RI 9401

REPORT OF INVESTIGATIONS/1992

Self-Contained Self-Rescuer Field Evaluation: Results From 1982-90

By Nicholas Kyriazi and John P. Shubilla

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

Report of Investigations 9401

Self-Contained Self-Rescuer Field Evaluation: Results From 1982-90

By Nicholas Kyriazi and John P. Shubilla

UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary

BUREAU OF MINES
T S Ary, Director

Library of Congress Cataloging in Publication Data:

Kyriazi, Nicholas.
Self-contained self-rescuer field evaluation : results from 1982-90 / by Nicholas Kyriazi and John P. Shubilla.

p. cm. — (Report of investigations / United States Department of the Interior, Bureau of Mines; 9401)

Supt. of Docs. no.: I 28.23:9401.

1. Self-contained self-rescuer (Mine rescue equipment)—Testing. I. Shubilla, John P. II. Title. III. Series: Report of investigations (United States. Bureau of Mines); 9401.

TN23.U43 [TN297] 622 s—dc20 [622'.89] 91-33351 CIP

CONTENTS

Page

ILLUSTRATIONS

TABLES

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	min	minute
h	hour	mm H_2O	millimeter of water (pressure)
kg	kilogram	m/s	meter per second
L	liter	pct	percent
L/min	liter per minute		

SELF-CONTAINED SELF-RESCUER FIELD EVALUATION: RESULTS FROM 1982-90

By Nicholas Kyriazi[1] and John P. Shubilla[2]

ABSTRACT

A joint effort by the U.S. Bureau of Mines and the U.S. Mine Safety and Health Administration (MSHA) was undertaken to determine how well self-contained self-rescuers (SCSR's), deployed in accordance with Federal regulations (30 CFR 75.1714), survived the underground environment with regard to both impact damage and aging. This report presents findings regarding laboratory-tested SCSR's from 1982 through 1990. The SCSR's were tested on human subjects and on a breathing and metabolic simulator (BMS). These results indicate that most of the apparatus, if they pass their inspection criteria, perform as expected except for units with manufacturing defects or design deficiencies. However, when the apparatus are carried in and out of the mine daily and stored at the working section, they may suffer abuse. Physical signs of abuse, unless extremely obvious, are frequently not detected by the miners or mine operators. This poses a potential danger to a user in an emergency. Recommendations include improved training in inspection procedures.

[1]Biomedical engineer.
[2]Engineering technician.
Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

On June 21, 1981, coal mine operators in the United States 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 O_2 source for at least 1 h, as rated by the certifying agency, the National Institute for Occupational Safety and Health (NIOSH). To ensure the safety of miners using these apparatus in an emergency, the U.S. Bureau of Mines and the U.S. Mine Safety and Health Administration (MSHA) are conducting a long-term, in-mine evaluation of SCSR's now deployed in underground coal mines. In this study, MSHA's responsibility is to identify the participating mines and to procure from those mines the SCSR's to be tested. The Bureau replaces the SCSR's to be tested with new apparatus and tests the SCSR's in its laboratories. The objective of this long-term program is to evaluate the in-mine, operational durability of SCSR's. Of utmost concern is the successful performance of any SCSR that passes its manufacturer's inspection criteria. The Bureau is interested only in apparatus that pass their inspection criteria. Such apparatus are relied upon to function successfully in an emergency. Apparatus that fail inspection criteria are expected to be removed from service.

EXPERIMENTAL PROCEDURE

This program involves testing approximately 100 SCSR's in each phase of the study. This report describes findings over the first 8 years of deployment, in which more than 300 apparatus were tested in 3 phases. Testing was conducted using a breathing and metabolic simulator (BMS) and human subjects on a treadmill.

The SCSR's tested were manufactured by CSE Corp.; Draegerwerk AG; Mine Safety Appliances Co., Inc. (MSA); Ocenco, Inc.; and Portable Air Supply Systems Corp. (PASS) and were sampled according to market share (table 1). The sampling was modified to ensure that at least 10 SCSR's from each manufacturer were sampled for each phase of the program.

Table 1.—Self-contained self-rescuers received for evaluation

Apparatus	Estimated market share, pct	Quantity inspected		
		Phase 1	Phase 2	Phase 3
CSE AU-9A1	20	26	17	24
Draeger OXY-SR 60B	21	21	17	23
MSA 60-min SCSR	4	15	12	12
Ocenco EBA 6.5	54	44	38	47
PASS 700	1	10	21	0
Total	100	116	105	106

Apparatus were not tested if they failed to pass inspection criteria or had a manufacturing defect or design deficiency that prevented testing.

MSHA selected the participating mines with regard to type of mining operation, seam height, and SCSR deployment mode to obtain a representative cross section of U.S. mines.

The researchers planned to conduct 90 pct of the tests using the BMS and 10 pct using human subjects. During phase 1 (1983-84) the old BMS was replaced with a newer design. For a period, no BMS was available, so human-subject testing was relied upon exclusively. Approximately half the apparatus were tested on the BMS in phase 1 and the remainder were tested on five human subjects, whose weights are given in table 2. Phases 2 and 3 were conducted according to the target of 90 pct BMS tests and 10 pct human-subject tests.

Table 2.—Weights of human subjects for treadmill tests, phase 1

Subject	*Weight, kg*
A	64
B	82
C	64
D	93
E	80

The human-subject test consisted of the treadmill equivalent of the 1-h man test 4 from 30 CFR 11. The BMS test consisted of the average metabolic work rate exhibited by the 50th-percentile miner weighing 87 kg while performing the 1-h man test 4. The metabolic workload (volumes at standard pressure and temperature, dry (STPD)) is given in table 3. The breath waveform shape of the first BMS was a sine wave.

In phase 2, during 1985 and 1986, two human subjects were used in the treadmill tests. The subjects walked on the treadmill at whatever speed resulted in an O_2 consumption rate of 1.35 L/min (STPD). Their weights and speeds are listed in table 4. Keeping the O_2 consumption rate constant for the different human subjects and the same as that of the BMS made the data from each human subject and the BMS more comparable. When different human subjects perform the same activity (1-h man test 4 in phase 1), O_2 consumption rates vary with weight, physical condition, and genetic differences.

Table 3.—BMS metabolic workload for phase 1

O_2 consumption rate	L/min	1.35
CO_2 production rate	L/min	1.30
Ventilation rate	L/min	31.9
Tidal volume	L per breath	1.21
Respiratory frequency	breaths per min	26.5
Peak respiratory flow rate	L/min	100

BMS Breathing and metabolic simulator.

Table 4.—Weights and speeds of human subjects for treadmill tests, phase 2

Subject	Weight, kg	Speed, m/s
A	64	1.8
B	82	1.6

The new BMS was used in phase 2. Although the metabolic workload and breath waveform shape (sine wave) were the same as in the first phase, the difference in design between the two BMS's makes the data between them incomparable. See Bureau IC 9110[3] for detailed descriptions of the designs of the old manual Reimers BMS and the new DEEC Inc. automated BMS.

In phase 3, during 1987 and 1988, the breath waveform used in the BMS testing was more humanlike, with lower peak flow rates than a sine wave generates for the same ventilation rate. In addition, while the same O_2 consumption rate was used, the other parameters of the metabolic workload were somewhat different, more closely resembling the human subjects (table 5). The human-subject testing procedure was not changed from that used in phase 2. The weights and speeds of the six human subjects are listed in table 6.

In all phases of the study, the parameters monitored were CO_2, O_2, temperature, and breathing pressures in both the BMS and treadmill testing. In the BMS testing, however, average inhaled levels of CO_2 and O_2 were measured as well as minimum levels of CO_2, whereas only minimum levels of CO_2 and maximum levels of O_2 were measured in the treadmill testing. Average inhaled gas levels reflect the overall quantity of gas inhaled, including the effect of apparatus dead space, whereas minimum values of CO_2, for example, reflect only the best performance of the scrubber. The BMS measures average inhaled values by summing electronically (new BMS) or mechanically (old BMS) all of the inhaled CO_2 and O_2 from the beginning to the end of each inhalation, as described in RI 9110. Maximum inhaled dry-bulb gas temperature was measured in phases 1 and 2, whereas end-of-inhalation, dry- and wet-bulb gas temperatures were measured in phase 3. In all phases, peak inhalation and exhalation breathing pressures were measured.

