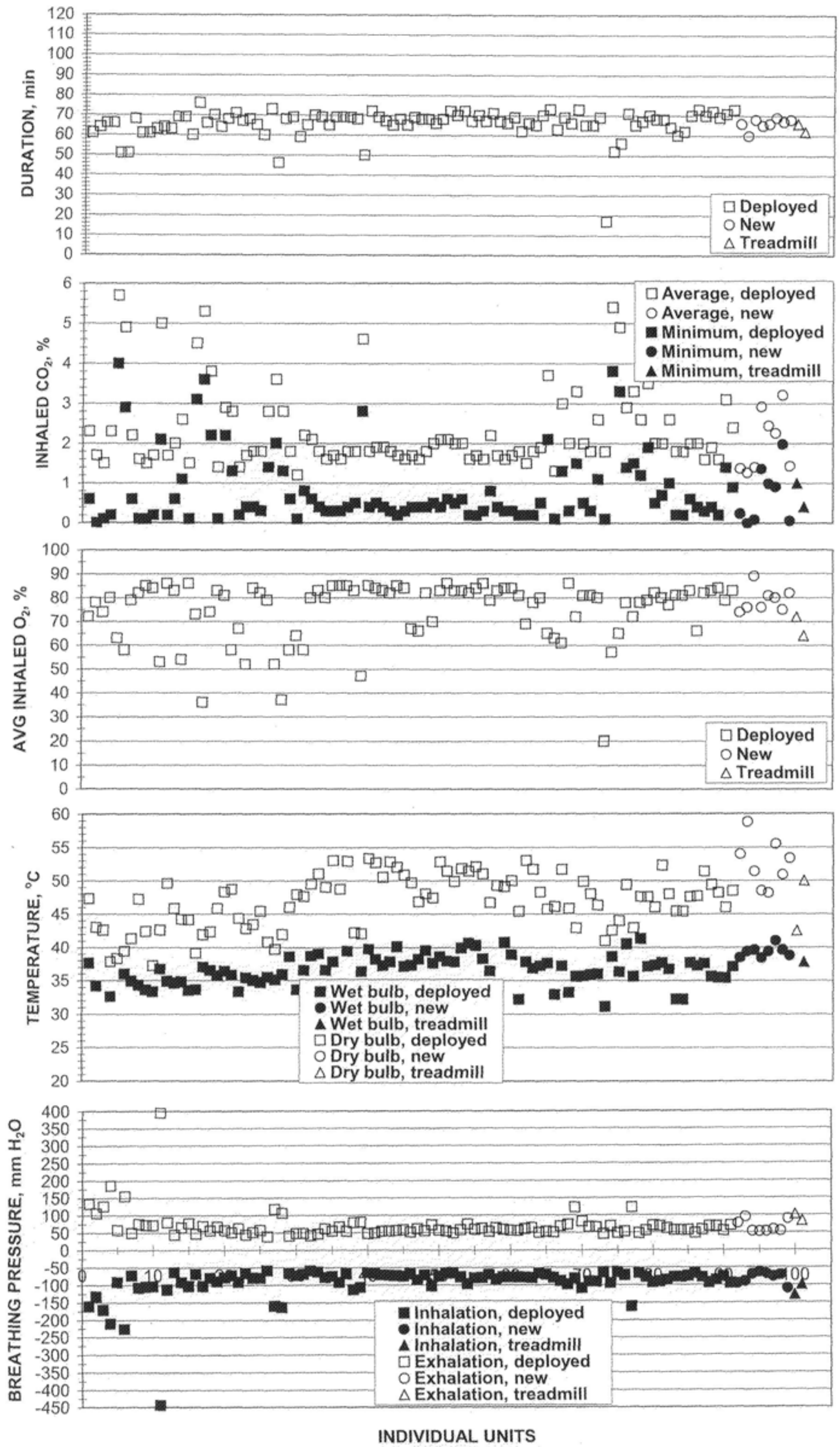

Figure 8. CSE SR-100 test results

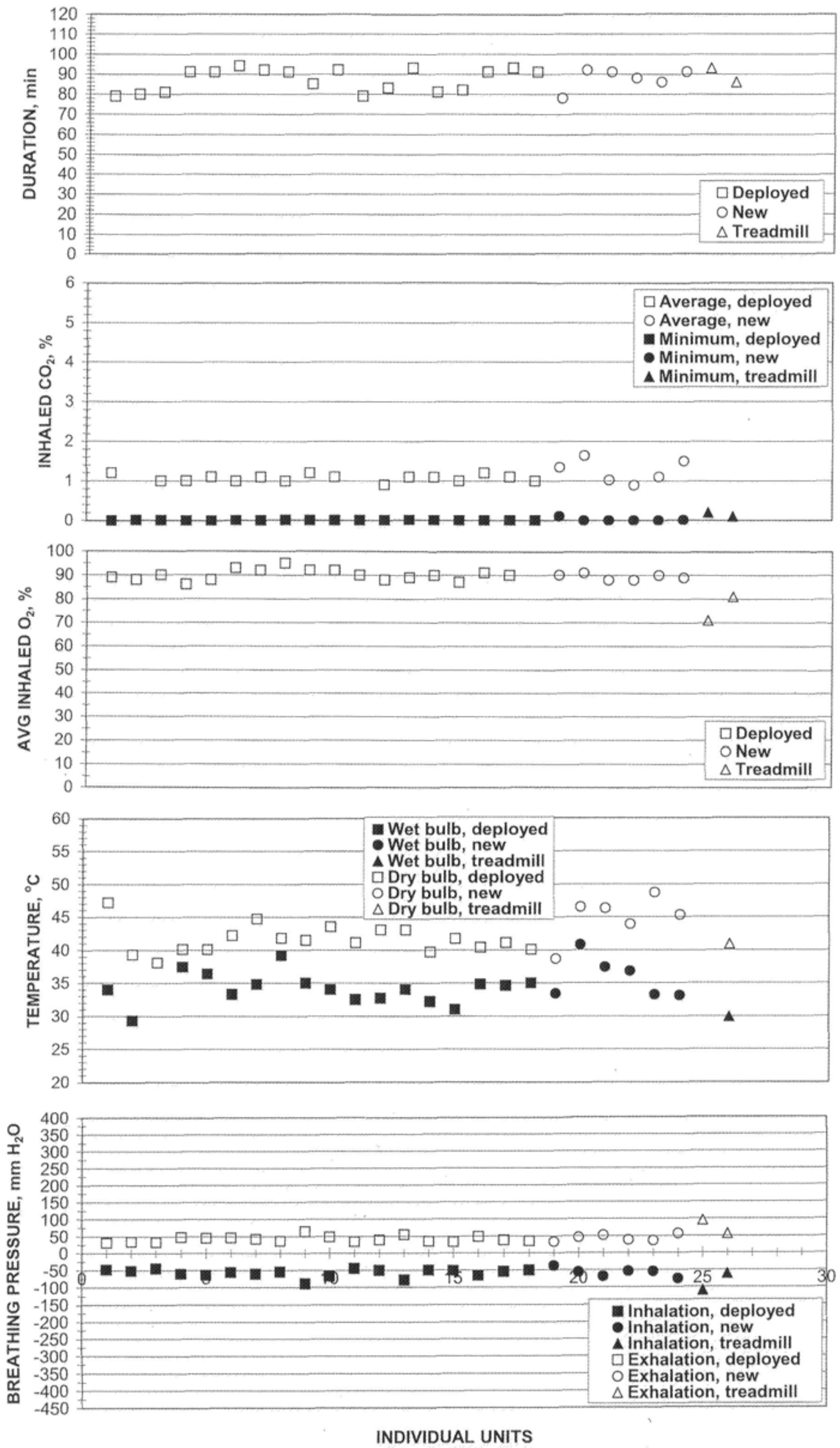

Figure 9. Draeger OXY K-Plus test results

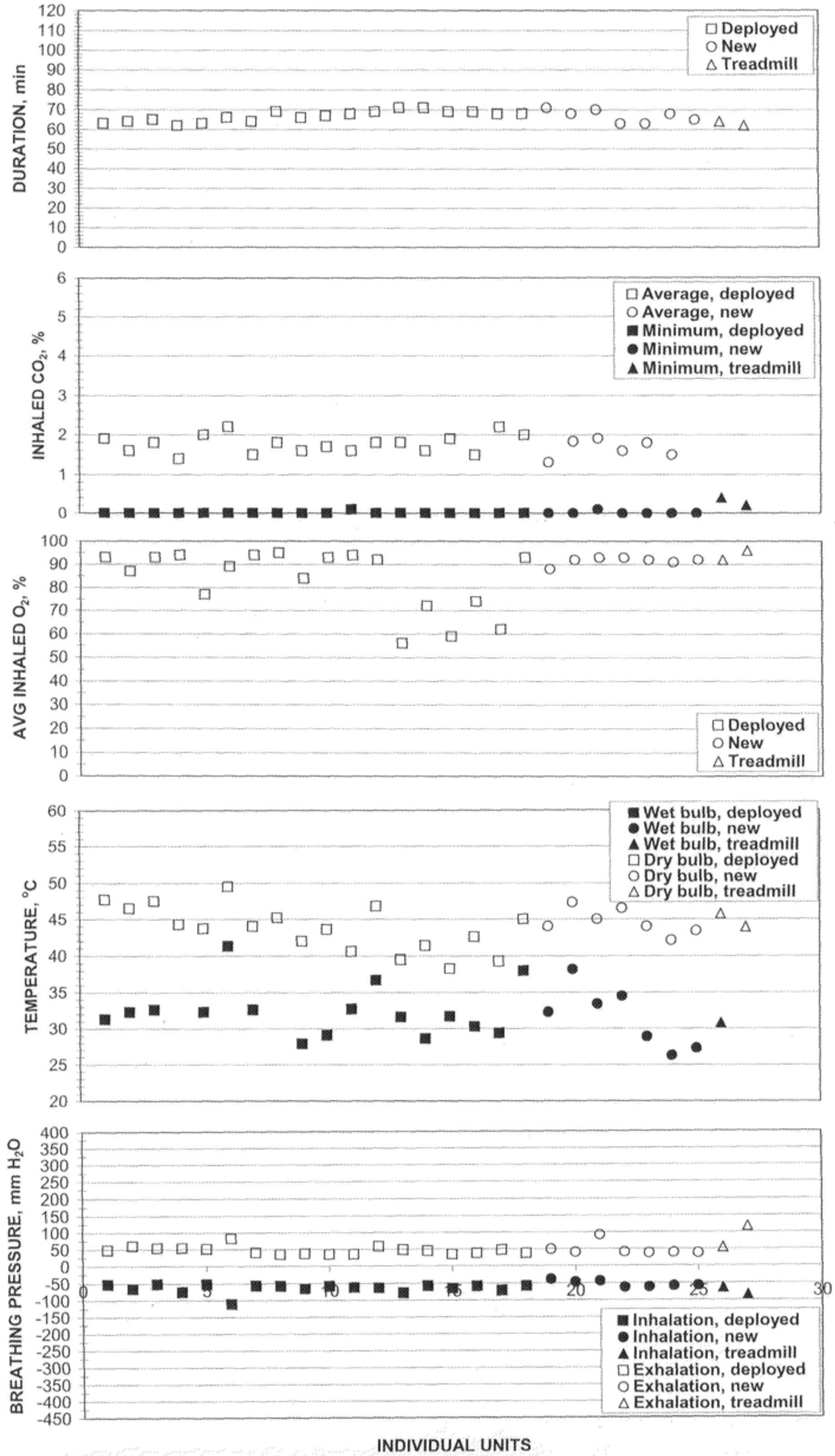

Figure 10. MSA Life Saver 60 test results

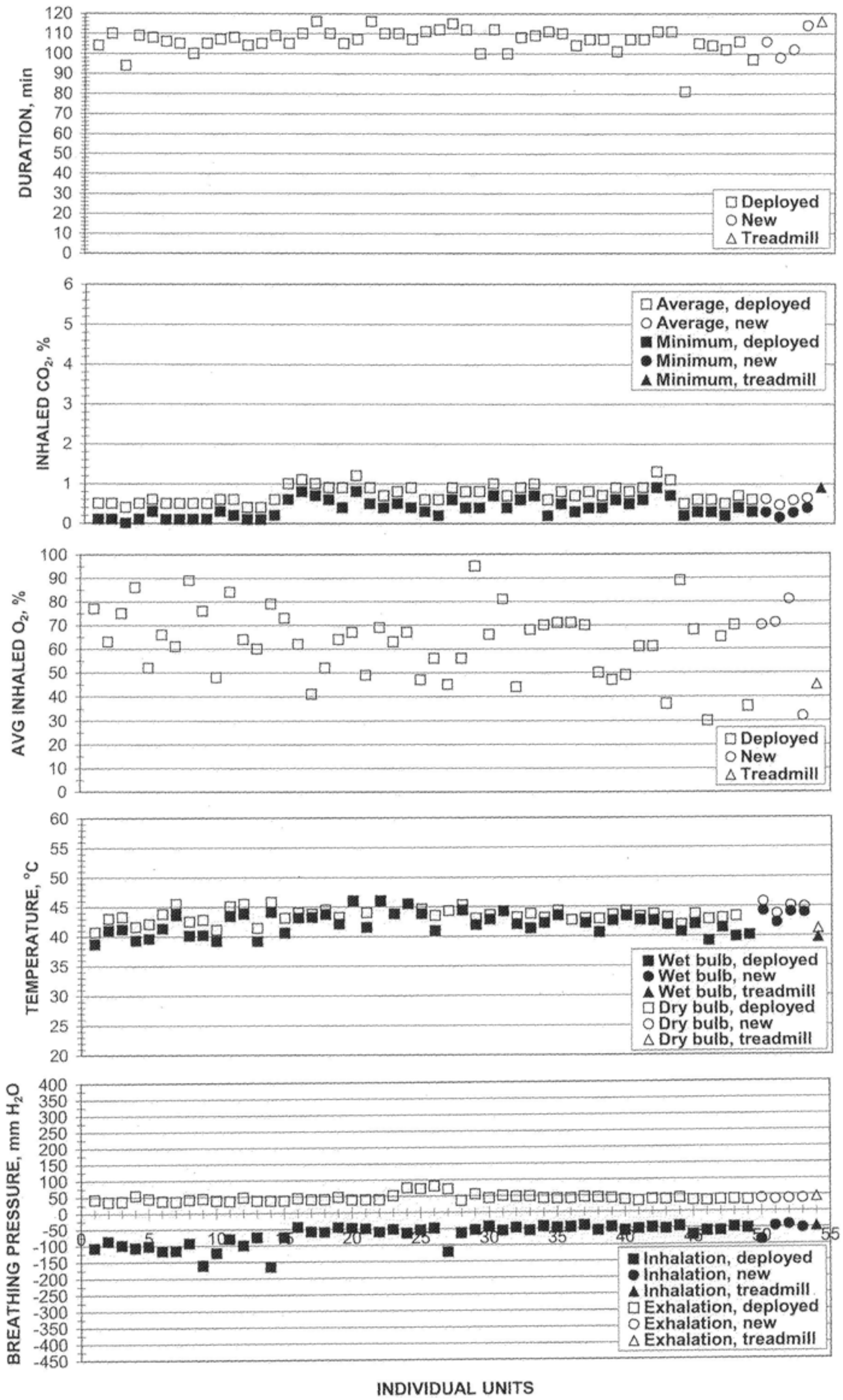

Figure 11. Ocenco EBA 6.5 test results

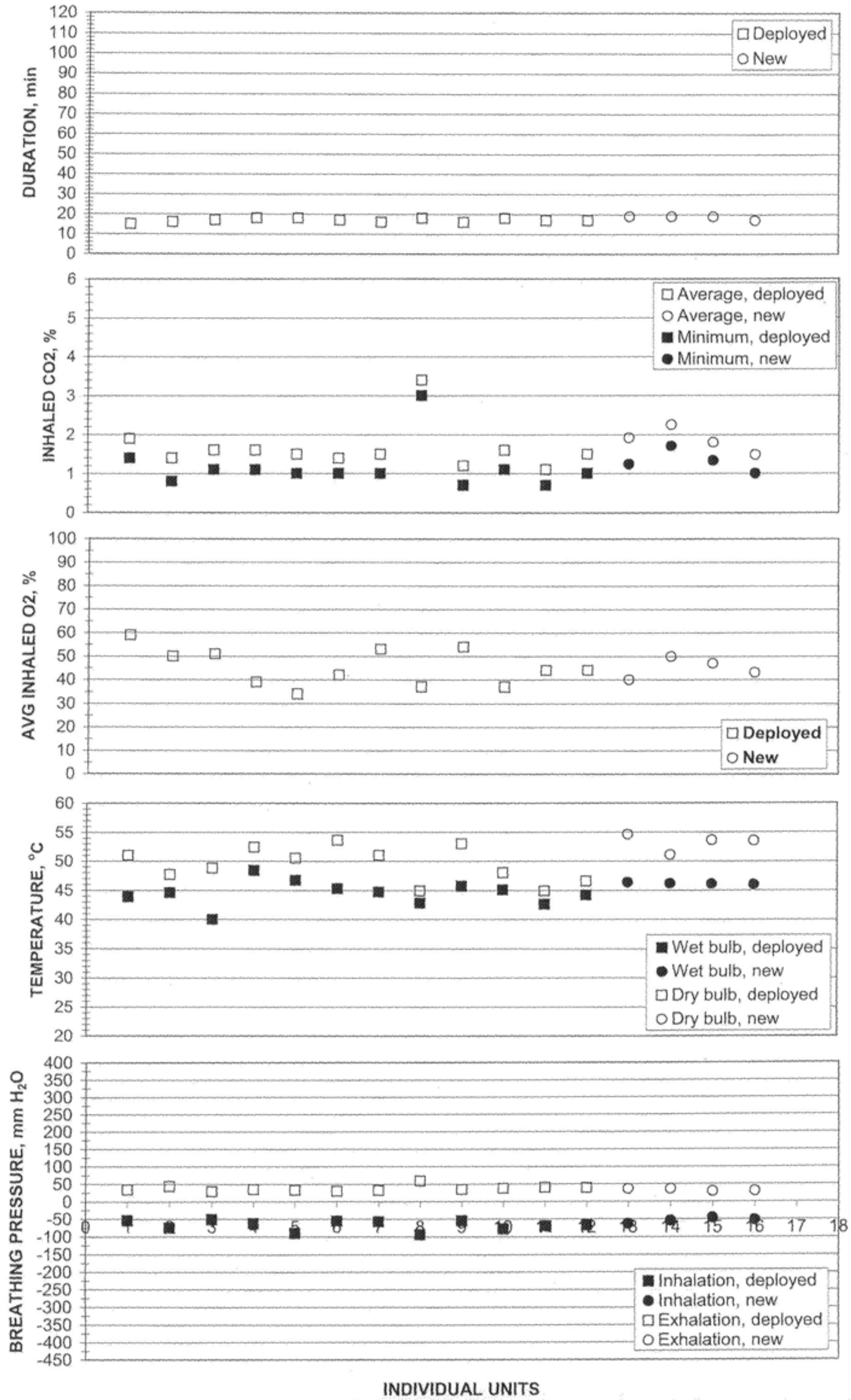

Figure 12. Ocenco M-20 test results

Manufacturer's Inspection Criteria

Some apparatus were found to fail their inspection criteria either after cleaning or performing the induced noise test. Table 4 lists the apparatus failing inspection and the reason for failure. The apparatus were tested for reasons of scientific interest; however, if performance problems were encountered, the manufacturers were not considered responsible since the apparatus should have been removed from service.

Table 4. – Apparatus failing visual inspection

Model	SN	Reason	Performance evaluation
