SECOND-GENERATION SELF-CONTAINED SELF-RESCUERS

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ABSTRACT

It appears to be technologically feasible to develop a second-generation SCSR that is approximately twice the size and weight of an FSR and that has a rated duration of 1 h. This paper summarizes proposed performance criteria, test methods, and approval and certification procedures for second-generation SCSR's. If designed and developed to meet the proposed standards, the resulting SCSR would be safe and reliable, and could be worn by a miner as personal equipment.

INTRODUCTION

Federal mining regulations (30 CFR 75.1714) require that every person who goes into an underground coal mine in the United States must be supplied with a self-contained self-rescuer (SCSR). An SCSR is an emergency breathing apparatus designed for use during mine escape. It must be capable of providing a breathable atmosphere, regardless of the ambient environment, and it must have a rated duration of 1 h. Only SCSR's approved by the Mine Safety and Health Administration (MSHA) and the National Institute for Occupational Safety and Health (NIOSH) can meet the provisions of the regulations.

Four models of MSHA- and NIOSH-approved, 1-h-duration SCSR's are commercially available: CSE AU-9A1, Draeger OXY-SR 60B, MSA 60-min SCSR, and Ocenco EBA 6.5. In order to meet the 1-h-duration requirement, all of the SCSR's are closed-circuit breathing apparatus. Both the Draeger OXY-SR 60B and the MSA 60-min SCSR use potassium superoxide (KO_2), a solid chemical, to generate O_2 and remove CO_2. The CSE AU-9A1 and the Ocenco EBA 6.5 store O_2 as a compressed gas and use lithium hydroxide (LiOH) to absorb CO_2. All of the 1-h-duration SCSR's are much larger and heavier than the conventional filter self-rescuer (FSR), which a miner wears on his belt as personal protective equipment. Unlike SCSR's, FSR's protect only against low levels of CO.

Because of the large size and weight of the current 1-h SCSR's, miners and mine operators have elected to either store or carry and store SCSR's in daily operational use rather than wear SCSR's as personal protective equipment.

It appears to be technologically feasible to develop a second-generation SCSR that is approximately twice the size and weight as an FSR, and that has a rated duration of 1 h, if testing and certification criteria are changed. Such an apparatus has been designated as a person-wearable self-contained self-rescuer (PWSCSR). A PWSCSR meeting these requirements could be worn on a miner's belt and replace the FSR. The mining industry, mine workers, breathing apparatus manufacturers, and MSHA are interested in an emergency breathing apparatus of this kind.

However, much work remains to be accomplished before prototype technology can be expected to function in a reliable manner. Additional research and development must be done to guarantee that the devices will provide safe and appropriate levels of life support capability and will be sufficiently rugged and mineworthy to serve as a replacement for FSR's. Practical deployment options, as well as miner training in the use of PWSCSR's must also be investigated.

The purpose of this paper is to summarize proposed criteria and test procedures for PWSCSR's that would provide safe performance, be rugged for underground use, and be within desirable

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physical limitations. The proposed testing and certification criteria for PWSCSR's are presented in the appendix.

The information presented in this paper is based on the technical recommendations of the Person-Wearable SCSR Task Force, which was an interagency task force composed of representatives from MSHA, the Bureau, and NIOSH. The task force used a variety of sources in formulating its recommendations, including current research findings, conversations with respirator manufacturers and other technical specialists, and discussions with representatives of miners and mine operators.

DEFINITION OF ESCAPE-ONLY DEVICE

There are emergencies in which the need for an escape breathing apparatus is immediate. In these situations, an individual who has an apparatus on his or her person is more likely to survive than an individual who has an apparatus located a distance away. Whether an individual wears an escape breathing apparatus or not depends to a large degree upon the physical requirements of the job and the size of the escape apparatus.

An escape-only device is designed to supply, in an emergency, an atmosphere that will permit the user to escape to a safe environment. The ideal escape-only device is one that is worn by the individual at the job, is rugged so that it will survive its environemnt and perform its function, and is safe for its intended use.

PWSCSR's are escape-only devices intended for use in underground coal mine emergencies.