Table 5.—BMS metabolic workload for phase 3

O_2 consumption rate	L/min	1.35
CO_2 production rate	L/min	1.10
Ventilation rate	L/min	30.0
Tidal volume	L per breath	1.68
Respiratory frequency	breaths per min	17.9
Peak respiratory flow rate:		
Inhalation	L/min	89
Exhalation	L/min	71

BMS Breathing and metabolic simulator.

Table 6.—Weights and speeds of human subjects for treadmill tests, phase 3

Subject	Weight, kg	Speed, m/s
A	88	1.56
B	90	1.74
C	96	1.65
D	86	1.70
E	77	1.79
F	92	1.74

In phase 1, the termination criteria were a collapsed breathing bag indicating an exhausted O_2 source, or average inhaled gas concentrations of ≥4 pct CO_2 or ≤15 pct O_2. In subsequent phases, the levels of gas concentrations were dropped as termination criteria upon consideration that the only positive signal a user would have in actual use would be an empty breathing bag.

[3]Kyriazi, N. Development of an Automated Breathing and Metabolic Simulator. BuMines IC 9110, 1986, 17 pp.

RESULTS AND DISCUSSION

Experience with each brand of apparatus is discussed separately for all phases. The numerical results of phase 1 have been published previously[4] and will not be repeated here. The major conclusion for phase 1 was that SCSR's that pass their inspection criteria can be expected to function successfully except for those that have quality control problems. In phase 1, apparatus were sent for evaluation that were obviously damaged and should have been removed from service. No performance degradation was experienced that could be attributed to exposure to the mining environment.

For phases 2 and 3, the parameters monitored were averaged over the entire test duration and are presented graphically (figs. 1-9) for each apparatus by parameter. The values for deployed units tested on the BMS are compared with the values for new units tested on the BMS and with deployed units tested on human subjects on a treadmill. Missing data points are indicative of equipment malfunction or other anomaly that invalidated the data.

The Wilcoxon rank-sum test was performed for each monitored parameter to determine whether or not the deployed units behaved differently from new units. This method tests 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 an acceptable range for the given sample sizes, then there is not sufficient evidence at the specified probability level to say that the means of the two samples differ. The rank-sum test does not rely upon the assumptions that either the baseline or deployed 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 two-sided, P = 0.05 Wilcoxon rank-sum tests are presented in tables 7 and 8. The probability of T, the rank sum of the baseline units, falling outside the given range is 0.05 if the populations have the same mean.

[4]Kyriazi, N., J. G. Kovac, J. Shubilla, W. Duerr, and J. Kravitz. Self-Contained Self-Rescuer Field Evaluation: First-Year Results of 5-Year Study. BuMines RI 9051, 1986, 12 pp.

CSE

In phase 1, one SCSR was rejected because of damage (no intact lead seal and rattling of internal components). When it was opened, its components fell out. This unit should have been removed from service. If there is internal damage to a CSE apparatus, it may rattle when shaken, or the O_2 bottle gauge may have shifted, making it hard to read.

When a CSE SCSR is dropped on the lower case latch, the case bottom is pushed in, which can puncture the breathing bag. Although this can be easily seen, sometimes it is not recognized. Improved training in inspection procedures could correct this situation.

Twenty-five deployed units were successfully tested in phase 1.

Table 7.—Wilcoxon rank-sum test results, phase 2

Apparatus	Duration		Av inhaled CO_2		Av inhaled O_2		Dry-bulb temp		Inhalation pressure		Exhalation pressure	
	Range	T	Range	T	Range	T	Range	T	Range	T	Range	T
CSE	15-41	25	14-38	36	15-41	20	15-41	21	15-41	20	15-40	32
Draeger	19-57	28	18-54	43	19-57	15	19-57	37	19-57	54	12-45	44
MSA	10-35	18	9-33	27	9-33	11	10-35	17	10-35	8	10-35	8
Ocenco	16-65	32	30-94	94	16-68	34	30-94	70	30-94	62	30-94	64
PASS	13-50	23	13-50	57	13-53	34	13-53	6	13-53	17	13-50	19

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

Table 8.—Wilcoxon rank-sum test results, phase 3

Apparatus[1]	Duration		Av inhaled CO_2		Av inhaled O_2		Wet-bulb temp		Dry-bulb temp		Inhalation pressure		Exhalation pressure	
	Range	T	Range	T	Range	T	Range	T	Range	T	Range	T	Range	T
CSE	24-72	62	23-69	41	14-58	41	13-53	44	14-55	37	24-72	44	24-72	49
Draeger	24-72	72	24-76	62	24-76	62	23-69	26	14-58	38	17-55	30	24-76	41
MSA	19-56	33	24-56	34	22-53	43	24-56	27	24-56	36	24-56	28	24-56	26
Ocenco	15-60	35	15-60	42	15-60	39	14-58	15	15-60	25	15-60	25	14-58	39

T Sum of the ranks of the smaller sample (new units).
[1]PASS not tested in phase 3.

