

Laboratory Testing of Chemical Oxygen Self-Rescuers for Ruggedness and Reliability¹

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The Bureau of Mines subjected two manufacturers' chemical oxygen (KO₂) self-rescue breathing apparatus to a series of laboratory environments designed to simulate various conditions in underground coal mines. The environments consisted of extremes of temperature, shock, and vibration. The tests were designed to be used as predictors of the ability of the self-rescuers to survive those environmental insults with no degradation in their protection to the wearer. Based on the severity of the environments, simulating conditions more severe than that offered by the mining environment, the two apparatus tested should be able to withstand the abuse offered by the mining environment and still function as intended in an emergency. Correlation of these tests with results of long-term field evaluations is needed to provide confidence in the laboratory tests as predictors.

Introduction

On June 21, 1981, coal mine operators were required to make available to each underground coal miner in the U.S. 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 self-rescuer that provides an oxygen source. The SCSR will replace the filter self-rescuer (FSR) as primary escape equipment. FSRs protect only against low levels of CO.

In January 1980, the Bureau of Mines began **an experimental program to examine the fire and explosion hazards of chemical oxygen SCSRs. Because the oxygen-generating chemical, potassium superoxide (KO₂), readily reacts with moisture and any fuel such as coal, the mechanical integrity of the canister in which it is encased became an additional concern.**

To assess the magnitude of these hazards, a large number of experiments were performed with KO₂, KO₂-fuel mixtures, and the self-rescuers containing KO₂. These included burning-rate studies of KO₂-fuel mixtures, studies to determine the temperature rise associated with KO₂-water and KO₂-CO₂ reactions, and tests to determine the impact and friction sensitivity of KO₂-fuel mixtures. Tests were conducted also to determine the potential ignition hazards of self-rescuers exposed to water and rifle fire and to determine their behavior when burned in a

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bonfire. To determine their mechanical integrity, the units were exposed to simulated roof falls, run over by various mine vehicles, and fed through a feeder-breaker.

The results of these mechanical abuse tests showed that the 1-hour self-rescuers were rugged and would probably survive massive roof falls and crushing by mobile mining machines, without releasing significant, if any, quantities of KO_2 . Experiments involving running over KO_2 -coal mixtures showed that the consequences of the release of KO_2 under such circumstances would be negligible (Watson et al., 1980).

The Mine Safety and Health Administration (MSHA) conducted an evaluation program to examine how the regulations for the use of SCSRs affected underground coal miners (Peluso et al., 1981). Goals for this evaluation were developed jointly by the Bureau and MSHA, and this report is an integral part of the evaluation program. The Bureau also sponsored the development of guidelines to assist the mine operator in proper handling and deployment of SCSRs (Berry and Mitchell, 1981).

The guidelines caution against the long-term effects of vibration for SCSRs stored on equipment. They do not recommend SCSR storage below 0°C , although both chemical SCSRs tested in this study are approved for operation at below freezing temperature. The effects on KO_2 (possible oxygen release due to inherent moisture) of storage at temperatures above 38°C are also mentioned. In addition, specific recommendations were made for selecting durable protective storage containers. These concerns are directly relevant to the development of adequate storage plans which will insure the availability of fully operable SCSRs in the event of a disaster.

In December 1980, the Bureau began laboratory environmental testing of the two chemical oxygen SCSRs that had been approved by the National Institute for Occupational Safety and Health (NIOSH) and MSHA: the Draeger OXY-SR 60B and the Mine Safety Appliances (MSA) 60-minute SSR; no other self-rescuers had NIOSH-MSHA approval at that time. The purpose of this series of environmental tests was to attempt to project the effects of the underground

mining environment on KO_2 SCSRs. Such studies are not always done on new equipment before large-scale deployment, but because SCSRs are used for life support, it is critical that they be maintained in operable condition. These laboratory tests were planned to give further knowledge and assurances about the readiness of SCSRs to operate when needed.

There is no implication that either NIOSH, MSHA, or the manufacturers have conducted less than thorough testing of these devices. On the contrary, as the NIOSH-MSHA approval indicates, these SCSRs have successfully demonstrated the adequacy of their design and manufacturing. There is a high level of confidence that they are dependable devices. However, the need to study environmental effects arises due to the gradual deterioration that all equipment and materials are expected to experience. Environmental testing can help in the estimation of equipment lifetime. In the case of SCSRs, the questions of concern are related to expected lifetime in various modes of section (container) storage, placing on mining equipment, and wear or carry.

The actual answers to these questions can come only from experience. The Bureau is currently planning the necessary long-term field evaluation to directly obtain the data. In the meantime, the laboratory tests offer the following benefits: (1) If the test is severe enough, one can directly observe the failure mode for a particular environmental assault on the equipment, and (2) laboratory test results can be used as indicators of areas where attention should be focused during the field evaluations.

The test results should not be applied to other SCSRs or breathing apparatus since they are specific to the two chemical O_2 devices evaluated.