NEW PERFORMANCE CRITERIA

The proposed performance criteria focus mainly on defining safe, physiologically defensible stressor levels for PWSCSR's. Four physiologically important variables are considered: carbon dioxide (CO_2) concentration, oxygen (O_2) concentration, breathing resistance, and inhaled gas temperature.

CO_2 Level

The present requirement for a 1-h escape apparatus is no more than 1.5% CO_2 in inspired air, during the course of person-testing when sampling breathing gases. Breathing gases are sampled during rest intervals, so gas concentrations are monitored intermittently.

The proposed requirement for CO_2 stressor levels is to raise the 1.5% CO_2 maximum inhaled concentration to 3.0% for a 1-h escape apparatus, while monitoring continuously. The new stressor level is to be determined by time-averaging the inhaled CO_2 levels over the entire duration of the apparatus. When testing presently approved 1-h-duration SCSR's, it was observed that some apparatus exhibited inhaled CO_2 levels exceeding 4% during certain exercise levels and near the end of life. This testing utilized continuous monitoring, unlike that presently conducted at NIOSH. Therefore, in addition to a 3% inhaled CO_2 average level for a 1-h apparatus, a termination peak concentration of 8% CO_2 for a single breath and a 1-min average concentration of 6% CO_2 are added for safety.

Oxygen Level

The oxygen concentration has been increased from 19.5% to 20.9% after the first 3 min. In addition, a 17% minimum O_2 concentration is required for the first 3 min. The reason for these two requirements is to eliminate the need for a self-starter. All presently approved 1-h apparatus exceed 21% O_2.

Breathing Resistance

The present standard measures breathing resistance utilizing a breathing machine as specified in 30 CFR 11.85-3. The maximum resistance for exhalation is 51 mm H_2O or less, and the maximum for inhalation is 100 mm H_2O minus the exhalation resistance.

The new proposal allows for a maximum of 80 mm H_2O for both inhalation and exhalation resistance when measured during the time-duration test. During the high-demand test, the allowable resistance levels are 300 mm H_2O for inhalation and 200 mm H_2O for exhalation.

Inhaled Gas Temperature

The present inhaled gas temperature requirement divides the inspired air into two categories, from 0% to 50% RH (relative humidity), and the other from 50 to 100% RH.

The new criteria allow for alternate wet bulb temperature measurements that automatically take into account temperature and relative humidity. Owing to the complexity of measuring wet bulb temperature, it may be more practical to monitor both relative humidity and dry bulb temperature of inspired air and use conversion charts. Both options are provided for in the criteria.

Time-Duration Test

The Escape Duration Analysis Task Force has determined that 80 L of usable O_2 will allow 95% of the miners to escape from working sections to fresh air. This quantity of O_2 will last 60 min when consumed at a rate of approximately 1.35 L/min. The 50th percentile miner, when performing the 1-h Man Test 4 (30 CFR 11), will use approximately 80 L O_2.

The proposed time-duration test uses a human subject who works at a fixed rate of 1.35 L/min O_2. This is a simple and repeatable test. According to the proposed procedure, a human subject would be placed on a treadmill, and the treadmill speed would be adjusted to require a metabolic demand of 1.35 L/min O_2. After the treadmill speed for a human subject had been determined, the human subject would remount the treadmill with the apparatus to be tested. This approach simplifies the time-duration test and provides repeatability. The apparatus being tested would have to supply the wearer with a breathable atmosphere for 1 h.

High-Demand Test

Man tests contained in 30 CFR 11 provide information on the function of breathing apparatus at various work rates. The new time duration test is performed at a fixed work rate. To determine how well a breathing apparatus functions at various work loads, a high-demand test has been proposed.

During the high-demand test, a human subject walks or runs in place on a treadmill, varying the rate of O_2 consumption, according to a predetermined schedule of exercises. The high-demand test ensures that the apparatus will function across a set of work rates. Stressor levels are monitored continuously to ensure a breathable atmosphere at the different work rates.