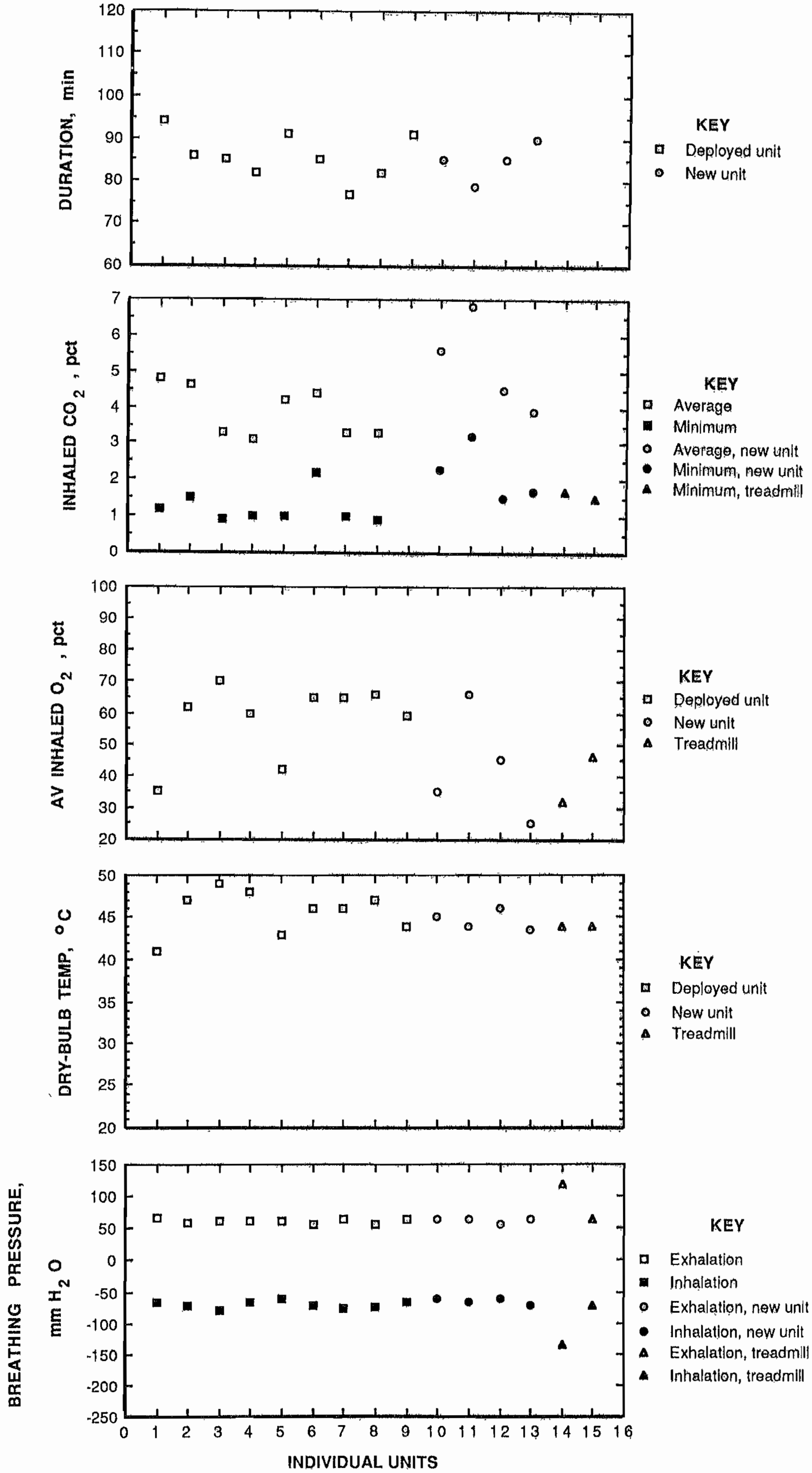

Figure 1.—CSE units, phase 2

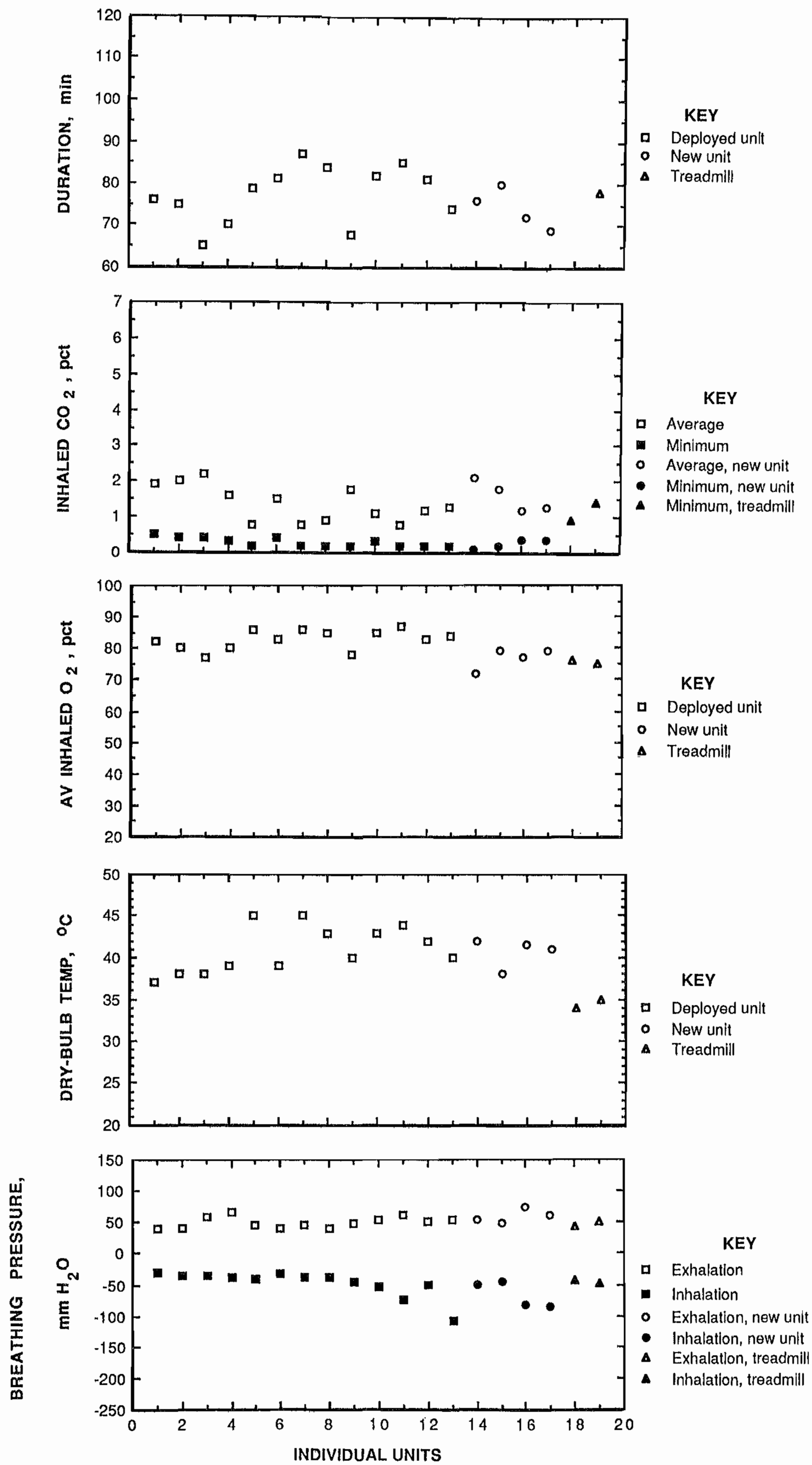

Figure 2.—Draeger units, phase 2

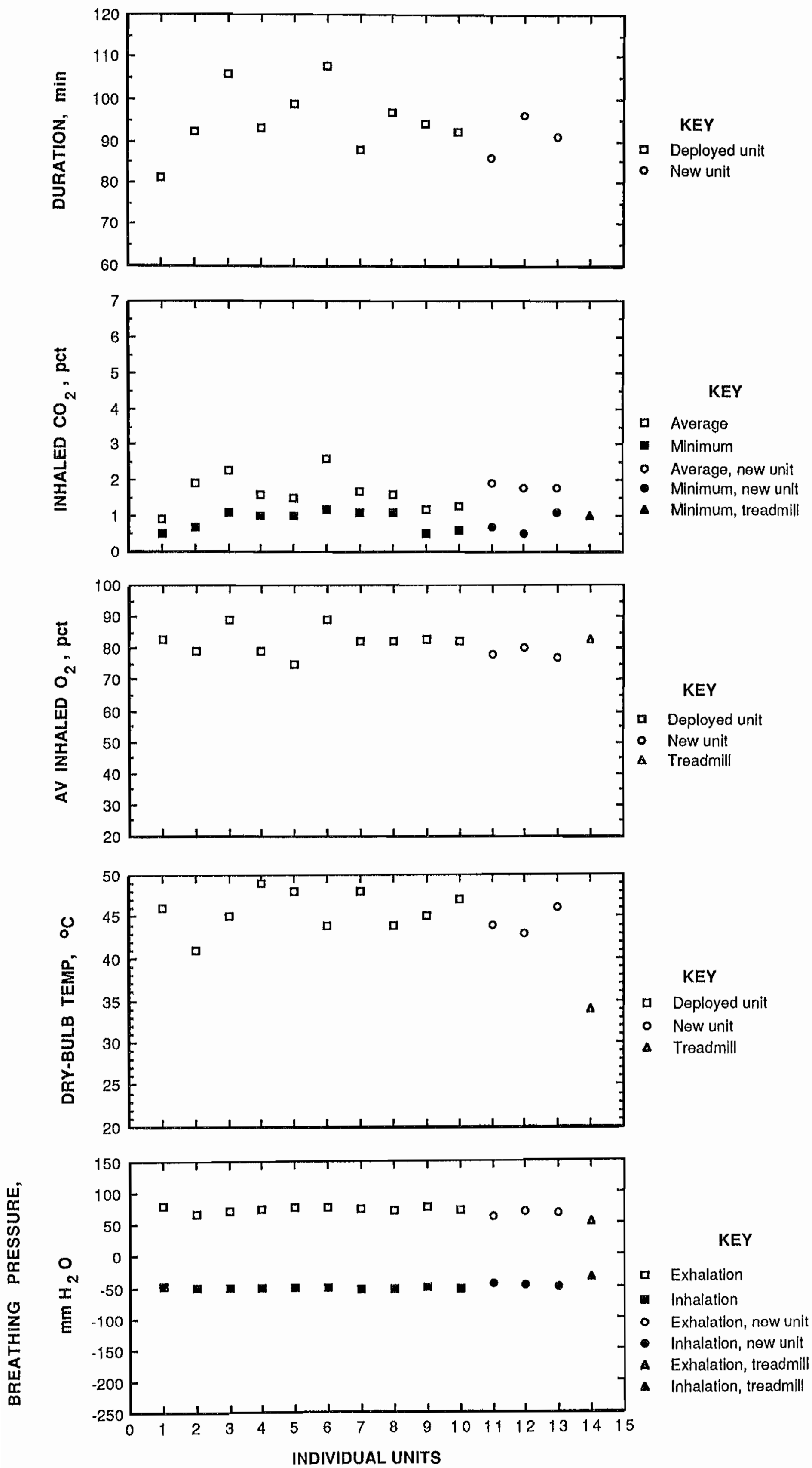

Figure 3.—MSA units, phase 2

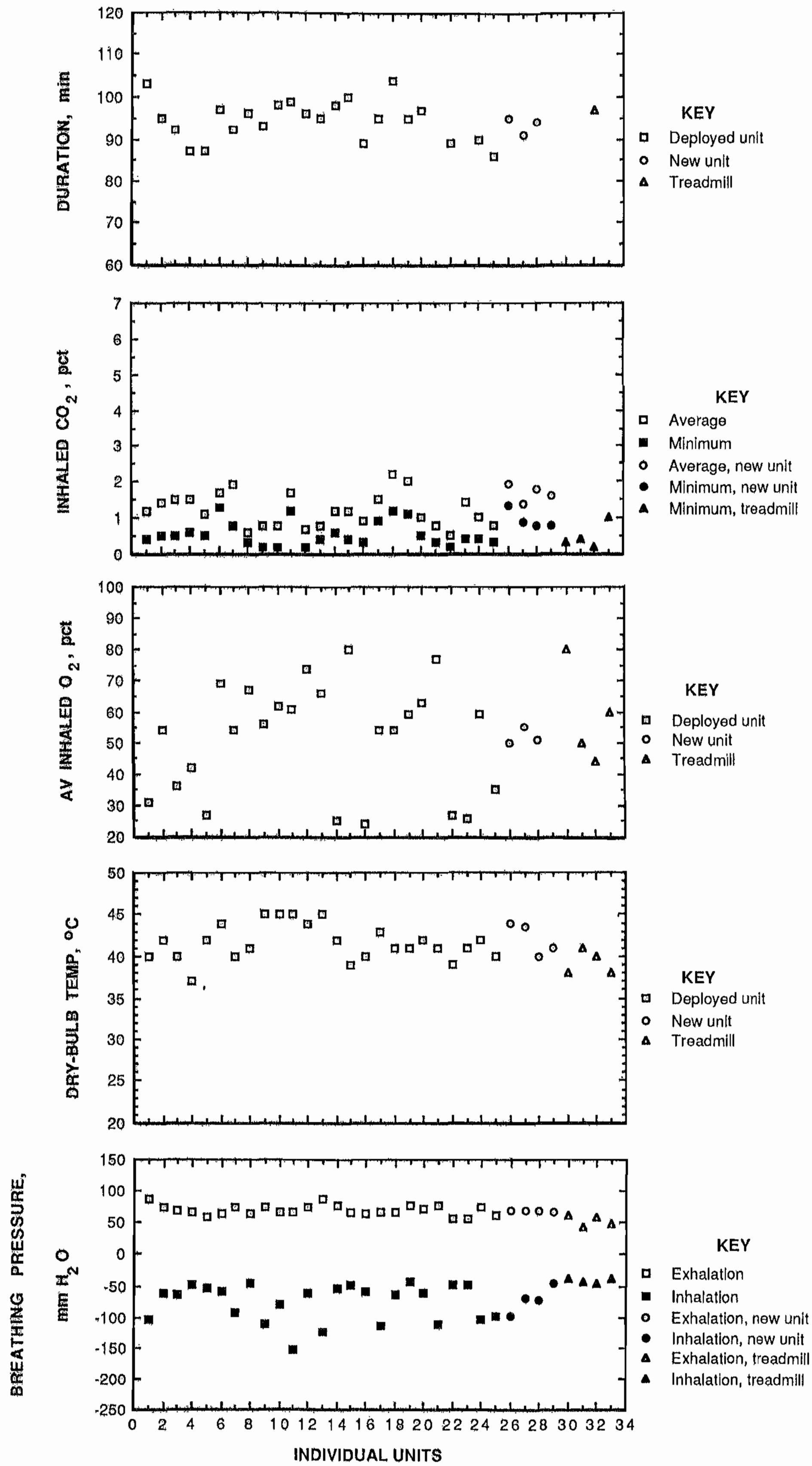

Figure 4.—Ocenco units, phase 2

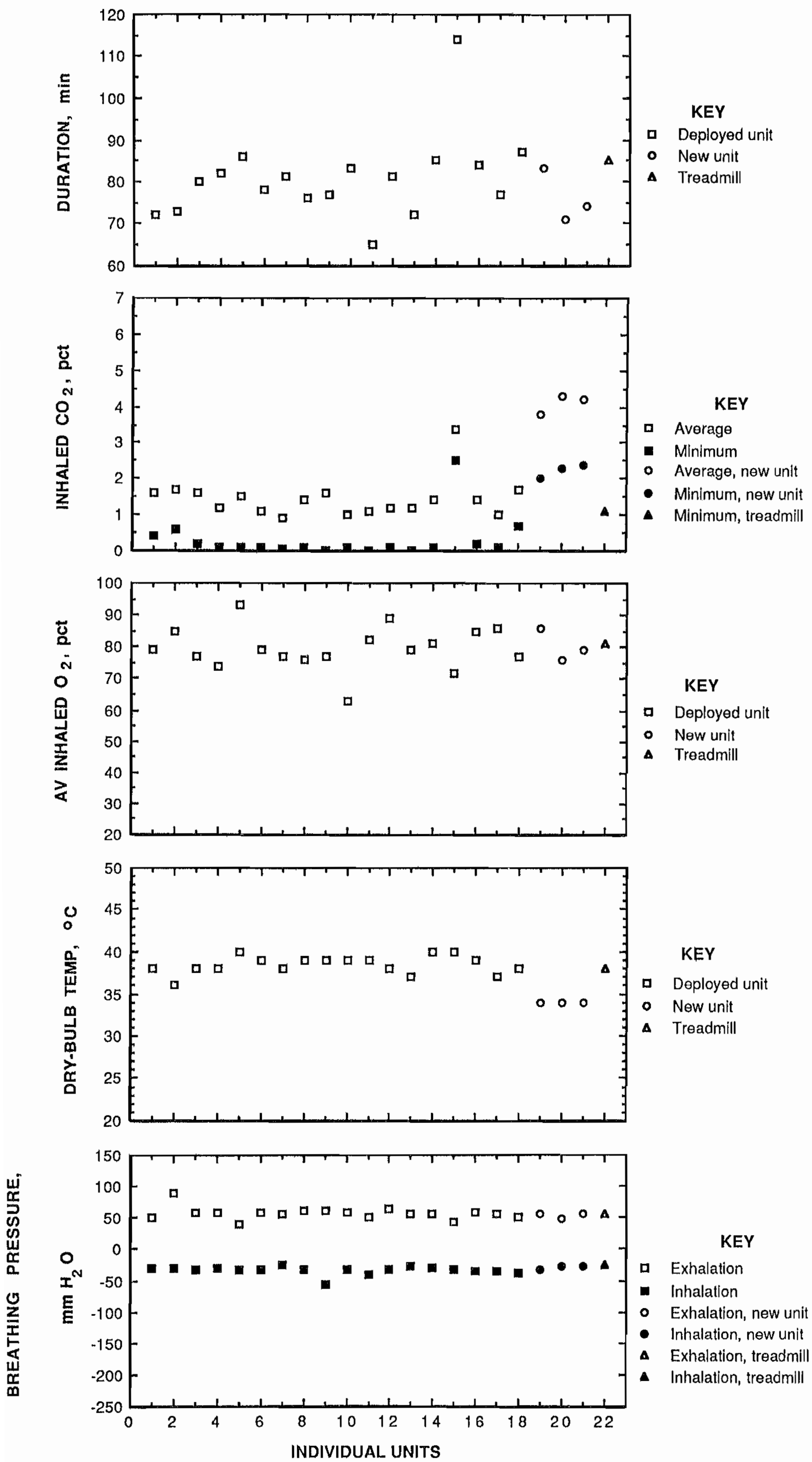

Figure 5.—PASS units, phase 2

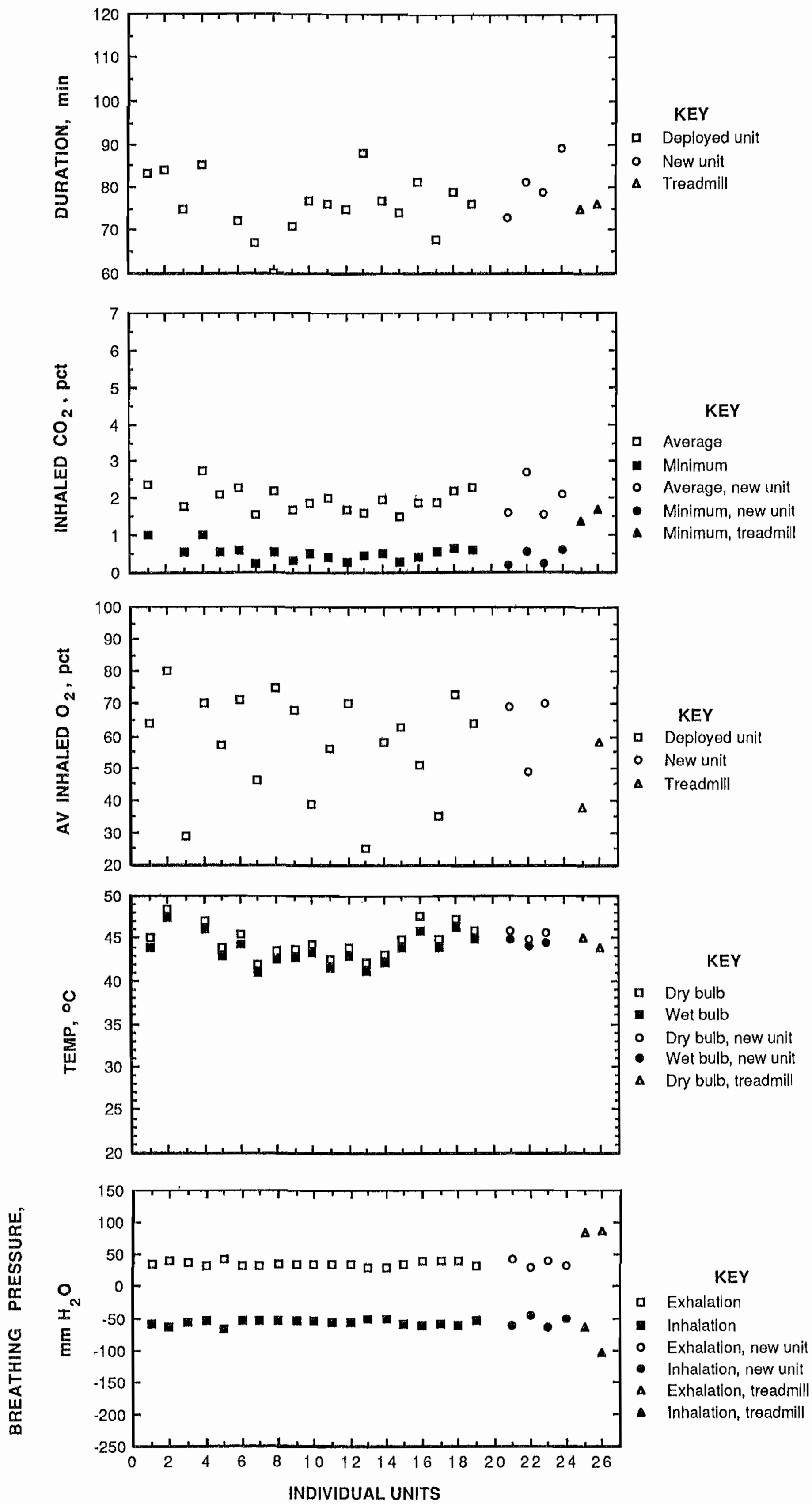

Figure 6.—CSE units, phase 3

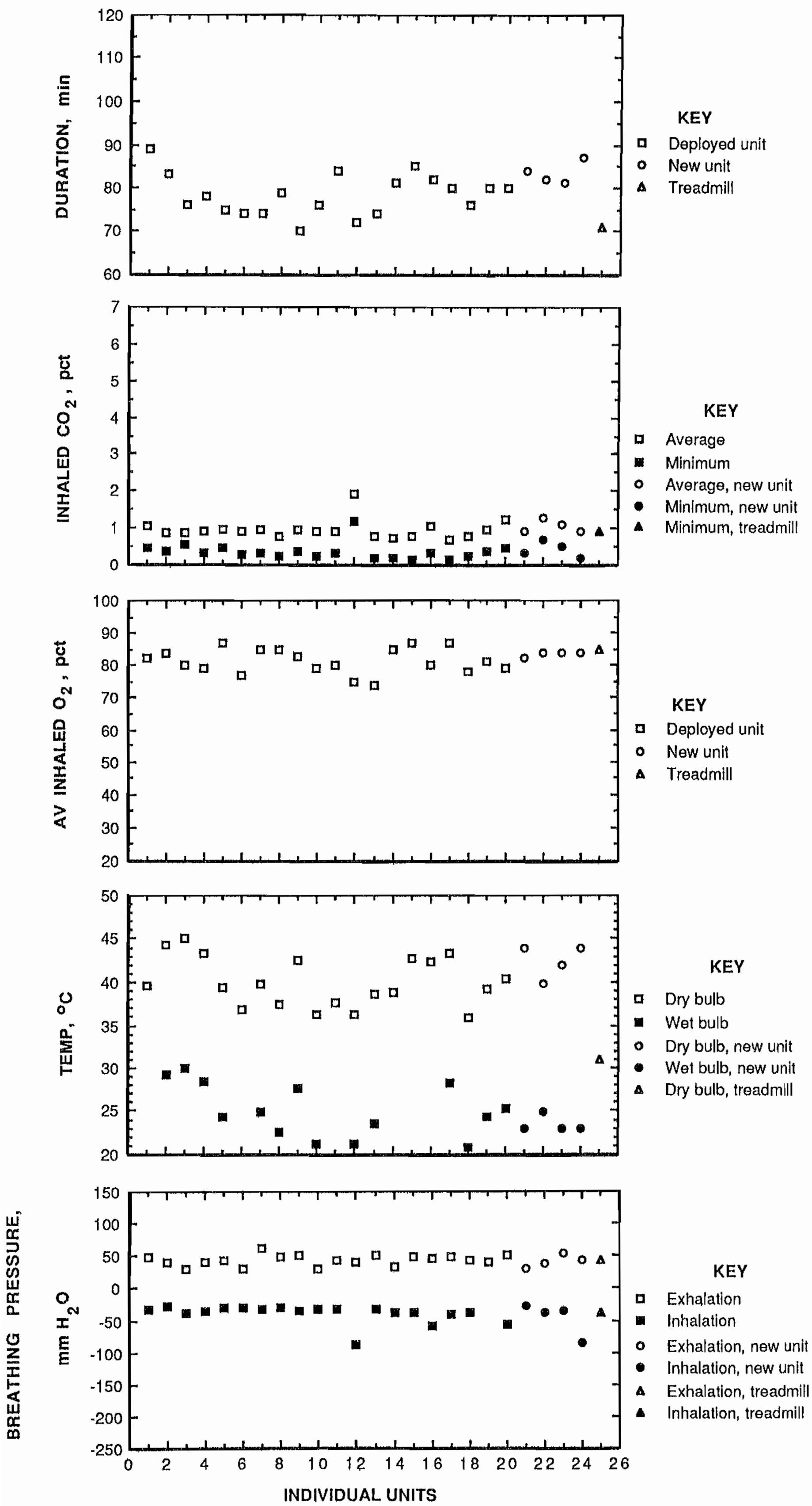

Figure 7.—Draeger units, phase 3

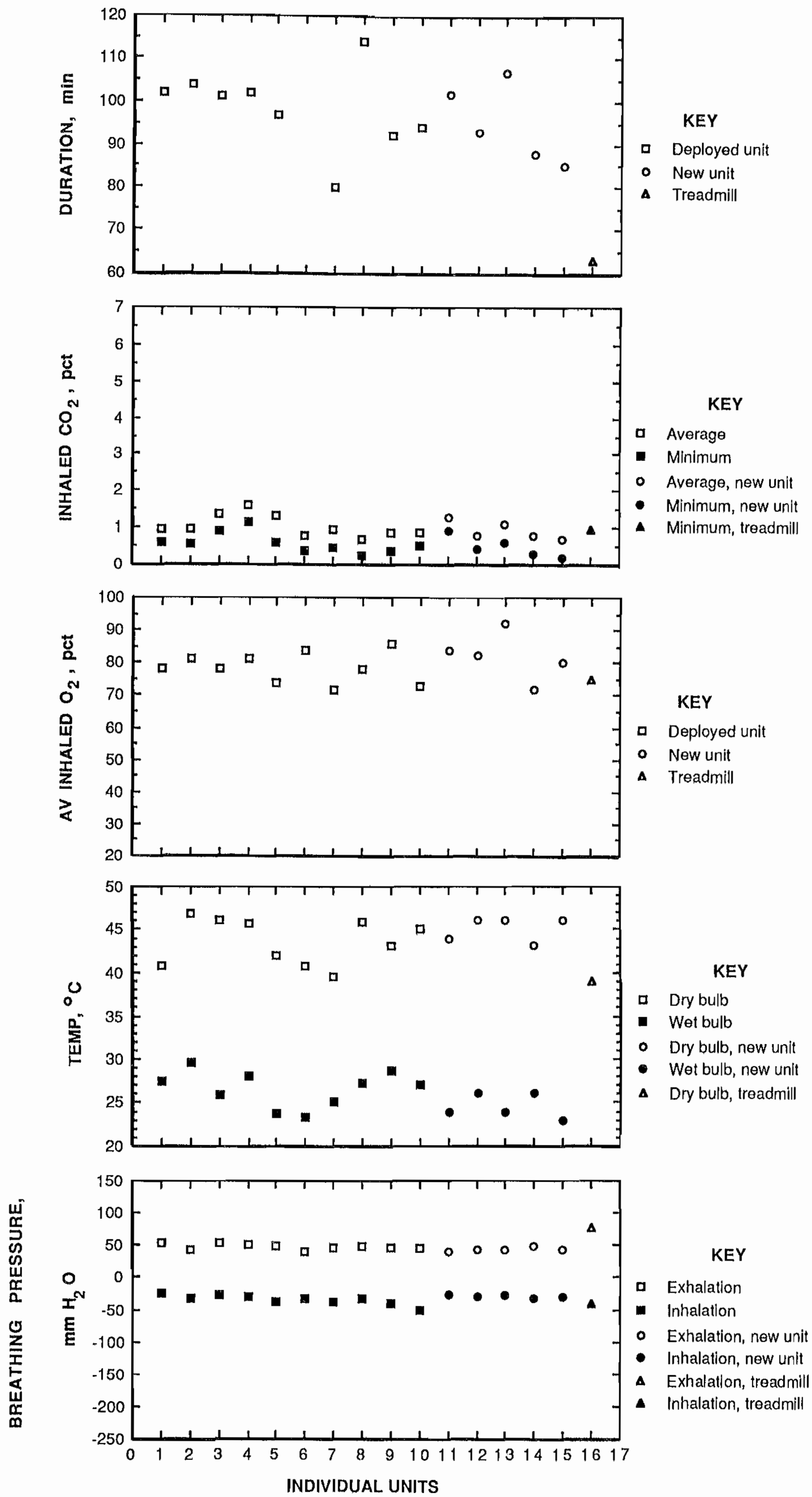