Description of Self-Rescuers

Basically, a closed-circuit, self-contained breathing apparatus of any type is composed

of a mouthpiece or facepiece and breathing hose, an oxygen source, a carbon dioxide absorbent, and a breathing bag. In the case of

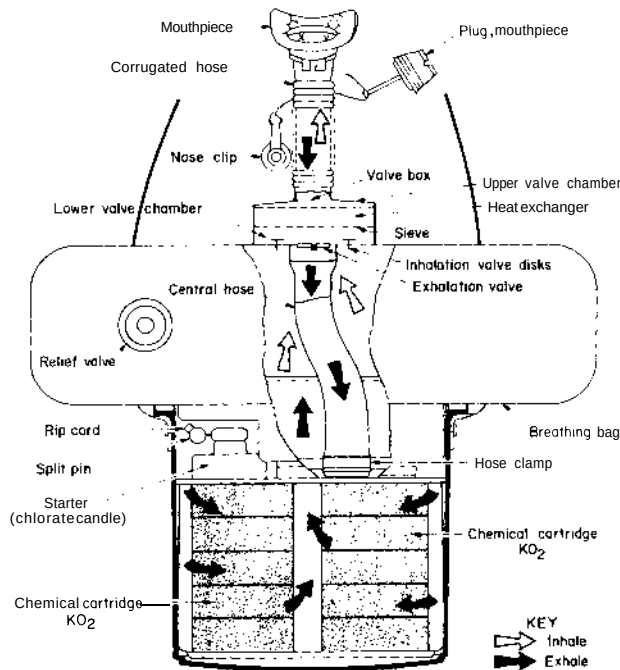


Figure 1. Draeger oxygen self-rescuer.

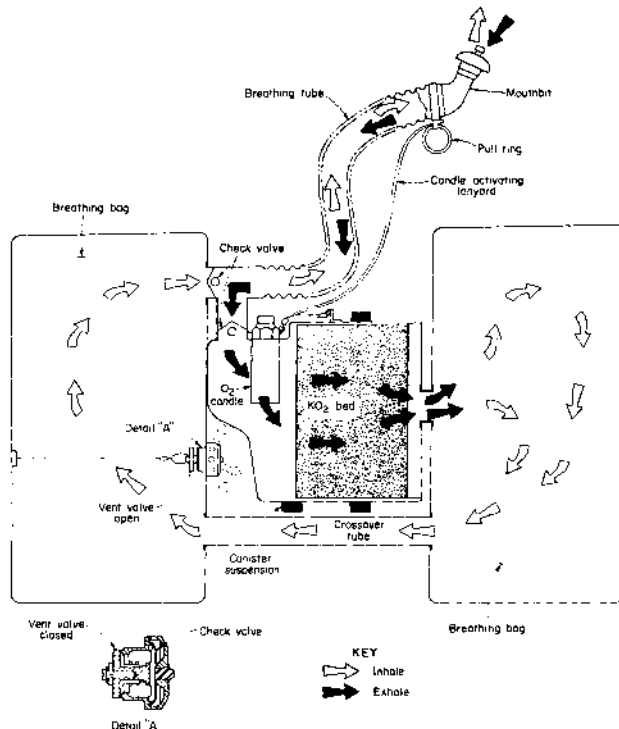


Figure 2. MSA oxygen self-rescuer.

chemical oxygen apparatus, KO_2 is both the oxygen source and the carbon dioxide absorbent, satisfying human physiological needs with a little excess oxygen. This excess oxygen has the effect of continually purging the system of nitrogen, which may exist in the breathing loop.

As can be seen from Figures 1 and 2, the MSA 60-minute SSR and Draeger OXY-SR 60B apparatus have different flow paths and arrangements of components. Their functions, however, are the same—to provide a portable life-supporting atmosphere. These oxygen self-rescuers are bigger and heavier than filter self rescuers (Figure 3), and there are other material differences. For example, inhalation temperatures for SCSRs may be high towards end-of-life, but this is unrelated to ambient conditions, whereas an FSR may heat up to unbearable temperatures and actually burn the lips of the user if ambient CO concentrations are high. Duration is determined in FSRs by ambient CO

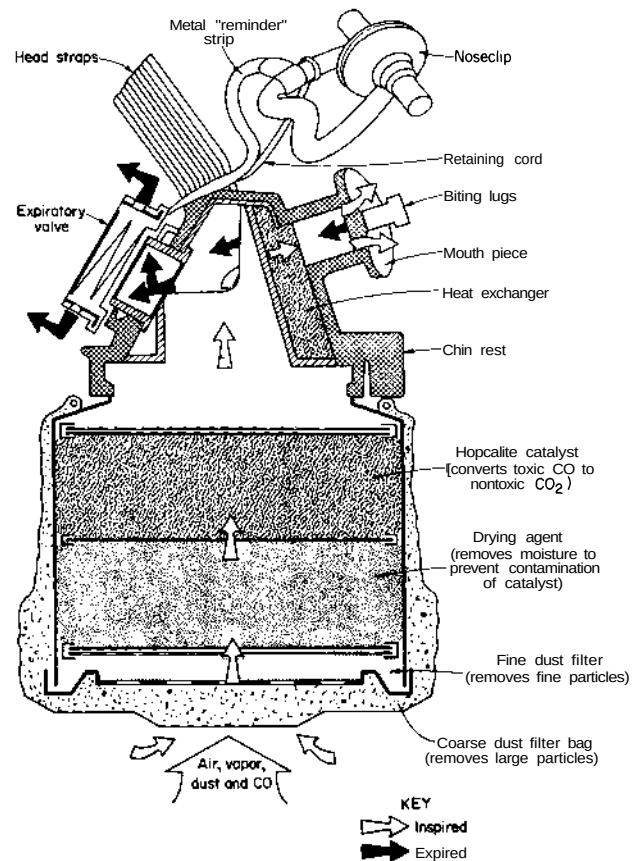


Figure 3. Filter self-rescuer (FSR).

concentrations, humidity, and physiological demand; in SCSRs the physiological demand of the user alone determines duration, and an SCSR may last as long as 5 hours if the user is sedentary (NIOSH man-test 5).