The rated duration of the units is established by the time-duration test and need not be achieved in the high-demand test. Time is monitored to ensure that the units can be worn for a minimum time period at the elevated work rates of the high-demand test. The minimum time for a 1-h unit during the high-demand test is 40 min. The time-duration and high-demand tests provide a simple means to objectively determine performance characteristics of the units.

Ruggedness Tests

Ruggedness tests are intended to determine mineworthiness of PWSCSR's that would be worn as personal equipment on a daily basis.

There are four ruggedness tests to simulate a range of environmental conditions likely to be found in underground coal mines. The first test exposes a PWSCSR to high and low temperatures. The second and third tests expose an apparatus to shock and vibration. The fourth test is a submersion test designed to evaluate the integrity of the protective case.

All four tests are applied to an apparatus. Afterwards, the respirator is inspected for safe operation, and then performance-tested.

Human Factors Test

The human factors test addresses ergonomic considerations for comfort and wearability of such apparatus. The human factors test is designed to evaluate the unit while human subjects are performing simple tasks that may be encountered during an escape. As in the time-duration and high-demand tests, physiological variables are monitored continuously during the human factors test.

The time required to perform these tests is not related to the rated duration of the units. A 1-h unit is required to be worn and perform the functions listed for 33 min. This time requirement is to assure that the performance of these activities does not reduce the wearing of time of the units.

ADMINISTRATIVE ISSUES

Administrative changes to current approval and certification procedures are recommended.

Third-Party Testing

The most significant administrative change is to allow third-party testing of respirators. A manufacturer can test his own apparatus, or use an independent laboratory. The Government reserves the right to witness all tests at the location specified by the manufacturer. The Government will review the test results, and, if necessary, require retesting.

Special Use Escape-Only Devices

The technical specifications developed by the Task Force apply to PWSCSR's, which are escape-only devices intended for use in underground coal mine emergencies. The proposed approval and certification criteria encourage other industries or organizations to recommend alternate performance criteria, test methods, and procedures for specialized escape-only devices.

Training

Hands-on training is critical for the successful deployment of PWSCSR's. Manufacturers are required to have realistic training units available for purchase.

CONCLUSIONS

The PWSCSR Task Force has developed proposed standards for second-generation SCSR's. These recommendations include new performance criteria, test methods, and procedures for approval and certification. If designed and developed to meet the proposed standards, the resulting PWSCSR would be safe and reliable and could be worn by a miner as personal equipment.

APPENDIX.--PROPOSED TESTING AND CERTIFICATION CRITERIA FOR PWSCSR'S

A. TEST PROCEDURES

MSHA and the Institute reserve their right to witness all tests at the location specified by the equipment manufacturer. The equipment manufacturer will reimburse MSHA and the Institute for travel, subsistence and incidental expenses of its representatives in accordance with Standardized Government Travel Regulations. MSHA and the Institute will be notified at least two months prior to testing in order to determine if instrumentation is adequate to perform tests. The notification will include one unit that represents the escape respirator to be tested. The equipment manufacturer will be responsible for all clearances necessary at the test facility for MSHA and Institute personnel. The equipment manufacturer is responsible for supply test reports, test procedures, instrumentation specifications, calibration traceability, instruction manual and other documentation as requested by MSHA or the Institute. MSHA or the Institute may require instrumentation capability to be verified prior to or during testing, by calibration standards, calibration gases, or by the testing of a respirator whose characteristics are known.

B. UNITS REQUIRED FOR TEST

MSHA and the Institue may require submittal of up to 12 units for testing. The applicant will not be charged for testing.

Units must meet the criteria and the tests outlined in "E" through "H-2". If the units are prototypes, six production units will be tested when available. The production units must meet all approval and certification criteria.

C. CRITERIA

Units must meet all the criteria specified in "C-1 through -4."

C-1. O_2 Levels

Inhaled oxygen will not fall below 17% (dry atmosphere) during the first 3 min of operation. After 3 min, the minimum O_2 level will not be less than 20.9% O_2 (dry atmosphere). During respirator testing, the O_2 will be monitored continuously at the mouthpiece by a sensing unit with at least a 90% response within 100 ms and an accuracy of $\pm 0.1\%$ O_2.