Figure 8.—MSA units, phase 3

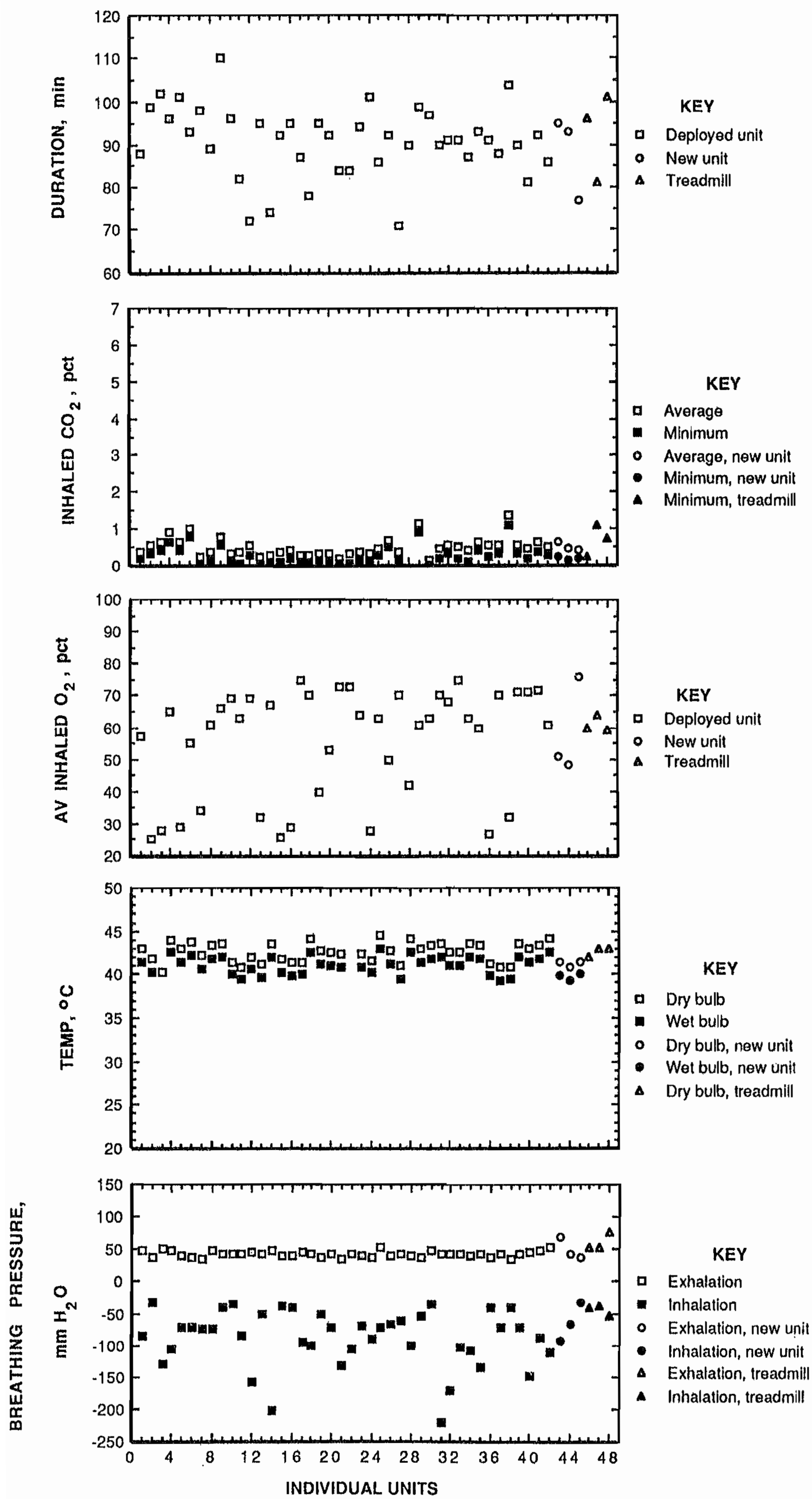

Figure 9.—Ocenco units, phase 3

In phase 2, regulators from several SCSR's blew apart when their cylinder valves were opened. One incident occurred at an MSHA district office; two more regulator bursts occurred in the Bureau laboratory where the tests were conducted; another occurred at NIOSH. CSE's response to NIOSH was to recall and retrofit the SCSR's with a modified regulator.

The human-subject tests in phase 2 were terminated arbitrarily shortly after 60 min for the benefit of the human subjects. Those durations are not shown in the graphs since the apparatus were not expended at termination as were the ones tested on the BMS.

One human subject experienced breathing pressures that became so high that he was barely able to complete the test. Afterward, the subject was exhausted and became lightheaded. The apparatus was taken to CSE and dismantled. No defect could be found in the apparatus, but the recorded high pressures, which reached 210 mm H_2O on exhalation and 280 mm H_2O on inhalation, cannot be denied. High ventilation rates may have caused the high pressures. The human subject is, perhaps, a CO_2 reactor, who responds to the inhalation of CO_2 with excessively increased ventilation. Since the CSE AU-9A1 has the highest values of inhaled CO_2 of any of the apparatus, this would explain why he experienced no similar problem with the others.

As in the first phase of this study, a few apparatus were sent that should have been removed from service because of obvious damage. Some rattled when handled. Usually, this rattling indicated that the plastic regulator clamps were broken.