CSE SR-100	49791	High dB level	Terminated for 10% CO_2
CSE SR-100	50243	High dB level	Terminated for 10% CO_2
CSE SR-100	54559	High dB level	6.4% CO_2 when empty
CSE SR-100	55078	High dB and severely dented top lid	Terminated for 10% CO_2
CSE SR-100	55138	High dB level	9.2% CO_2 when empty
CSE SR-100	57046	High dB level	8.5% CO_2 when empty
CSE SR-100	64967	High dB level	Terminated for 10% CO_2
CSE SR-100	68802	High dB level	9.0% CO_2 when empty
CSE SR-100	76194	Top moisture indicator cracked	7.5% CO_2 when empty
CSE SR-100	76695	Top moisture indicator cracked	4.1% CO_2 when empty
CSE SR-100	81496	High dB and severely dented bottom lid	Terminated for 10% CO_2
CSE SR-100	82355	High dB and dent in top front seal	Terminated for 10% CO_2
CSE SR-100	90491	High dB level	5.5% CO_2 when empty
CSE SR-100	91812	Bottom moisture indicator cracked	OK
CSE SR-100	92620	Moisture indicator cracked	OK
CSE SR-100	92988	Bottom moisture indicator cracked	OK
CSE SR-100	96917	High dB level	5.9% CO_2 when empty
CSE SR-100	99361	High dB level	5.7% CO_2 when empty
Draeger OXY K-Plus	ARLN 0099	Outwardly dented and loose belt plate	OK
Draeger OXY K-Plus	ARLN 0478	Dented belt plate	OK
Draeger OXY K-Plus	ARME 0159	Red tamper clip missing	OK
Ocenco EBA 6.5	91010115	Dented canister	OK
Ocenco EBA 6.5	91020198	Dirt inside case and rusty canister	OK
Ocenco EBA 6.5	94020147	Crack in case bottom	OK
Ocenco EBA 6.5	94080019	Dented canister	OK
Ocenco EBA 6.5	94080023	Stress cracks in case bottom; shifted bottle band	OK
Ocenco EBA 6.5	94080024	Shifted bottle band	OK
Ocenco EBA 6.5	94080245	Cracks in case bottom	OK

Table 4. – Apparatus failing visual inspection

Model	SN	Reason	Performance evaluation
Ocenco EBA 6.5	97080496	Misaligned gasket	OK
Ocenco EBA 6.5	97080550	Spray painted corner prevented inspection	OK
Ocenco EBA 6.5	97080861	Crack in case bottom and spray-painted case	OK
Ocenco EBA 6.5	99030820	Top strap unanchored on one side, then fell off	OK
Ocenco EBA 6.5	99031179	Screw loose on top strap; SN tag fell inside case	OK
Ocenco M-20	511184	Security ball missing	OK
Ocenco M-20	511196	Security ball missing	OK
Ocenco M-20	511383	Security ball missing	OK
Ocenco M-20	511415	Security ball missing	Terminated for 10% CO_2
Ocenco M-20	511426	Security ball missing	LiOH fused to regulator occluded O_2 flow preventing use

All 14 M-20s were beyond their service lives by 3-4 months

Table 5. – Summary of collected Devices

Apparatus	Number Collected	Number failing Inspection	Number Tested	Terminated before 60 minute	
				Pass inspection	Fail inspection
CSE SR-100...............	93	18	93	1	14
Draeger OXY K-Plus.	22	3	21	0	0
MSA Life-Saver 60 ...	20		20	0	0
Ocenco EBA 6.5........	50	12	50	1 hose disconnected	
Ocenco M-20.............	14	all out of date 5 visual problems	14		3
Total.......................	199		198		

One OXY K-Plus test was aborted due to equipment malfunction.

