A mining research report
JULY 1990

DEVELOPMENT OF A SECOND-GENERATION, PERSON-WEARABLE, SELF-CONTAINED SELF-RESCUER (PWSCSR)

Contract H0368013
CSE Corp.

BUREAU OF MINES
UNITED STATES
DEPARTMENT OF THE INTERIOR

50272-101

REPORT DOCUMENTATION PAGE	**1. REPORT NO.**	**2.**	**3.** PB92-109206

4. Title and Subtitle

Development of a second-generation, person-wearable, self contained self-rescuer (PWSCSR)

5. Report Date

6.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

CSE Corporation
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10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C) H0368013

(G)

12. Sponsoring Organization Name and Address

U.S. Bureau of Mines, Pittsburgh Research Center
P.O. Box 18070
Pittsburgh, PA 15236

13. Type of Report & Period Covered

Final Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Initially, the objective of this contract was to develop a PWSCSR that could meet proposed criteria (that were different from 30 CFR 11(Title 30 of the Code of Federal Regulation part II) and that would be less than twice the size and weight of a filter self rescuer. This objective was met. Consequently, the original contract was extended to develop a PWSCSR that would meet existing CFR-30 criteria within the same size and weight constraints. This resulted in the development of a PWSCSR (the SR-100) that received NIOSH/MSHA approval (TC-239).

This report presents a historical discussion of the design and development of the SR-100 as developed by CSE Corporation under Bureau of Mines contract number H0368013. The technical parameters and the test results of NIOSH/MSHA 30 CFR 11 certification are also presented.

17. Document Analysis a. Descriptors

Self-Rescuers
Rebreathers

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement	**19. Security Class (This Report)**	**21. No. of Pages**
	20. Security Class (This Page)	**22. Price**

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U.S. Government.

FOREWORD

This report was prepared by CSE CORPORATION, 600 Seco Road, Monroeville, Pennsylvania 15146, under USBM Contract number H0368013. The contract was initiated under the PWSCSR Program. It was administered under the technical direction of the Pittsburgh Research Center with J.G. Kovac acting as the Technical Project Officer. J. A. Gilchrist was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period 9/29/86 to 8/31/89. This report was submitted by the authors on May 1, 1989.

Special thanks should be given to the Bureau's Mining Systems and Human Engineering division and the Life Support Group for their help in test work and informative discussions pertaining to the PWSCSR. We also wish to thank the Mine Safety and Health Administration for its help and guidance as well as the MSHA volunteer test subjects who were on constant duty for testing. Noll Laboratories at Penn State University also had a vital role in this project as they helped CSE obtain numerous ergonometric data and did some of the presubmittal testing. Additionally, the authors thank S. B. Shearer of CSE CORPORATION, for his guidance and expertise with regard to ergonometric theory and practice. He was responsible for the development of a suitable simulation program that closely matches the results obtained from actual man testing.

CONTENTS

ILLUSTRATIONS

TABLES

DEVELOPMENT OF A SECOND-GENERATION, PERSON-WEARABLE, SELF-CONTAINED SELF-RESCUER (PWSCSR)

By E. A. Pelczarski,[1] R. E. Brayton,[2] and H. A. Hughes[3]

*** ABSTRACT

Initially, the objective of this contract was to develop a PWSCSR (SR-80) that could meet newly proposed criteria (that were not as difficult as 30 CFR 11) and that would be less than twice the volume and weight of a filter self-rescuer. The SR-80 met this objective. Consequently, the original contract was extended to develop a PWSCSR that would meet existing 30 CFR 11 criteria within the same volume and weight constraints. This resulted in the development of a PWSCSR (the SR-100) that received NIOSH/MSHA approval (TC-239).

This report presents a historical discussion of the design and development of the SR-100 as developed by CSE CORPORATION under Bureau of Mines contract number H0368013. The technical parameters and the test results of NIOSH/MSHA 30 CFR 11 certification are also presented.