One unit was missing a lead seal and had a paper seal that had curled away from the case, revealing the remnants of an old paper seal. When it was opened, the mouthpiece was found to be missing. This unit was put into service in June 1982, was checked by CSE in December 1982 as part of a recall of all its SCSR's, and was collected for this study in November 1984. As a result of this finding, 10 more units were procured from the same mine and were inspected. No further problems were discovered. In addition to the missing mouthpiece, this apparatus had a constant O_2 flow rate of 1.47 L/min, which is less than the required 1.5 L/min. The expiration date for the unit had passed between the time it was collected and tested. This is not sufficient reason to excuse the apparatus, but, in any case, a low flow rate on the constant-flow regulator is easily made up through increased use of the demand valve. All of the other CSE SCSR's had O_2 flow rates above the required minimum. Eleven deployed units were successfully tested in phase 2.

In phase 3, two units that had been procured for the study before the recall involving replacement of defective regulators vented their O_2 bottles when the cylinder valves were opened.

One apparatus that had legally expired 18 months before it was received was tested in phase 3 for informational purposes only. This apparatus had large and small dents in the outer case, and one of its paper seals was broken. This apparatus had CO_2 levels higher than any other, with average inhaled values exceeding 4 pct for the last 20 min beginning at 55 min. According to the manufacturer, if the CO_2 absorbent, lithium hydroxide (LiOH), absorbs moisture, its efficiency is lessened. If that was the case with this particular apparatus, removing an expired unit from service can be seen as important. Twenty-two deployed units were successfully tested in phase 3.

DRAEGER

In a study of Draeger SCSR's carried by MSHA inspectors, two units had broken clamps around the flow-splitting valve housing at the interface of the breathing bag and breathing hose. During the simulated escape test in which these were discovered, one unit's breathing hose separated from its breathing bag, rendering the unit unusable. The other unit held together. Draeger recalled its apparatus to replace this clamp as well as the nose clip clamp, which had also been found to experience some breakage.

One other discovery was that a significant percentage of the Draeger SCSR's had breathing hoses that were crimped where they were folded for packaging. Uncrimping the hose is usually simple but should be mentioned in the training procedure. Draeger has added this instruction to its manual.

Inspection of 13 units that had been subjected to explosive forces in the Clinchfield Coal Co.'s McClure #1 Mine disaster in 1983 showed that even apparatus with significant damage performed normally and could have been used for an escape.

There have been two cases in which Draeger SCSR's were sent in from various MSHA districts with reports that they failed to function properly. Upon testing, the apparatus were found to function normally, implying improper use. Improved training procedures may prevent such occurrences. Twenty-one deployed units were successfully tested in phase 1.

In phase 2, one apparatus from the McClure #1 Mine had sufficient talcum powder in the breathing hose to cause mild irritation and to make the test subject want to spit. This raises concern that some users may choose to abandon the apparatus. Another apparatus, from the Ranger Fuel Corp.'s Beckley #2 Mine, had a severely crimped breathing hose that could not be uncrimped. In addition, talcum powder was visible below the crimp in the hose. A frayed waist strap indicated that the apparatus had been carried frequently. All other inspection criteria were met. It seems that the presence of talcum powder, even in copious quantities, is not an effective method of preventing the breathing hose from sticking shut. It is an effective irritant when inhaled, however.

One problem that resurfaced in phase 2 was the incidence of broken nose clip clamps. This was no surprise, as the apparatus procured for the study were collected prior to the recall of the OXY-SR 60B SCSR's.

Two deployed apparatus had inhalation check valves that resonated during inhalation, causing higher inhalation pressures. The same phenomenon occurred on baseline units. This occurred only at one particular inhalation flow rate drawn by the BMS. The phenomenon was reproducible with human subjects but occurred only at that same flow rate. It is unlikely that this phenomenon would adversely affect an emergency escape.

The Wilcoxon rank-sum test (table 7) for average inhaled O_2 indicates a lower mean value for the new units than for deployed units. As can be seen from the O_2 graph (fig. 2), however, the average inhaled O_2 values are all close. In any case, higher O_2 concentration in deployed units is not worrisome if the differences are, indeed, real.

Fifteen deployed units were successfully tested in phase 2.

In phase 3, another unit with a broken nose clip clamp was found, indicating that all users have not responded to the manufacturer's recall. Three deployed and one new apparatus had inhalation check valves that resonated during inhalation as indicated on the graphs as the greater-than-normal inhalation pressures. As before, these pressures would be only intermittent on human subjects and would present no problem to the user.

Also, in phase 3, more complaints were received about crimped breathing hoses. After opening 150 Draeger SCSR's collected from MSHA inspectors, it was discovered that the crimp problem was more widespread and that some crimps were difficult to undo. As a result, Draeger retrofitted all of its apparatus with new hoses in 1991.

As can be seen in the inhaled CO_2 chart (fig. 7), one deployed apparatus had much higher levels of CO_2 than the others. In an effort to explain this, the data of other apparatus tested on the BMS that day were reviewed and it was found that the apparatus had normal CO_2 values, so it is unlikely that the BMS put too much CO_2 into the circuit. The apparatus was stored on a mantrip, as were many others that had normal levels of CO_2. It may be that a manufacturing error resulted in the apparatus containing less chemical than intended. The average inhaled CO_2 level exceeded 4 pct after 66 min. This is high for the Draeger OXY-SR 60B but physiologically tolerable and no higher than the average of the CSE AU-9A1. In the future, apparatus with such abnormal characteristics will be disassembled in an attempt to explain their behavior. This apparatus also had high inhalation pressures due to resonating inhalation check valves.

Twenty-one deployed units were successfully tested in phase 3.

MSA

In phase 1, it was found that many human subjects cough during the first several breaths from MSA SCSR's. Although the exact cause is not certain, there are several possibilities:

1. Talcum powder in the breathing circuit, used to keep the rubber parts from sticking together.
2. Potassium superoxide (KO_2) dust that was not fully vacuumed out of the breathing circuit at the time of manufacture.
3. KO_2 dust that escaped the filters of the chemical bed resulting from shock and vibration sustained during normal use.

While one case can be attributed to cause 3, most cases were attributed to causes 1 and 2 if there was no damage to the filters or beds. In any case, MSA has applied warning stickers to its apparatus advising that, should coughing occur, the apparatus is not defective and should not be removed.

Several early apparatus produced for the Bureau and MSHA, and used by MSHA inspectors, were found to have internal component frames that were dislocated from their shock mounts and were in danger of falling out of the lower case halves. This would have made the units difficult to use. The condition was caused by one or more severe drops; however, no damage to the outer case was visible. This problem was resolved in commercially available models.

Fourteen deployed units were successfully tested in phase 1.

In phase 2, the only problem found with an MSA SCSR was one unit with a chlorate candle that failed to fire, necessitating a manual start. Inspection of the unit at MSA revealed a missing spring in the firing mechanism. This was a quality assurance problem and was reported to NIOSH.

The Wilcoxon rank-sum test (table 7) on both inhalation and exhalation pressures indicates lower mean values for baseline (new) units than for deployed units. As can be seen on the breathing pressures graph (fig. 3), the differences are slight. Since the Wilcoxon rank-sum test for breathing pressures in phase 3 (table 8) does not show a significant difference between new and deployed units, increasing resistance does not seem to be a trend.

Eleven deployed units were successfully tested in phase 2.

In phase 3, the apparatus tested on a human subject was accidentally run at a workload 30 pct higher than desired; the test was graphed but should not be compared with the other tests. Eleven deployed units were successfully tested in phase 3.

OCENCO

In phase 1, an Ocenco SCSR used in an actual escape in the Greenwich Collieries mine fire of 1984 was found to have its check valves reversed. This was considered to be a quality assurance problem and was resolved by NIOSH, MSHA, and the manufacturer.

The major problems with the Ocenco SCSR are its stiff demand valve and its strong outer case. The pressure required to elicit 30 L/min of O_2 from some of the demand valves can reach -200 mm H_2O, compared with approximately -40 mm H_2O for the CSE demand valve. At high O_2 use rates (higher than the usual constant flow rate of 1.8 L/min), the demand valve is needed. Unless aware of the high activation pressure, the user is likely to think that the apparatus is malfunctioning. When 12 Ocenco SCSR's were used in the Greenwich Collieries mine fire, 5 testimonies indicated that the users felt that they could not get enough air. In response, the users removed the mouthpiece or nose clip, breathed around the mouthpiece, or slowed down. Training would remedy this problem to some degree, but the best solution is to replace this demand valve with one that is not as stiff.