Units were terminated either for low O2 or high CO2

CSE SR-100

Eighteen of 93 (19%) units failed their inspection criteria (See Table 4.). Eighty-six of the 93 units passed the leak-tightness test. Of the seven new units that were leak-tested, 6 passed the test. The leak test is not required by CSE, nor by NIOSH for certification.

The Wilcoxon rank-sum tests for the CSE SR-100 showed that, as in the past three phases, wet- and dry-bulb temperatures were significantly higher in new units than in deployed units. Since temperature is indicative of chemical reaction, this apparently shows deployed units having lower levels of chemical reaction. Since no statistically significant difference was found with regard to CO_2 levels, however, however, this is not considered an important finding.

Test Termination

Most of the tests were terminated empty, but seven were terminated for high CO_2 levels and two for low O_2 levels. Of the seven tests terminated for high CO_2 levels (10% average inhaled CO_2) six apparatus failed inspection criteria and should have been removed from service: five apparatus had noise-test dB levels higher than 60; one apparatus had a cracked moisture indicator lens and a large dent in the bottom lid. The other apparatus passed its inspection criteria and had a punctured breathing hose in addition to the high CO_2 levels. The two apparatus with tests terminated for low O_2 levels (10% average inhaled O_2) both passed their inspection criteria. One also had a punctured breathing hose and no starter O_2. The low O_2 level in this apparatus when terminated at 68 minutes can be attributed to the in-leakage of ambient air through the hose puncture. The other apparatus had insufficient starter O_2 and lasted only 17 minutes before O_2 levels fell below 10%. No obvious reason was found for this behavior.

Induced Noise Test

The correlation coefficient between the dB levels obtained in the ASMD induced-noise test and the test-average, average inhaled CO_2 levels (Figure 13) was 0.71 for the apparatus tested in this phase.

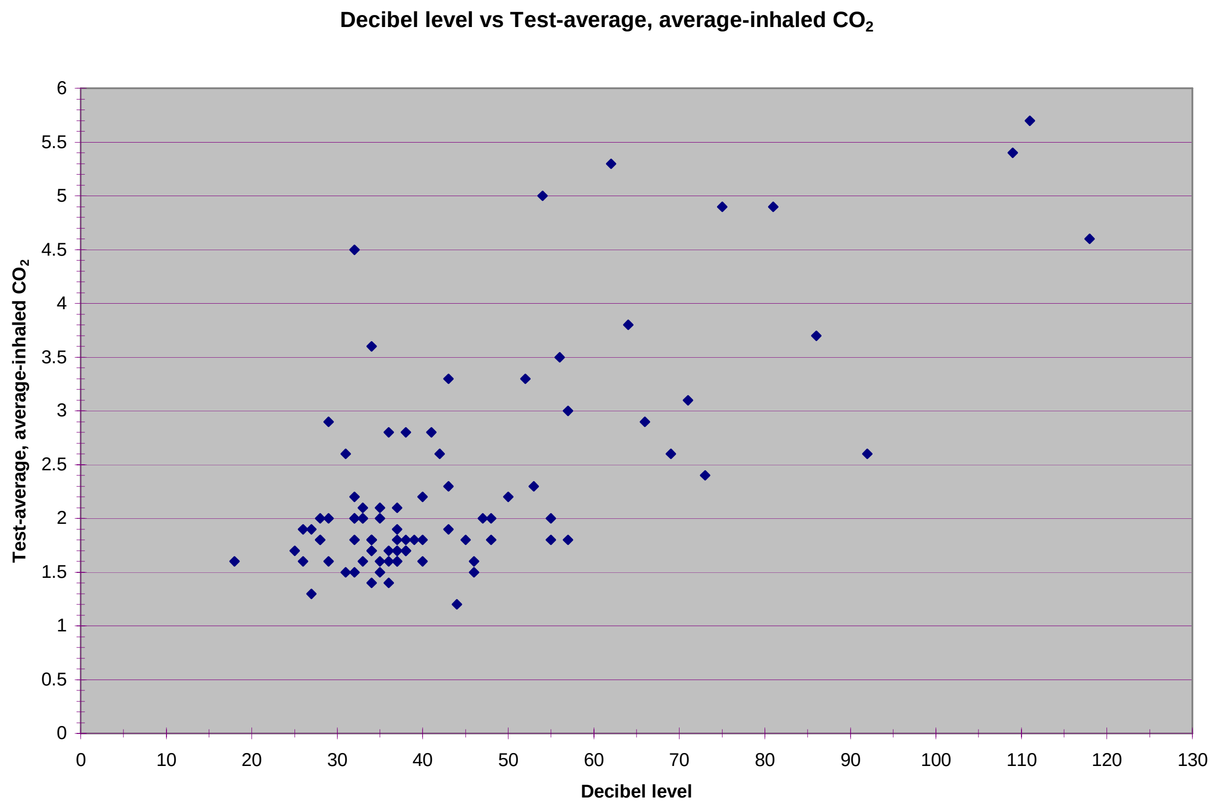

Figure 13. CSE SR-100 decibel level versus CO_2 level

High Breathing Pressures

Twenty-nine deployed apparatus reached exhalation breathing pressures of +200 mm H_2O while 23 reached inhalation pressures of -300 mm H_2O. These pressures were the limits of tolerance for 80% of test subjects in a study contracted by the Bureau of Mines (Hodgson, 1993). Two new units also exceeded these pressures; one of which was terminated for high breathing pressures at 60 minutes.