Experimental Design and Test Methods

Laboratory testing consisted of (1) environmentally treating the SCSRs, and (2) measuring the effects of the treatments on operational lifetime. The treatments considered were temperature extremes (71°C for 48 hours,* 100°C for 4 hours, and -45°C for 16 hours) and shock and vibration. Both human-subject tests on a treadmill and machine tests using a breathing and metabolic simulator (BMS) were used to measure the effects of the environmental treatments on SCSR performance. Human-subject testing provided relevant human

factors information, while the BMS tests provided a more reproducible method for quantifying the duration of respiratory protection. Duration of respiratory protection is necessarily a function of the workloads performed during testing. The BMS, unlike a human subject, can be programmed to precisely reproduce a given demand (work load) from test to test.

An apparatus could fail in two ways: Measured parameters could exceed predefined limits, or the apparatus could cease to support life completely. In other words, even though an apparatus may be very hard to breathe through, for example, and may exceed the predefined limits, it could still be used in a life-and-death situation to escape from an irrespirable atmosphere. The difference between these two definitions was recognized and noted in some cases in this study.

Treadmill Testing

The human subject test used was the treadmill equivalent of NIOSH man-test 4 for 60 minutes (Table 1). The treadmill

* MIL-STD-810 C, 10 March 1975, Environmental Test Methods, Method 501.1, Procedure I.

Table 1. NIOSH man-test 4 and treadmill equivalent.

Time (min) ^a	NIOSH man-test 4 ^b	Treadmill equivalent
2	Sampling and reading	Stand
2	Walk at 3 mph	Walk at 3 mph
1	Climb vertical treadmill (1 ft/sec)	Walk at 4.5 mph at 15% grade
2	Walk at 3 mph	Walk at 3 mph
5	Pull 45-lb weight to 5 ft (60 times in 5 min)	Walk at 4.2 mph
3	Walk at 3 mph	Walk at 3 mph
8	Carry 50-lb weight over overcast (4 times in 8 min)	Walk at 2.7 mph
2	Sampling and reading	Stand
4	Walk at 3 mph	Walk at 3 mph
1	Run at 6 mph	Run at 6 mph
9	Carry 50-lb weight over overcast (6 times in 9 min)	Walk at 3.6 mph
3	Pull 45-lb weight to 5 ft (36 times in 3 min)	Walk at 4.2 mph
2	Sampling and reading	Stand
6	Walk at 3 mph	Walk at 3 mph
5	Pull 45-lb weight to 5 ft (60 times in 5 min)	Walk at 4.2 mph
3	Carry 45-lb weight and walk at 3 mph	Walk at 4.2 mph
2	Sampling and reading	Stand

^aOverall test takes 1 hour.

^b30 CFR 11h.

simulation of the test was based on the published studies of Kamon et al. (1975). Treadmill testing permitted continuous monitoring of CO_2 and O_2 measured in the breathing bag and temperature and pressure measured in the mouth bit. At the end of 60 minutes, a constant speed chosen by each subject was maintained until apparatus failure. Three human subjects were used for the treadmill testing. Characteristics of untreated, new SCSRs were measured during human subject and machine tests in order to establish the normal range of performance. These tests were used as control for comparisons with the treated SCSRs. Since each subject would put a different demand on the apparatus, owing to differing weights and end-run speeds, these factors were normalized by comparing the duration of each subject's treated units only with his or her own control unit. Normalization consisted of dividing each duration for a treated unit by the duration of the control unit. This was done for each test subject so that each control apparatus would have a normalized duration value of 1.00 with the treated units having normalized duration values varying around 1.00. Weights of the subjects and their end-run speeds are given in Table 2. Duration was defined by the termination time. Factors determining termination were inhaled gas concentrations of CO_2 greater than 1.5% or of O_2 less than 21%, inadequate gas volume (bag bottoming on inhalation), any subjective intolerable discomfort, such as breathing resistance or high temperature of inhaled gas or of apparatus surface, or an excessively high heart rate (greater than 90% of maximum). If a treated unit reached the duration of a control test, the test was usually stopped for the benefit of the test subject.

More than one test for each treatment and control per person were not run for several

reasons. Additional testing on the BMS of the treated units was planned and, taken with the treadmill testing, was felt to be sufficient. The treadmill testing results cannot be considered definitive if taken alone, however. More control tests per person were not run since previous experience with laboratory testing of the SCSRs showed our control tests to be typical. Also, the physiological demand for a human subject varies with changes in running style, weight, fitness, and diet. This would preclude any reliance on human subject testing for providing reproducible physiological demand. This was the purpose of the BMS testing.

Breathing Metabolic Simulator (BMS) Testing

A prototype breathing metabolic simulator built by Reimers Consultants,* Falls Church, Virginia, was used in the machine testing part of the study (Figure 4). The metabolic state used in the machine testing represented the average work rate that would be exhibited by a 50th percentile miner (87 kg) performing man-test 4 for 60 minutes (Kamon et al., 1975). The physiological parameters at standard temperature and pressure, dry, follow:

V_{O_2} —Oxygen consumption—1.35 liters per minute.

V_{CO_2} —Carbon dioxide production—1.30 liters per minute.