*** INTRODUCTION

30 CFR 11 75.1714 requires that each miner who goes underground has available a self-rescue device(s) to protect such a person for one hour or longer. The self-rescue device "shall be worn or carried at all times by each person when underground". "Where the wearing or carrying of the self-rescue device is hazardous to the person, it shall be placed in a readily accessible location no greater than 25 feet from such person." The merit of this regulation was demonstrated in the Marianna mine fire on March 7, 1988. It was the first major use of self-contained self-rescue devices that resulted in a successful mine evacuation.

Because existing devices are rather large and bulky, it at times

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becomes difficult for the miners to carry them continuously during their normal work regime. On occasions, even the less than 25 foot distance requirement is insufficient to overcome the effect of self-rescuer close proximity on hazardous operating conditions. Consequently, variances are granted that permit storage at even greater distances provided that the District Manager gives his approval. This, to some degree, compromises miners safety.

The Assistant Secretary of Labor was not satisfied with the level of safety provided to the miners and held a series of meetings with labor and industry to resolve the problem. The two groups agreed that a need exists for a person-wearable, self-contained self-rescuer (PWSCSR), that would be no more than twice the weight and volume of current self-rescuers. It was also agreed that the use of a small, short-duration unit that the miner could use to reach stored (one-hour-duration devices) units would not be permitted. The reason for this was that the user may be in a toxic atmosphere while removing the small unit's mouthpiece and inserting the new mouthpiece from the one hour unit.

The Bureau of Mines[4] addressed this problem as part of an interagency task force established by the Assistant Secretary of Labor. Initially, the objective was to develop a PWSCSR that would be twice the volume and weight of currently used, filter self-rescuers (FSR). Test criteria for acceptance of the PWSCSR were somewhat different from those presently used in man testing under 30 CFR 11. Based upon task force recommendations, requests for proposals were made to private industry to develop such a device.

CSE Corporation, won the open bid contract and met the proposed objectives with a prototype device called the SR-80. The results appeared promising enough to extend the contract to develop a PWSCSR that would meet 30 CFR 11 regulations and still be within the volume and weight constraints put forth by the task force. After some considerable effort, a PWSCSR called the SR-100 was developed that received NIOSH/MSHA approval (TC-239). The design, technical parameters and the results of 30 CFR 11 man testing are presented in this report.

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[4] Kravitz, J. H. and Kovac, J. G., Person Wearable SCSR Task Force Final Report.

*** TECHNICAL DISCUSSION

A. THE SR-100 SYSTEM

a. DESIGN CONSIDERATIONS

CSE's and the BOM's objective was to design a person-wearable, self rescuer that would not only receive NIOSH/MSHA approval, but would also provide optimum user protection and comfort. Optimum protection would be established if the SR-100 received NIOSH/MSHA approval. Emphasis was then placed on comfort in the sense that the self-rescuer would be acceptable to users for day to day carrying or wearing of the unit. Hence, volume and weight become paramount considerations. Comfort also meant minimizing the physiological stressors that the user would experience during actual use. This means that inhaled gas temperature, carbon dioxide content, exhaled and inhaled pressures during use should be as low as possible. With these constraints, the SR-100 was designed as a lightweight package that minimized the physiological stressors that the user would experience during normal wearing as well as actual use.

To meet the weight and volume criteria (approximately twice the volume and weight of an FSR) CSE chose to develop a chemical oxygen based system. The reason for this was as follows. A compressed oxygen system using a steel bottle weighs approximately 16 grams per liter of oxygen generated plus carbon dioxide absorbed (gr/(g+a). Using an aluminum fiberglass wrapped bottle, reduces the weight to about 12 gr/(g+a). A chemical oxygen system, although it produces much more oxygen than is needed, is limited by the amount of CO_2 that can be absorbed and weighs about 6 grams/liter of CO_2 absorbed and about 2.4 gr/(g+a). Because of the low theoretical weight requirement, CSE chose a chemical oxygen system.