Premature CO2 Breakthrough

Table 5 shows that 61 of 93 deployed apparatus tested experienced CO_2 breakthrough before expenditure of the O_2 supply. Four in eight of the new units also experienced CO_2 breakthrough before expenditure of the O_2 supply. The response to high inhaled levels of CO_2 will be increased ventilation rates in most users, approximately doubling with 4% CO_2. Increased ventilation rates will result in higher breathing pressures experienced by the user. Breathing resistance in the SR-100 increases rapidly toward end-of-life even in some new apparatus, and elevated CO_2 levels will only add to this.

Table 6. –CSE SR-100 4% CO_2 breakthrough times, minutes

Type of unit and test method	CO_2 breakthrough time	Test duration	Maximum CO_2
Deployed: BMS	17	51	10.0
	18	52	10.6
	18	64	10.3
	22	50	10.6
	22	51	10.0
	22	66	10.0
	24	56	10.3
	29	76	9.0
	33	46	10.5
	39	70	9.2
	45	68	8.5
	47	73	9.0
	51	70	8.5
	52	65	10.0
	54	61	4.3
	54	64	5.5
	55	66	7.5
	57	67	6.0
	57	71	5.9
	59	69	6.7
	59	71	7.2
	60	60	4.0
	60	69	6.4
	61	63	5.1
	61	65	4.9
	61	68	6.0
	61	71	6.1
	61	73	8.5
	62	63	4.2
	63	66	4.6
	63	68	5.4
	63	73	7.5
	64	65	4.1
	64	68	4.9
	65	65	4.0
	65	65	4.2
	65	66	4.4
	66	67	4.4
	66	68	4.4
	66	68	4.6
	66	68	4.6
	66	69	4.9

Table 6. –CSE SR-100 4% CO_2 breakthrough times, minutes

Type of unit and test method	CO_2 breakthrough time	Test duration	Maximum CO_2
	66	69	5.1
	67	67	4.0
	67	67	4.1
	67	68	5.7
	67	69	4.6
	67	69	4.8
	67	71	5.9
	68	68	4.4
	68	69	4.2
	68	69	4.4
	69	69	4.1
	69	69	4.1
	69	70	4.1
	69	70	4.2
	69	72	4.6
	70	70	4.0
	70	70	4.1
	71	72	4.1
	72	72	4.0
New: BMS	49	67	8.3
	51	65	6.5
	58	66	5.6
	63	69	5.6

Insufficient Starter Oxygen/Manual Start/Coughing/Hypoxia

Fifteen units had little or no starter oxygen, requiring a manual start before beginning or shortly after beginning the test. Manual starts consist of exhaling into the apparatus until the breathing bag is full (3-6 breaths). Since exhaled breath contains sub-ambient levels of O_2 (approximately 17%) the inhalation levels of O_2 will start at that point and decline unless the chemical in the bed is very reactive. With the SR-100 inhalation O_2 levels drop below 15% within a couple of minutes, bottoming out at approximately 12% before rising. One apparatus with insufficient starter oxygen required four manual starts before the chemical reaction kicked in after 20 minutes, terminating for high CO_2 at 68 minutes.

In both of the human-subject tests, the user coughed to some degree when donning the apparatus. This was due to the inhalation of loose particles of corn starch which the manufacturer uses in the breathing hose to absorb saliva. The corn starch prevents the saliva from reaching the KO_2 bed where it would speed up the chemical reaction and waste O_2. After noticing the corn starch in the breathing hoses, it was decided to shake out the loose particles before testing the units. This resulted in dislodging small pieces of metal (end-cuttings from the wire-mesh heat-exchanger) from the hoses, occurring in 21 apparatus. (The manufacturer has added a step during manufacture to blow out the loose metal cuttings.) Given these circumstances, the donning procedure was changed such that the human subject is now instructed to wet down the loose particles by exhaling repeatedly into the unit. Since this dilutes the starter O_2 and is essentially a manual start, as the manufacturer instructs in case of lack of starter O_2 (which happened in 16% of the units tested), we decided to delay activating the starter O_2 to see if the O_2 levels fell like they did in BMS tests. They did. However, when O_2 fell below 15%, the user was instructed to activate the starter O_2.

Miscellaneous

Ten units had breathing hoses with severe creases with the hose walls sticking to each other. A modest effort to unstick the hose and open the flow path was attempted; however, in previous phases, the hoses tore when attempting to unstick them. Therefore, if the hoses were badly stuck, they were left stuck and partially occluded. The manufacturer has asserted that this degradation is caused by heat exposure.

In eight units, there was evidence of dirt and/or past water leakage into the case. The color indicators were blue in all units. All had some degree of performance degradation, either high CO_2, low O_2, or high breathing pressures.

There were four instances in which the breathing hose was either punctured or slit, apparently from being pressed against sharp internal components. Such holes would permit toxic gases and nitrogen to enter the breathing circuit in emergency use, compromising the effectiveness of the apparatus. In response, the manufacturer has changed its packing procedures.

The lids were stuck and difficult to remove on four apparatus to varying degrees.

Conclusions.

Of 15 units terminated at less than 60 minutes duration, only one unit passed the initial inspection. Almost 20% of the samples obtained for CSE units did not pass the manufacturer's Inspection criteria.

Draeger OXY K-Plus

Three of 22 units (14%) failed their inspection criteria (See Table 4.). All the deployed units passed the leak-tightness test; three new units passed the test and one failed.

The Wilcoxon rank-sum tests for the Draeger show that new units had significantly higher dry-bulb temperatures than deployed units. Dry-bulb temperature is indicative of chemical bed reaction; however, since there were no performance problems in any of the deployed units, this is of no concern to users.

All units were terminated empty, the preferred mode for termination.

One apparatus had a loose back plate that was (inexplicably) outwardly dented and should have been removed from service; it performed normally, however.

The computer controlling the BMS froze twice during one test causing delays in testing. After a 15-minute delay the second time, the apparatus could not be restarted and the test was aborted. The apparatus had been performing normally before that, however.

MSA Life-Saver 60

All 20 of the Life-Saver 60s passed their inspection criteria (See Table 4.). Twelve deployed units passed the leak-tightness test and eight failed; all three new units passed.