V_E —Ventilation—31.89 liters per minute.

V_T —Tidal volume—1.21 liters per breath.

RF—Respiratory frequency—26.5 breaths per minute.

Termination factors were inhaled gas concentrations with more than 1.5% CO_2 , or less than 21% O_2 , or inadequate gas volume. For a treatment to be considered to have had no impact on an apparatus, the chlorate candle must function and there must be no significant degradation in the duration

Table 2. Human subject weights and end-run speeds.

Subject	Weight (kg)	Constant end-run speed (mph)
A	49	3
B	68	6
C	73	6

* Reference to specific equipment or manufacturers does not imply endorsement by the Bureau of Mines.

compared with the control tests. A discussion of the various environmental treatments and methods follows.

Shock and Vibration Treatment

There is no specific NIOSH or MSHA requirement in the Code of Federal Regulations for shock or vibration testing of breathing apparatus. At present, however, NIOSH requires that self-rescuers survive 40 hours of shock and vibration on a Rotap sieve shaker. The two chemical SCSRs tested by the Bureau had successfully passed this test during NIOSH-MSHA approval testing.

The Rotap machine subjects the SCSRs to vibration from rotary motion and an impact from a hammer blow (2.5 impacts per second). The SCSR is rigidly mounted to avoid excessive accelerations and monitored to maintain accelerations within 15 g, peak to peak, for the entire test period. The test's origin is from experience with FSRs and

simulates the extent of damage suffered in worst case tests of harsh mining environments, including carrying and mounting on machines for 1 year. The Rotap test itself, though, does not simulate vibration spectra and types likely to be seen on mining machinery. To resolve this problem, we devised a composite test based on the reported vibration levels experienced on portable equipment, on underground mining machines (longwall, continuous) measured on the frame, and on underground and surface haulage vehicles (Dayton T. Brown, Inc., 1980). A shaker table of the types used in military standard (MIL-STD) vibration tests was used in the vibration treatment with motion along the vertical (Z) axis only (Figure 4). The test conditions follow:

Frequency (Hz)	Acceleration g ($\pm$ peak)
5-92	2.5
92-500	3.5
500-2000	1.5



Figure 4. Vibration treatment equipment.

There is no consensus on what constitutes an appropriate vibration treatment simulating the mining environment. MIL-STD-810B, which specifies a frequency range of 9 to 500 Hz at an acceleration of 4 g ($\pm$ peak), has been recommended (Bolt Beranek and Newman, Inc., 1979), but others recommend MIL-STD-810C (Berry and Mitchell, 1981), which specifies 1.5 g ($\pm$ peak) from 5.5 to 30 Hz, increasing to 4.2 g ($\pm$ peak) at 5 to 500 Hz, as being a more appropriate test.

One variation on vibration tests we made was to vibrate the self-contained self-rescuers loose rather than strapping them down as is usually done. We felt that, based on European experience (Berry and Mitchell, 1981), the self-rescuers would not be strapped tightly to machines, but would be simply placed in unpadded holders if not just thrown on the floor or other surface, unrestrained. We restricted their lateral motion (± 1 cm) with pegs, which were screwed into the 1.3-cm aluminum table. While at first inspection it would seem that the bouncing of the

apparatus at lower frequencies would make individual treatments vastly different in terms of vibration and shock insult, we believe that the cumulative effect of the undamped vibration treatment over an entire test is similar and reproducible.

The control accelerometer was screw-mounted as close to the SCSR on the table as possible without any danger of contact with it. With another accelerometer glue-mounted on top of the self-rescuer sensitive to motion in the Z-axis, we did resonance searches at an input of 1 g ($\pm$ peak). A maximum of three resonances, usually fewer or none, was noted. A resonance was defined as being consistent regardless of self-rescuer orientation and greater than 2 g ($\pm$ peak). For each resonance, the self-rescuer was vibrated at the appropriate g level for 30 minutes. The remaining test time was spent sweeping the frequency range with a sweep time of 20 minutes for a total test time of 3 hours. This procedure was performed for each axis for a total vibration test duration of 9 hours (Figure 5).