Typically, conventional potassium superoxide (KO_2) systems contain about twice the amount of chemical than is theoretically needed. This is true because of poor CO_2 absorption, overproduction of oxygen and bed coalescence or swelling. It is beyond the scope of this report to present a theoretical/experimental discussion of the phenomena involved. Suffice it to say that CO_2 absorption, oxygen generation and increased pressure drop (bed coalescence/swelling) are intimately related.

To overcome poor CO_2 absorption, CSE built a hybrid KO_2-LiOH system. The lithium hydroxide (LiOH) increased the carbon dioxide absorption capacity of the system. At the same time, the amount of KO_2 was reduced to more nearly match the theoretical amount of oxygen available to that required by the user. The lithium hydroxide also had the desirable effect of maintaining the bed relatively open which offset, to some degree, increasing pressure drop that is normally experienced as the KO_2 is consumed. This concept reduced the volume and weight of the self-rescuer.

To decrease inhaled gas temperatures, the SR-100 uses a compressed oxygen starter bottle rather than a chlorate candle to supply starter oxygen (about 8 to 9 liters) to the user. This eliminates the heat of reaction associated with chlorate candles, provides a heat sink due to the mass of the bottle and some cooling from the release of compressed gas. It was felt that the oxygen bottle was more certain to function than a chlorate candle and provided psychological assurance as the user could physically see the breathing bag fully inflate in a short time (about one half minute). Further cooling was achieved by incorporating a stainless steel heat exchanger within the breathing hose.

The amount of carbon dioxide that must be absorbed by the SR-100 was minimized by placing a volume-activated, relief valve on the top side of the canister next to the breathing hose. This has the advantage that the last portion of an expired breath (containing the highest percentage of CO_2) is exhausted from the system rather than relatively CO_2 free gas from the breathing bag. The net effect is that less scrubbing is required from the scrubbing agent.

Water is the main cause of oxygen overproduction by reaction with KO_2. To control the water that is introduced into the system, through water vapor in the user's breath, saliva and by chemical reaction, a number of techniques were used. Saliva and water vapor from the user's breath are controlled by a unique saliva trap located within the breathing hose. The trap collects any saliva by absorption with a commercial corn derivative product that absorbs up to about two thousand times it's own weight of water. It also has the unique feature that it comes to equilibrium with water vapor at a given temperature. Hence, it also partially removes some of the expired water vapor from the user's breath. Water that is produced by various reactions within the chemical bed is partially removed by calcium chloride that resides within the breathing bag. By controlling (partially or totally) the amount of water vapor that is introduced into the system, oxygen production is also controlled. The SR-100 does so and more nearly matches the theoretical oxygen content of the KO_2 to the metabolic needs of the user.

To minimize exhaled and inhaled pressure resistance due to the swelling/coalescence of the KO_2, lithium hydroxide and wire screens are used in the chemical bed. As mentioned earlier, lithium hydroxide, to a partial degree, maintains bed porosity. Corrugated wire screens on the other hand, allow room for bed expansion or coalescence to occur without the resulting large increase in bed pressure drop. These factors add to user comfort.

So that the user can feel acclimated to the PWSCSR in the shortest possible time, the SR-100 was designed to resemble previously used filter self-rescuers. The opening procedure is the same and donning complies with the BOM's 3+3 method in existence for currently used self-contained, self-rescue breathing apparatus. This will simplify training and accelerate user acceptance.

To minimize the time to don the SR-100 and to make sure the mouthpiece plug is removed before donning, the plug is attached to the canister. The plug is automatically removed from the breathing hose when the hose is stretched by the user to insert the mouthpiece into his mouth. Nose clips are attached to the breathing hose for quick access to the user.