The strength of the clear, outer case of the Ocenco SCSR enables it to withstand shock better than its internal components. During the Greenwich Collieries mine fire, 12 of 17 units used for escape evidenced internal damage sufficiently severe that, if damage occurred before use (the likely case), the apparatus should have been removed from service. LiOH from the scrubber was found in the breathing circuits of five of the damaged units. All damage to these apparatus was evident, but apparently not recognized by the miners, the mine operators, or the mine inspectors. Improved training in inspection procedures is obviously necessary.

Another problem is the tight-fitting case halves, which are extremely difficult to open without proper training. It is recommended that training include special mention of the opening procedure.

Thirty-eight deployed units were successfully tested in phase 1.

In phase 2, three of five Ocenco SCSR's from the Greenwich Collieries #2 Mine failed their inspection criteria and were returned to the mine and traded for apparatus that passed their inspection criteria. One apparatus had a shifted bottle band. Another had a cracked case. A third had a shifted bottle band and a piece of loose rubber in the case. A fourth had a very scratched case but passed its inspection criteria. This apparatus was found to contain enough LiOH in its breathing bag and hose to cause severe coughing. Some LiOH had even escaped the breathing circuit and could be seen through the scratched case upon close inspection. It is not believed, however, that a user would have detected this even under laboratory conditions and certainly not under routine mining conditions. This type of problem—an apparatus that passes its inspection criteria but is unusable—is of primary concern in the long-term field evaluation. As a result, the manufacturer has added an inspection criterion that reads as follows:

"Inspect the apparatus for indications of high force impacts. If the view through the case is obstructed such that a proper examination cannot be performed (e.g. scuff marks, stickers, paint) the unit must be removed from service."

Two of the Ocenco SCSR's had O_2 flow rates below the required minimum of 1.5 L/min. The measured rates were 1.44 and 1.48 L/min; shortfalls of these amounts would have minimal effect on use.

As the flow rate from a normal regulator diminishes during a test, the demand valve is activated more often. The more the demand valve is activated, the higher the inhalation pressure becomes because of the nature of the stiff demand valve. The variation in regulator performance with diminishing O_2 flow over time is evidenced by the wide range of values for inhalation pressures that can be seen in the graphs. Also contributing to this wide range of values is the variation in stiffness of the demand valves.

Twenty-nine deployed units were successfully tested in phase 2.

In phase 3, an apparatus with a missing cylinder neck clamp was found. This would not have compromised a successful emergency escape.

On the phase 3 graph for CO_2 (fig. 9), there are two apparatus with higher-than-average values. High CO_2 values can be attributed to natural variation in the efficiency of the CO_2-absorption chemical, environmental impact, or incorrectly high CO_2 add-rate during testing. The apparatus were not close in serial number (60627 and 68218), but were from the same mine and had the same deployment history: first carried in and out of the mine daily for 28 months, and then stored underground for 10 months. The other units from that mine had different deployment histories. The apparatus were tested 5 days apart, with other apparatus tested between, before, and after that all behaved normally, which tends to diminish the possibility of an incorrectly high CO_2 add-rate while testing. The values of the other monitored parameters were normal. The fact that both apparatus had the same deployment history leads one to believe that the environment or their handling had some effect on the CO_2-absorbent bed. It is not known what type of environmental treatment would reduce the efficiency of the LiOH bed. In any case, the apparatus had durations of 99 and 104 min, by which time the average inhaled CO_2 had reached approximately 4 pct. This would hardly have been noticed by a user, especially for the brief period of exposure.

In May 1990, a new unit experienced ignition of the Kel-F plastic (homopolymer of chloro-trifluoroethylene) valve seat in the O_2 cylinder valve when the valve was opened. A strong smell of chlorine and/or fluorine emanated from the breathing hose; this would have prevented the apparatus from being used in an emergency. Whether the ignition occurred because of hydrocarbon contamination in the valve or a Kel-F plastic shaving, industry experience suggests the susceptibility of Kel-F plastic to ignition in 100 pct O_2 atmospheres. Other manufacturers have switched valve seat material from Kel-F plastic to Vespel polyimide resin with no further reported problems. NIOSH has been notified of the incident. Forty-five deployed units were successfully tested in phase 3.

PASS

In phase 1, two of the PASS SCSR's, for reasons still unknown, underwent a decrease in O_2 concentration to below 15 pct, requiring termination of the tests. When these units were later refilled with O_2 at PASS's facility, the O_2 flow rates were found to be in compliance with specification. Since other apparatus were successfully tested immediately after their failures, malfunctioning measurement equipment was ruled out. One possible explanation is that the constant-flow regulators were initially clogged with particulate matter that later freed itself. Since these incidents could not be repeated nor the causes determined, they were not pursued beyond reporting them to NIOSH.

One SCSR, during treadmill testing, permitted high inhaled CO_2 concentrations during the first several breaths. It was found that the inhalation check valve was missing. This was considered to be a quality assurance problem and has been handled by NIOSH. Six deployed units were successfully tested in phase 1.

In phase 2, one unusual occurrence involved a PASS SCSR with an extraordinarily long duration (114 min). This is not to say that a user could have worn the unit that long, since both average and minimum inhaled CO_2 had reached 15 pct before that time. It is believed that the constant-flow regulator was not releasing its required 3 L/min of O_2 over the first 60 min of use. Since only 1.35 L/min STPD was removed from the apparatus on the simulator test, nothing unusual was noticed until the apparatus performed longer than the usual time. After 60 min, even normal apparatus are permitted to have flow rates less than 3 L/min, so this postulation could not be positively determined.

In phase 2, all of the baseline (new) units had average and minimum inhaled CO_2 levels significantly higher than those of the deployed units (fig. 5). The dry-bulb temperatures for the baselines were also much lower than those of the deployed units, indicating that the soda-lime beds were less reactive, permitting more CO_2 to pass through the beds unabsorbed and, thus, producing less heat. There are several possible explanations for this behavior. Since the baseline units were tested as a batch, close in time to each other, approximately 9 months before the deployed units were tested, it is possible that too much CO_2 was injected into the units. To test that theory, more new units were tested in 1990. They had even higher levels of CO_2. It was noticed that the baseline units had much higher serial numbers than the deployed units. The deployed unit serial numbers ranged from 317 to 2689. The baseline unit serial numbers ranged from 3110 to 3308. More units of lower serial number were tested and both good and bad results regarding CO_2 breakthrough were recorded. MSHA obtained two units from different mines and one from storage at its facility. The two from the mines did well but the one from storage had high CO_2 levels. A direct correlation was found, with one discrepancy, between CO_2 breakthrough time and canister weight. No other correlation has been determined as of this writing.

One unit was rejected because of a cylinder gauge that was not visible. Nineteen deployed units were successfully tested in phase 2.

No PASS SCSR's were tested in phase 3 since few remain in use and the manufacturer has ceased operations. The PASS SCSR is no longer considered approved by MSHA and NIOSH.

CONCLUSIONS

A number of quality control problems were discovered in the long-term field evaluation. These problems were reported to NIOSH, MSHA, and the breathing apparatus manufacturers. In each case, action has been taken to solve the problems.

Certain SCSR's collected during the study were damaged by daily in-mine use and should have been removed from service. The damage was generally apparent and visible and should have been detected if the SCSR's had been properly inspected. Improved inspection training is recommended.

The results of this study suggest that the large majority of SCSR's that pass their inspection criteria can be relied upon to provide a safe level of life support capability for mine escape purposes. No problems have arisen involving subtle performance degradation due to the mining environment. Manufacturing defects or improper design were found, such as the CSE bursting regulators and missing mouthpiece; the Draeger broken clamps and crimped hoses; the MSA defective starter candle and coughing problems; the Ocenco reversed check valves, burning Kel-F valve seat, and scratched outer case hiding internal damage; and the PASS missing check valve, incorrectly set regulator, unpredictable high CO_2 levels, and still-mysterious low O_2 levels. All of the defects were detected immediately upon attempting to don the apparatus except for those of the PASS SCSR, which is being removed from service. The discovery of a defective apparatus gives the user the opportunity to use another one, since usually extra SCSR's are stored. Even with this option, however, these problems evidence the need for continued monitoring, preferably by the Government, whose independence is important.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1992--611-209

INT.BU.OF MINES,PGH.,PA 29501