The Wilcoxon rank-sum tests show that new units were not significantly different from deployed units in any measured parameter. After adding in four more baseline tests of new units having lower durations of the three previous baseline tests, the statistical significance of lower durations in deployed units found in previous phases has disappeared. This could be for a number of reasons including actual performance difference in the two batches of new units, actual performance differences in the samples of deployed units, or difference in some testing parameter between the first batch of new units tested in 1999 and the second batch tested in 2004. In any case, the difference is minimal.

All units were terminated empty, the preferred mode for termination.

The chlorate candle of one unit activated immediately upon opening the apparatus case. This occurred on one of three new units, also. Although this would not necessarily compromise successful use of the apparatus, users should be made aware that it could happen. In contrast, the candle of one unit did not fire until minute 55 of the test.

One apparatus had its ID strap inside-out as well as its relief valve stuck open. The relief valve was manually closed before starting the test and the apparatus performed normally. A user would have been at risk of inhaling toxic gases in the ambient air through the relief valve if it were open to ambient as found.

OCENCO EBA 6.5

Twelve of 50 (24%) units failed their inspection criteria (See Table 4.). Nine deployed units passed the leak-tightness test and 41 failed; one new unit passed the test and three failed. The leak-tightness failures are observed to be due either to leakage between the rubber mouthpiece boot and the hard-plastic check-valve frame or back-flow through the relief valve.

The Wilcoxon rank-sum tests show that new units were not significantly different from deployed units in any measured parameter.

All tests were terminated empty, the preferred mode for termination. One caveat: the O_2 supply hose of one unit was not attached to the breathing bag making the unit unusable unless the user were very familiar with the apparatus and could re-attach the hose which we did for testing. It performed normally and terminated empty as well.

The wide range of average inhaled O_2 test averages is due to the difference in the apparatus O_2 regulator flow rates, which ranged in this phase from 1.02 to 1.90 L/min ATPD. The O_2 concentration in a breathing circuit will rise if the O_2 supply rate is higher than the O_2 consumption rate.

We tested numerous apparatus with visible damage that should have been removed from service (see Table 4.). Four units had cracks in their outer cases indicating severe impact, one of which also had a shifted cylinder band. Two units had dented canisters, one severely so and had LiOH in the O_2 supply hose which undoubtedly would have caused coughing. Three units had displaced canister gaskets. One unit had a rusty canister. One had a case strap that was unattached on one side which fell off completely during cleaning. The EBA 6.5 is difficult to open without the presence of the case straps. Another had loose screws on the case straps and a serial number tag that had fallen inside the case and could not be read. Finally, the O_2 supply hose of one unit tore when removing it to measure the O_2 flow rate. This indicates material decay, although it would not have prevented successful use of the apparatus unless someone pulled on it.

OCENCO M-20

All 14 of the apparatus had exceeded their service life dates by three or four months and had been removed from service. Since the M-20 is not in wide use and is difficult to obtain, we took the apparatus knowing that they were technically out of compliance. In addition to being beyond the end of their service lives, five of the units (36%) failed their inspection criteria for additional reasons (see Table 4.). Three deployed units passed the leak-tightness test; 12 failed. Two new units passed the leak-tightness test; one failed.

The Wilcoxon rank-sum tests show that the durations of deployed units were significantly lower than new units and that the dry-bulb temperatures of deployed units were significantly lower than new units. Both differences were small, however, and are only of academic interest.

One unit was terminated simultaneously empty and with 10% CO_2 at 18 minutes. Its security ball was missing, however, so we cannot say with certainty that it had not been previously opened. One unit was terminated at four minutes due to low (10%) O_2. Another unit was terminated at two minutes with insufficient bag volume. These last two suffered from low O_2 flow as described below.

Two apparatus were found with large quantities of LiOH powder in the breathing bag that apparently escaped the chemical bed, working its way through the bottom filter. This has been found in the past with no apparent effect on performance. In these cases, however, the O_2 flow rate on both units was severely reduced resulting in low O_2 levels and insufficient breathing bag volume, both preventing successful use of the apparatus. Dismantling of the apparatus revealed hardened LiOH powder adhered to the outside of the demand valve/O_2 regulator. It is assumed that the same phenomenon is found on the inside of the regulator, restricting O_2 flow. We cannot explain the phenomenon of powdered LiOH in the breathing bag adjacent to LiOH fused to the surface of the anodized aluminum regulators. If it is caused by the passage of time, we would certainly urge all users to pay close attention to the service life date. Since the other 12 apparatus did not experience this phenomenon, however, time alone is unlikely the cause. Ocenco provided no insights or explanation other than to point out that the apparatus were beyond their service life dates.

Five apparatus showed evidence of mine dust in-leakage. In addition, the security ball seal of five units were missing. These factors did not correlate with any performance problem, however.

Conclusions

The results of this study suggest that the large majority of SCSRs that pass their inspection criteria can be relied upon to provide a safe level of life support for mine escape purposes. However, the mining environment seems to have caused some performance degradation in all the apparatus to some degree. The CSE SR-100 is exhibiting problems of CO_2 exceeding 4% (66%), stuck-together breathing hoses (11%), starter-O_2 failure (16%), breathing hose punctures and tears (4%), breathing pressures exceeding +200 mm H_2O or -300 mm H_2O (31%), and loose particulates in the breathing hose (23%). The loose particulates caused coughing in human-subject tests.

We found no significant problems with the Draeger OXY K Plus in this phase.

The MSA Life-Saver 60 had only one significant problem in this phase: a stuck-open relief valve that would have compromised its successful use unless closed before using.

In this phase, the only significant finding for the Ocenco EBA 6.5 was an unattached O_2 supply hose. Unless re-attached, this unit could not have been used for a successful escape.