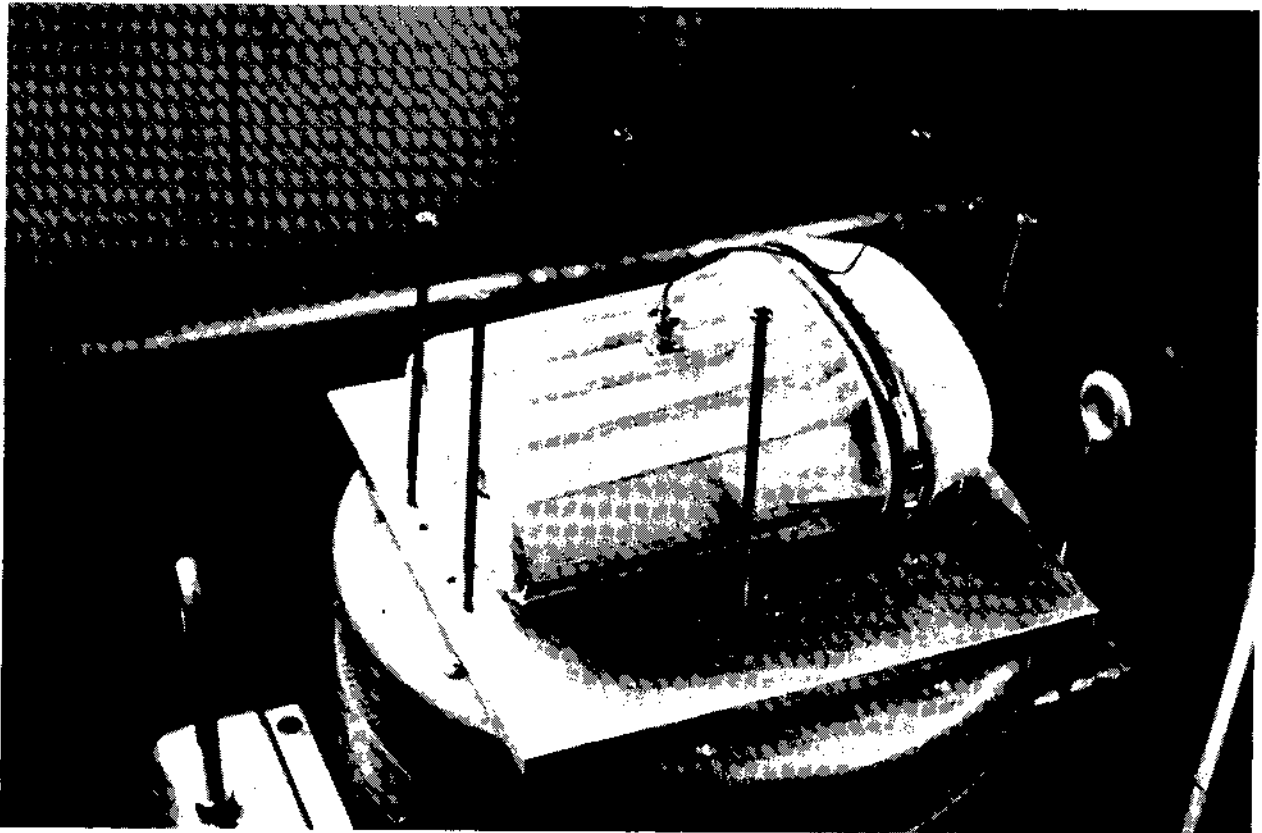


Figure 5. Draeger OXY-SR 60B, showing one of the three orientations used during vibration testing.

The shock portion of the treatment was a drop of 1 meter (belt height) onto a concrete floor. This was performed on each axis also. We consider this to be a worst case, realistic expectation for in-mine use.

High-Temperature Treatment

71°C for 48 hours. This treatment was conducted according to procedures described in MIL-STD-810C, Test Method 501.1, 10 March 1975, except that the oven was preheated.

100°C for 4 hours. This treatment was performed not out of any anticipation of similar in-mine conditions, but as a research probe to study failure modes for the apparatus under unrealistically high temperatures. If the apparatus were, however, not affected by this treatment, a higher degree of confidence would be gained in their performance ability. The manufacturer's recommended high storage temperatures were 70°C for Draeger and 38°C for MSA. A convection oven was used in both heat treatments.

Low-Temperature Treatment

Summary of Treatments

1. Precool units for 16 hours at approximately -45°C, then bring to equilibrium with room temperature. Note: -45°C was arbitrarily determined to be a worst case condition.
2. Precool units for 16 hours at approximately -45°C, then place in 0°C environment. Record time required to reach manufacturer's recommended lowest operating temperature (MRLOT).
3. Precool units for 16 hours at approximately 0°C, then transfer to a -45°C environment for exactly 1 hour. Transfer units to a 0°C freezer and record time required for units to reach MRLOT.

Procedure

Ten new SCSRs underwent cold treatment 1. These 10 units, 5 Draegers and 5 MSAs, were placed on wooden pallets in a precooled (-45°C) environmental chamber. The units were evenly spaced, approximately 15 cm apart, to allow for circulation of the -45°C air. Three units from each manufacturer were human-subject-tested, and two were machine-tested. Results from these tests indicate whether or not a one-time exposure to extreme cold degrades the level of respiratory protection provided by an untreated control unit.

Cold treatments 2 and 3 were carried out with two specially modified breathing apparatus. The modification allowed for continuous monitoring of temperatures within the KO₂ bed. This was accomplished by drilling three 0.6-cm holes in the KO₂ beds of one MSA and one Draeger SCSR. A thermistor was inserted into each hole and tightly sealed with putty and vinyl tape. Temperature recordings were then collected to determine (1) the average time required to reach the MRLOT and (2) the average time required to reach the Bureau's recommended minimum storage temperature (BRMST):

	MRLOT (°C)	BRMST (°C)
Draeger OXY-SR 60B	-5	0
MSA 60-minute SSR	-12	0

Rationale for Treatments

MRLOT is selected by the manufacturer before the respirator is submitted to NIOSH and MSHA for testing and certification. During testing and certification, the respirator is precooled for 4 hours at the MRLOT and then man-tested according to 30 CFR 11.85 in an environmental chamber at the MRLOT. This test insures that the unit is capable of life support at this temperature.

The Bureau's recommendations were based on three arguments:

1. A 0°C storage temperature will unify all SCSR low-temperature limits, thereby simplifying compliance with, and enforcement of, the regulations.

2. The freezing point of water is not only well understood but also easily determined without instruments.

3. A margin of safety is built in by storing units above 0°C. This is crucial if the mine operator follows the Bureau's recommendation, which allows an SCSR to be subjected to lower temperatures for up to 1-hour without removing the unit from service. Selection of a 1-hour excursion period was arbitrary.