C-2. CO_2 Levels

CO_2 will be monitored continuously at the mouthpiece and the average inhaled CO_2 concentration will not exceed 3% over the time rating of the unit. This value will be an arithmetical average of CO_2 concentration over the inhalation cycle. The arithmetical average of the CO_2 level for any 1-min-time period will not exceed 6.0% for the inhalation cycle; and for a single breath, the average will not exceed 8%.

C-3. Temperature Levels

Inhalation temperatures will not exceed 45° C wet bulb temperature. If wet bulb temperature cannot be measured at the test location by instrumentation having a 90% response within 500 ms with an accuracy of $\pm 1°$ C, the temperature will meet the requirements in 30 CFR, Section 11.85-18(c).

C-4. Pressure Limitations

The exhalation pressure will not exceed 80 mm H_2O, and the inhalation pressure will not exceed 80 mm H_2O measured at the mouthpiece with a breathing machine as described in 30 CFR 11.85-3. Pressure will be continuously monitored during the time duration and high-demand tests and will not exceed 300 mm H_2O for inhalation and 200 mm H_2O for exhalation when measured by a sensing unit with at least a

90% response within 5 ms and an accuracy of ±1 mm.

D. GENERAL CRITERIA

Devices are intended for escape only and will be made as small and lightweight as possible to improve the user-wearing capability.

D-1. Special-Use Escape Devices

Escape devices for use in specialized areas or industries will be designed for use during escape from those environments expected to be encountered. The following four examples of specialized areas/industries are in no way intended to limit the number of users or types of testing involved. Users with special requirements should meet with the Institute and MSHA to develop performance criteria, test methods and procedures to meet their needs, which will then be distributed to all "interested parties." Limitations will be identified on the manufacturers' labels.

1. Fire Service - Fire service escape devices will have fire-resistant exposed parts, and be self-contained devices.
2. Chemical Industry - Chemical industry escape devices may have exposed parts that must be resistant to chemical vapors expected to be encountered in the specific environment.
3. Mining Industry - Mine escape devices will be self-contained, and must be worn by miners as part of their personal protective equipment.
4. U.S. Naval Shipyards - Confined space escape devices will be self-contained, have fire resistant parts and hood, provide means for carrying by shipyard personnel, and be streamlined, small, and lightweight to allow rapid escape through 20-in accesses.

D-2. Time Duration Test

Escape-only devices will have the time duration of the apparatus as specified by the manufacturer displayed on the labels, and will meet or exceed all criteria listed for the specified duration as evaluated in "F. Time Duration Test."

E. TEST METHOD

The 12 units will be randomly divided into four groups of three units each. These groups will be tested as specified in "F" through "H-2."

E-1. Human Subject Testing Procedure

The equipment manufacturer is responsible for all testing and test equipment, as well as obtaining the human subjects, appropriate medical releases, pretesting physicals, and all other necessary physical and documentary evidence for conducting a safe human subject testing procedure on these apparatus. Appropriate medical attendance at the human subject testing is the responsibility of the equipment manufacturer.

E-2. Human Subject Profile

a. Test subject Type A will be an individual of at least 100 kg body weight.
b. Test subject Type B will be an individual between 65 and 100 kg body weight.
c. Test subject Type C will be an individual with a maximum body weight of 65 kg.

F. TIME DURATION TEST

Three units will be evaluated on human subjects as follows:

a. Human subjects (one of each subject type) will be mounted on a treadmill. The speed of the treadmill, for each human subject, will be adjusted to obtain the following minimum oxygen consumption rates, based on the apparatus time rating, according to the following table:

TABLE A-1. - Apparatus time rating

Time, min	O_2 consumption rate, L/min
10.....	2.1
15.....	2.0
30.....	1.7
45.....	1.5
60.....	1.35

For example, if a 60-min device is to be tested, each human subject type would mount the treadmill and the treadmill speed would be adjusted until the oxygen consumption rate is 1.35 L/min. The treadmill speed for each human subject type would then be documented.

b. A human subject, wearing the apparatus to be tested, will mount a treadmill with the speed preset to at least the value determined in "a" above for that subject. Treadmill speed must meet or exceed the value determined in "a" for rated duration of the apparatus.

c. All units will meet or exceed the criteria listed under "C" for the time duration specified.