An unexplained phenomenon occurred with the Ocenco M-20: low O_2 flow rates preventing their successful use. This phenomenon was seemingly caused by hardened deposits of LiOH on the anodized aluminum regulator occluding the O_2 flow. We have seen LiOH in the breathing bag before; we have not seen a performance effect until now. Since the apparatus had exceeded their five-year service lives by three months, Ocenco could not be held accountable for this problem.

Acknowledgements

Without the cooperation of the coal mines and MSHA field offices, this study would not be possible. The following coal mines and MSHA field offices participated in the tenth phase of this study:

MSHA Office:	**Wilkes-Barre District Office Dis 1**
Mine Name:	**7 ft. Slope**
Mailing Address:	R.D. 2, Box 118 C, Hegins, PA 17938
Mine Name:	**Buck Mt. Slope, S&M Coal Co.**
Mailing Address:	1744 East Ave., Tower City PA 17980
Mine Name:	**Joliett Coal Co. #3 Vein Slope**
Mailing Address:	837 E. Grand Ave. Tower City PA 17980
Mine Name:	**Orchard Coal Co. Orchard Slope**
Mailing Address:	214 Vaux Ave Tremont PA 17981
Mine Name:	**RS&W Coal Co.**
Mailing Address:	207 Creek Rd Klingerstown PA 17941
Mine Name:	**Little Buck Coal Co. #2 Slope**
Mailing Address:	57 Lincoln Rd. Pine Grove PA 17963
Mine Name:	**R&D Coal Co. Buck Mountain Slope**
Mailing Address:	P.O. Box 214 Vaux Ave. Tremont PA 17981
Mine Name:	**R&R Coal Co.**
Mailing Address:	538 W. Center St. Donaldson PA 17981
Mine Name:	**Six M Slope #1**
Mailing Address:	482 High Rd Ashland PA 17921

MSHA Office:	**New Stanton Dis. Office Dis. 2**
Mine Name:	**Enlow Fork Mine**
Mailing Address:	920 East Finley Dr., West Finley, PA 15377

MSHA Office:	**Morgantown District Office Dis. 3**
Mine Name:	**Double H Mining Co. Inc., Cabin Mine**
Mailing Address:	P.O. Box 338 Morgantown, WV 26501

Mine Name:	**Odyssey Energy Mine #1**
Mailing Address:	PO Box 431 Bruceton Mills 26525
Mine Name:	**Dana Mining, Prine #1 Mine**
Mailing Address:	2141 Lazzelle Union Rd. Maidsville WV 26541
Mine Name:	**Whitetail Kittanning**
Mailing Address:	Kingwood mining, Rt 1 Box 294C Newberg WV 26410

MSHA Office:	**Mt. Hope District Office Dis. 4**
Mine Name:	**Ambush Mining #2**
Mailing Address:	H.G. Caretta WV
Mine Name:	**Rocksprings Development Co.; Camp Creek Mine**
Mailing Address:	P.O. Box 390 East Lynn WV 15512
Mine Name:	**Pinnacle Mining Co., LLC; Pinnacle Mining Co**
Mailing Address:	P.O. Box 330, Pinville, WV 28474
Mine Name:	US Steel Mining Co. # 50
Mailing Address:	Box 338 Pineville WV 24874Pinnacle Creek Rd.

MSHA Office:	**Pikeville District Office Dis 6**
Mine Name:	**Excel Mining, Mine #3**
Mailing Address:	100 Fae Ramsey Lane, Pikeville KY 41501
Mine Name:	**Consol Mil Creek**
Mailing Address:	PO Box 10 Deane KY 41812
Mine Name:	**Excel Mining, LLC Mine# 2**
Mailing Address:	HC6T Box 615 Pilgrim, KY 41250
Mine Name:	**Patrick Processing LLC.**
Mailing Address:	458 Village Lane, Hazard KY 41701

MSHA Office:	**Barbourville District Office, Dis. 7**
Mine Name:	**Bledsoe Coal, Shamrock Coal**
Mailing Address:	P.O. Box 349 Bledsoe Ky. 40810
Mine Name:	**Bell County Coal Corp., Coal Creek**
Mailing Address:	RT. 1 Box 290 Middlesboro KY

Mine Name:	**Consol KY, Jones Fork Rt 80 Slope**
Mailing Address:	P.O. 13 Mousic KY
Mine Name:	**Lake View Mine**
Mailing Address:	P.O. Box 784 Hazard KY 41702
Mine Name:	**Stillhouse Mining LLC, NO 1 Mine**
Mailing Address:	P.O. Box 1226 Norton, VA 24273
Mine Name:	**Tennco Inc. Valley Creek #2**
Mailing Address:	P.O. 16 Harrsgate TN 37752

MSHA Office:	**Vincennes Dis. Office Dis. 8**
Mine Name:	Air Quality Mine, Black Beauty
Phone No.:	812-743-2910

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Appendix 1
Certified Product Investigation Program (CPIP)
Investigations Initiated from LTFE 10

Task Number	Date Opened	Date Closed	Type	Description	Approval Number	Resolution
CSE						
TN-13958	2/28/2005	8/10/2005	CSE SR - 100	High CO_2 unit had moisture active bed.	TC-13F-0239	Improper user handling of unit
TN-14363	1/27/2006	9/22/2006	CSE SR - 100	Visible holes and punctures in breathing hose.	TC-13F-0239	O_2 exceeded requirements and CO_2 off gas measured was with acceptable ranges.
MSA						
TN-14163	8/12/2005	3/13/2006	MSA Lifesaver 60	Tear in breathing bag of Lifesaver 60.	TC-13F-0385	Tested units met O_2 requirements and units in field were approaching end of service life.
Ocenco						
TN-14261	10/24/2005	3/24/2006	OCN M – 20	Low O_2 flow and demand valve malfunction.	TC-13F-0269	Units were three months beyond the end of carried-service interval.
TN-14366	1/30/2006	16/6/2006	OCN M – 20.2	Presence of lithium hydroxide in mouthpiece of respirator caused user to cough.	TC-13F-0386	30 stored units were tested in Man Test 4 and met performance requirements.

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