A 1-hour excursion is defined as the time that an SCSR can be subjected to below-freezing temperatures without being removed from service (Foster-Miller Associates, Inc., 1981). Allowing such an excursion would ease compliance with the regulations by allowing units stored on mantrips, for example, to remain on mantrips during changes of shift or loading of materials where cold temperature extremes cannot be avoided. However, the mine operator must still comply with the

MRLOT in that the units do not comply with the law if they are operated at temperatures below the MRLOT. Given the fact that an SCSR should not be depended upon for life support below the MRLOT, cold treatment 2 was designed to provide the user with the average time at 0°C that mandates removal from service should a unit inadvertently be exposed to a long-term (overnight) deviation below the MRLOT.

Cold treatment 3 was designed as a worst case test. Results from this test should provide better insight into the Bureau's guidelines, which allow for a 1-hour excursion from an above-freezing storage temperature. Maintaining a readily accessible unit dictates that an SCSR should never be deliberately exposed to such harsh conditions.*

* Readily accessible is defined as the condition that gives reasonable assurance that an SCSR can be opened and activated quickly and upon activation will protect the user for 1 hour or longer.

Table 3. Treadmill test results.

Draeger			MSA		
Subject	Duration (min)	Failure mode	Subject	Duration (min)	Failure mode
Control					
A	118	Low bag volume	A	119	High CO ₂
B	66	High CO ₂	B	63	Do
C	64.5	Do	C	68.5	Do
71°C for 48 hours					
B	66	Exceeded control	A	120	Exceeded control
C	66	Do	B	63	Do
C	67	Do	C	69.5	Do
100°C for 4 hours					
A	71 ^a	Candle failure; high CO ₂ ; low O ₂	B	63	Exceeded control
B	64 ^a	Do	B	63	Do
C	64 ^b	Do	C	69.5	Do
-45°C for 16 hours					
A	118	Exceeded control	A	119	Exceeded control
B	66	Do	B	63	Do
C	64.5	Do	C	65	High CO ₂
Shock and vibration					
A	120	Exceeded control	A	120	Exceeded control
B	64.5	High CO ₂	B	62	High CO ₂
C	64.5	Exceeded control	C	63	Do

^a Technical failure at start.

^b Life support failure.

Results and Discussion

Treadmill Tests

The results of the treadmill tests (Figure 6) are presented in Table 3. Included are the test subject codes, the duration of the tests, and failure modes for each test. Because control test durations varied considerably owing to the different physiological demands placed on the SCSRs, control durations were normalized to unity for the sake of analysis and comparison. Also, owing to scheduling problems, cases arose where one test subject ran a treated unit in place of another subject. Again, normalization takes this into account. The normalized test times for both treadmill and simulator tests are given in Table 4. Failure modes were high CO₂ and low bag volume.

The most severe treatment for the Draeger unit was heating to 100°C for 4 hours.



Figure 6. Treadmill testing.

Inspection of the apparatus showed bulging of the plastic case (Figure 7). An average volumetric increase of approximately 4% was measured. Other noted changes were cracked and warped lenses on goggles in some cases (Figure 8) and warping of the three inhalation valves at the breathing bag-breathing tube interface (Figure 9). During treadmill testing, it was apparent that the chlorate candles were not working. Manual startings of the apparatus were necessary in all cases. The three inhalation valves, which were warped, permitted exhaled gas to flow into the breathing bag where we measured gas concentration continuously. All the Draeger tests for this treatment were considered technical failures owing to candle failure, sporadic high CO₂, and initially low oxygen. Two test subjects were able to start their units manually and finish man-test 4, while a third was unable to continue due to lightheadedness. The third subject also

Table 4. Normalized test times.

Treatment	Draeger	MSA
Treadmill tests		
71°C for 48 hours	1.00	1.01
	1.02	1.00
	1.04	1.01
100°C for 4 hours	^a	1.00
	^a	1.00
	^b	1.01
– 45°C for 16 hours	1.00	1.00
	1.00	1.00
	1.00	0.95
Shock and vibration	1.02	1.01
	0.98	0.98
	1.00	0.92
Simulator tests		
71°C for 48 hours	1.06	0.99
	0.89	1.14
100°C for 4 hours	^b	0.94
	^b	0.82
– 45°C for 16 hours	0.98	0.88
	1.04	1.07
Shock and vibration	0.95	1.12
	1.08	1.06
	0.98	—

^a Technical failure at start.

^b Life support failure.

experienced O_2 concentrations as low as 15.1% before the KO_2 bed started. While the tests were technically failures, they would have successfully protected a person in an irrespirable atmosphere in two cases and with some physiological side effects in the third case. Cold treatment, shock and vibration, and heating at $71^\circ C$ did not affect the Draegers to any significant degree.

The most severe treatment for the MSA unit was the shock and vibration. A coughing problem was noted in both control and treated apparatus and became more severe for the vibrated units. This led to taking outside breaths and exhaling through the unit to clear it of what we believe to have been KO_2 dust. Coughing occurred upon initial donning in all cases and any time the apparatus was jostled during the first 5 minutes. Suspecting KO_2 dust as the cause, we disconnected the bag-hose assembly from the KO_2 canister of a new MSA SCSR. Inhaling from the bags and hose did not cause coughing, whereas inhaling from the KO_2 canister directly did cause coughing. A more effective filter on the KO_2 bed would easily

solve this problem.