G. RUGGEDNESS TESTS

Three units with protective cases will be tested as specified in "G-1 through 6," and in the sequence listed.

G-1. Temperature Test

Temperature tests will be conducted by exposure of all three units to a temperature of at least -30° C for 8 h. All three units will thereafter be stabilized at room temperature before exposure to a temperature of 71° C for 4 h. After exposure to a temperature of 71° C, all three units will then be stabilized at room temperature.

G-2. Vibration Test

The three units will be vibrated as per MIL-STD-810B.

G-3. Shock Tests

The three units will be dropped from a height of 1 m onto a concrete floor. Each unit will be dropped a minimum of six times, at least once on each axis.

G-4. Water Submersion Test

The three units will be stabilized at a room temperature of 22° C±2°, and then will be submerged in a water bath until they are completely covered with water, for a period of 1 min. The water bath must be at a temperature of 15° to 18° C. Upon completion of this test, all units must be intact without water penetration to the unit interior.

G-5. Inspection

The three units will be inspected to ensure they are in safe operating condition.

G-6. Time Duration Test for Environmentally Treated Units

All units will meet or exceed the criteria listed under "C" for the time duration specified.

H. OTHER TESTS

H-1. High-Demand Test

One human subject of each profile type (total of 3), wearing an apparatus, will mount a treadmill which will be run at the conditions specified in the High-Demand Test table.

a. Temperature will be monitored during this test and will meet the requirements in "C-3."

b. Oxygen, CO_2, and pressure will be continuously monitored and will meet the criteria in "C-1, C-2, and C-4" respectively.

c. All subjects must complete the demand test.

TABLE A-2. - High-demand test

Activity	Service time, min				
	10	15	30	45	60
Walk.....	2	2	2	2	2
Run, uphill.....	1	1	1	1	1
Walk.....	2	2	2	2	2
Run.....	3	3	3	3	3
Walk.....	2	2	2	2	2
Run.....	NAp	2	2	2	2
Walk.....	NAp	3	3	3	3
Run, uphill.....	NAp	1	1	1	1
Walk.....	NAp	NAp	3	11	11
Run.....	NAp	NAp	1	2	3
Walk.....	NAp	NAp	2	6	10

Walk - 0% grade, 3.0 mi/h;
Run - 0% grade, 5 mi/h;
Run uphill - 15% grade, 5 mi/h.

H-2. Human-Factors Test

One human subject of each profile type (a total of 3) will perform the tests as specified in the Human Factors Test table after donning a unit.

a. Carbon dioxide and oxygen will be continuously monitored and will meet the requirements in "C-1 and C-2" respectively.

b. Due to the short service times of the 10- and 15-min units, the sequence of activities for human factors testing will be divided into two equal groups. At least one test subject will perform the activities of each group. All three test subjects will perform all the activities listed for the 30-, 45-, and 60-min units.

TABLE 3. - Human factors test

Activity	Service time, min				
	10	15	30	45	60
Bending motion.....	2	3	3	3	3
Stand.....	2	3	1	3	3
Stretching.....	2	3	1	3	3
Stooped walking (127 cm, 2.5 mi/h)	2	3	3	3	3
Crawl (0% grade, 1.5 mi/h).....	2	3	3	3	3
Carry 20 kg (0% grade, 3 mi/h)....	2	3	2	3	3
Twisting.....	2	3	2	3	3
Lie on back side, front.....	2	3	3	3	3
Duck walk.....	2	3	3	3	3
Walk (0% grade, 3 mi/h).....	0	0	0	3	3
Run (0% grade, 5 mi/h).....	2	3	0	0	3

I. TRAINING MATERIAL

Manufacturers who obtain an approval are required to have available to users training units that closely duplicate the stressor levels that the approved unit exhibits, and training manuals.