Coughing was experienced in some tests of the MSA units previously at NIOSH and in the MSA field evaluation, but not to the degree that we experienced it. We postulated that those test subjects whose lungs have not been subjected to a dusty coal-mine environment are more likely to experience coughing since their lungs would have more sensitivity to irritating particulates. We conclude that while the coughing necessitated outside breaths in some cases, the problem was not serious enough to consider the tests in which it occurred failures; in any case, MSA plans to remedy this problem in production models of the unit.

The shock portion of the treatment apparently caused the canister assembly portion of several of the MSA apparatus to disconnect from the frame onto which they are secured with rubber shock mounts. It was necessary to tie the canister assembly to the frame with wire in some cases. The heat and cold treatments did not affect the MSAs to any significant degree.

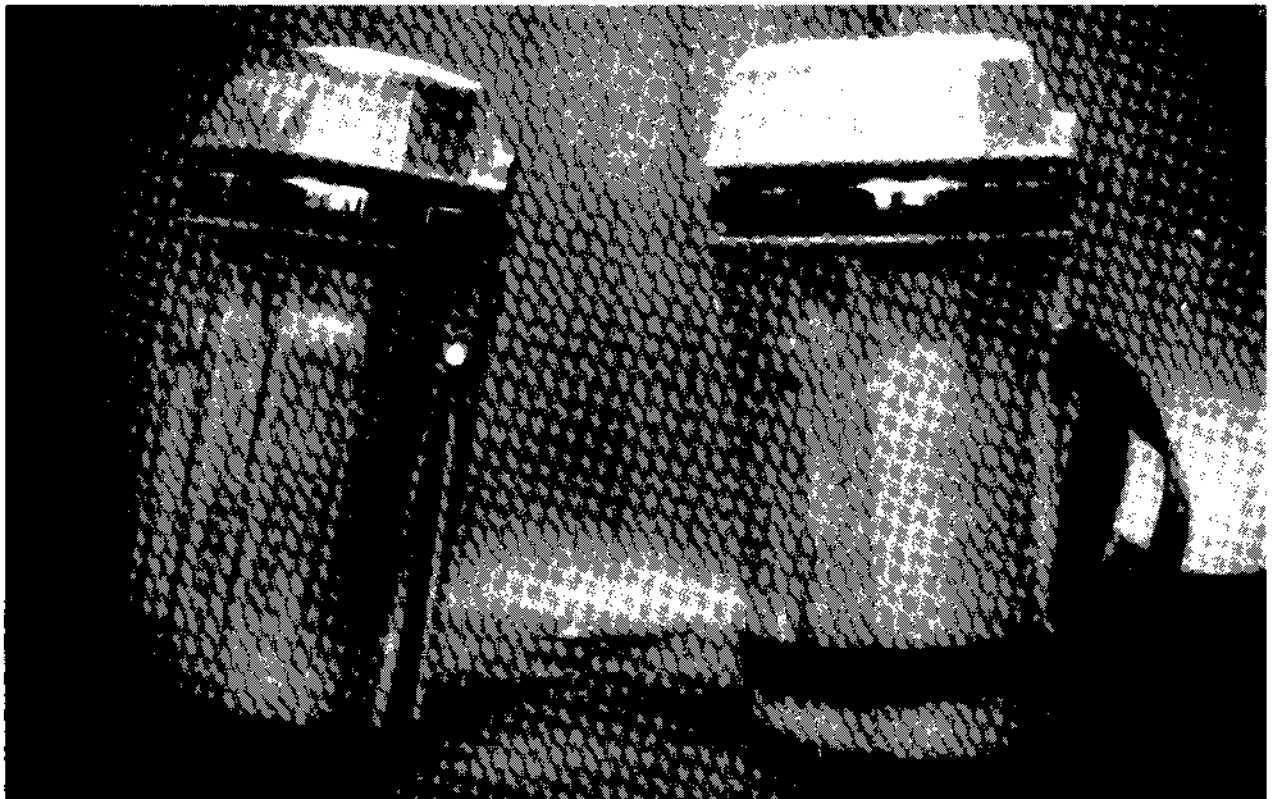


Figure 7. Draeger unit after $100^\circ C$, 4 hours, showing bulging of the plastic case.



Figure 8. Draeger goggles after 100°C, 4 hours.



Figure 9. Draeger inhalation valves after 100°C, 4 hours, showing severe warping.

BMS Tests

The results of the simulator tests are presented in Table 5. Durations and failure modes are given. We discarded one MSA vibrated unit that accidentally was vibrated more than the others. Temperature and breathing resistance limits as defined by NIOSH (maximum inhaled temperature—46°C; maximum peak-to-peak resistance at a 120-liter-per-minute flow rate—100 mm H₂O) were exceeded in some cases, but were not used as termination factors since NIOSH standards apply specifically to NIOSH testing, which is different from the simulator test. Failure modes included low bag volume, high CO₂, and low O₂.

As with the treadmill testing, the two Draeger units heated to 100°C suffered candle failure and had to be manually started. They

were both technical failures and life support failures owing to candle failure, low oxygen (12%), and high CO₂ (5.8%) which occurred at the start of the test. The other treatments did not affect the Draegers to any significant degree. None of the treatments affected the MSAs to any significant degree.

Figures 10 and 11 show plotted results of the treadmill and BMS tests for the Draeger and MSA SCSRs, respectively, in normalized form with treadmill control tests having a value of 1.00. As can be seen, none of the treatments, except the 100°C treatment on the Draegers, had much effect on duration of the units. For comparison, the control test durations of the simulator tests were averaged and standard deviations computed, normalized with respect to the average, and plotted. This shows that the variation of the treated units compared with that of the untreated units is similar.

Table 5. Simulator test results.

Draeger		MSA	
Duration (min)	Failure mode	Duration (min)	Failure mode
Control			
52	Low bag volume	82.5	High CO ₂
59	Do	75	Do
76	Low O ₂	61	Low bag volume
61.5	Low bag volume	76	High CO ₂
58	Do	53	Do
71°C for 48 hours			
65	High CO ₂	68.5	High CO ₂
54.5	Low bag volume	79	Do
100°C for 4 hours			
^a	Candle failure;	65	High CO ₂
	high CO ₂ ; low O ₂	57	Do
^a	Do		
– 45°C for 16 hours			
60	Low bag volume	61	High CO ₂
64	Do	74.5	Do
Shock and vibration			
58	Low bag volume	78	Low bag volume
66	Do	74	High CO ₂
60	Do		

^a Life support failure.

Low-Temperature Tests

Cold treatment 1: See results and discussions, treadmill tests and BMS tests.

Cold treatment 2: The Draeger required an average of 201 ± 23 minutes for the chemical bed to reach the MRLOT of -5°C . The MSA bed required an average of 177 ± 18 minutes to reach the MRLOT of -12°C . The Draeger unit required approximately 6 hours and the MSA unit not less than 7 hours to equilibrate with the 0°C environment.

Cold treatment 3: The Draeger unit required 154 ± 8 minutes while the MSA unit required 62 ± 3 minutes to reach MRLOT. A time period of 4 hours and 45 minutes was required for both SCSRs to reach the 0°C temperature. Two separate trials of cold treatment 3 were averaged to generate these results.

Conclusions

The results of this study show that the Draeger OXY-SR 60B and the MSA 60-minute

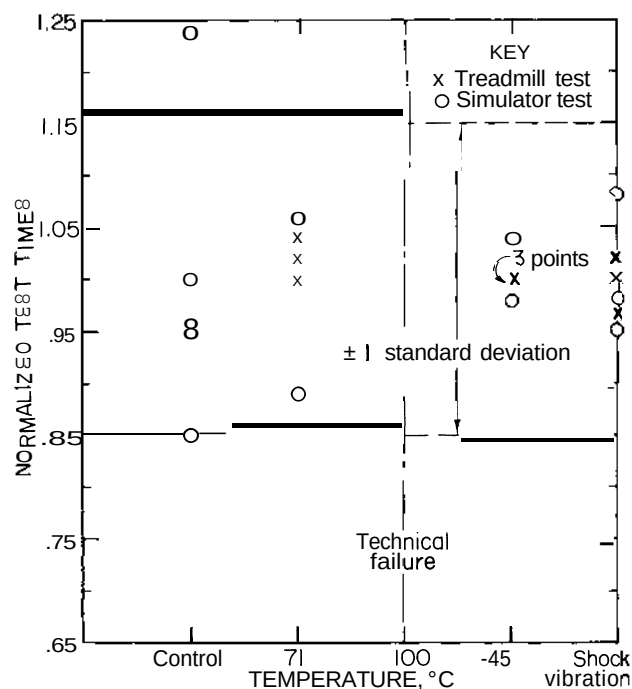


Figure 10. Normalized treadmill and BMS test data for Draeger.

SSR chemical oxygen self-rescuers approved by NIOSH and MSHA will successfully withstand the mining environment in the areas of temperature extremes and physical abuse likely to be encountered when SCSRs are either mounted on mining machines, carried, or transported.

The Draeger OXY-SR 60B experienced candle failure when heated to 100°C for 4 hours. It is recommended that the unit be kept below its approved maximum storage temperature (70°C). The MDSA 60-minute self-rescuer evidenced problems with coughing upon initial donning with most units, treated and untreated. This problem was magnified when the unit was vibrated and shocked. A simple modification of the exit filter in the KO_2 canister can be made to increase its effectiveness, and MSA plans to make this modification in production models.

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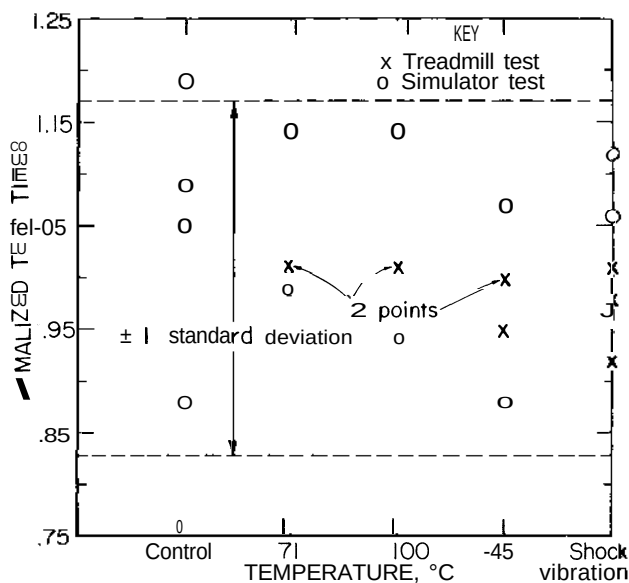


Figure 11. Normalized treadmill and BMS test data for MSA.

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