The carrying case is a lightweight plastic that covers the canister and is an integral part of the working unit. Thus there is no need to remove the working unit from a case. Additionally, all external metal parts are made of stainless steel. This adds durability to the unit as has been proven by previously used FSR's.

Daily inspections are simple enough and require only that the user observe the humidity indicator to determine if the SR-100 is in usable condition. A blue indicator coloration means that the SR-100 is acceptable for use. A pink to white color means that the SR-100 should not be used.

Internal heat shielding is also built into the SR-100 that precludes the user from sensing the temperature of the canister on his chest (the normal position of the SR-100 during use). In addition the carrying case is designed in such a manner that the working unit is maintained at a distance from the user's body for extra heat protection.

The pull tab for opening the starter oxygen bottle is a large tab that is fluorescent orange in color (highly visible) and easily pulled--even with gloves. The tab is connected to the oxygen bottle by a stainless steel cable. Pulling the tab causes the release (within thirty seconds) of about eight to nine liters of oxygen into the breathing bag. This amount of oxygen permits the user to start his egress procedures immediately.

These design considerations were incorporated within the SR-100 to produce a person-wearable, self-rescue device that not only met NIOSH/MSHA approval criteria, but also adhered to the 3+3 donning and escape procedure taught to users at this time.

b. <u>THE SR-100</u>

Figure 1 presents a schematic diagram of the SR-100. The apparatus is a closed circuit pendulum rebreathing system in which the exhaled gas makes two passes through the absorption/oxygen generation canister before the gas returns to the user. Why use a pendulum system? The reasons are as follows:

1. A pendulum system minimizes the space required either in the canister or the case for the separation of exhaled and inhaled gas. This reduces the volume of the unit.
2. A pendulum system eliminates the need for moving parts such as inhalation and exhalation valves. This minimizes maintenance and reliability problems.
3. Scrubbing efficiency is increased in a two pass system and minimizes the weight of the scrubbing agent.
4. Construction costs are minimized.

As shown in Figure 1, the user exhales into the SR-100 causing the exhaled breath (down arrows) to pass into the oxygen generator/CO_2 absorber (canister). Here the carbon dioxide is scrubbed out of the gas and the water vapor contained within the exhaled breath reacts with the KO_2 to produce oxygen. The gas then leaves the canister and enters the breathing bag after the first pass. The gas in the breathing bag, that may contain water vapor generated by the CO_2 removal reaction, is partially dried by contacting powdered calcium chloride lying in the breathing bag. During inhalation, the gas leaves the breathing bag and makes a second pass through the canister which removes residual CO_2 not scrubbed during the first pass. Additional oxygen is also generated by the residual water vapor left in the inhaled gas. This two-pass, pendulum system cleans the inhaled gas so that very low concentrations of carbon dioxide are inhaled.

The relief valve is connected to the breathing bag by means of a stainless steel wire that passes through the canister. As the bag fills, the expansion of the bag causes the steel wire to pull down on the relief valve so that excess gas is vented. The relief valve opens when the breathing bag is full. This occurs near the end of the exhalation cycle. Because of the location of the relief valve, carbon dioxide rich (near end tidal CO_2 content) exhaled gas is vented. This action reduces the amount of scrubbing agent required and thus reduces the overall weight of the SR-100.

The saliva trap, located right below the mouthpiece, removes most of the saliva that may enter the breathing hose and some water vapor. This water removal, in either liquid or vapor form, controls oxygen production and minimizes waste. This in turn reduces the amount of KO_2 in the canister and more nearly matches the theoretical amount needed to produce the oxygen required by the user. As the KO_2/water reaction is exothermic, minimizing oxygen overproduction also tends to minimize heat generation and results in cooler inhaled gas.

To further cool the gas, the breathing hose contains a stainless steel mesh heat exchanger. The temperature of the inhaled gas is dropped when the gas contacts the heat exchanger. This heat is retained in the steel mesh. During exhalation, the relatively cool gas contacts

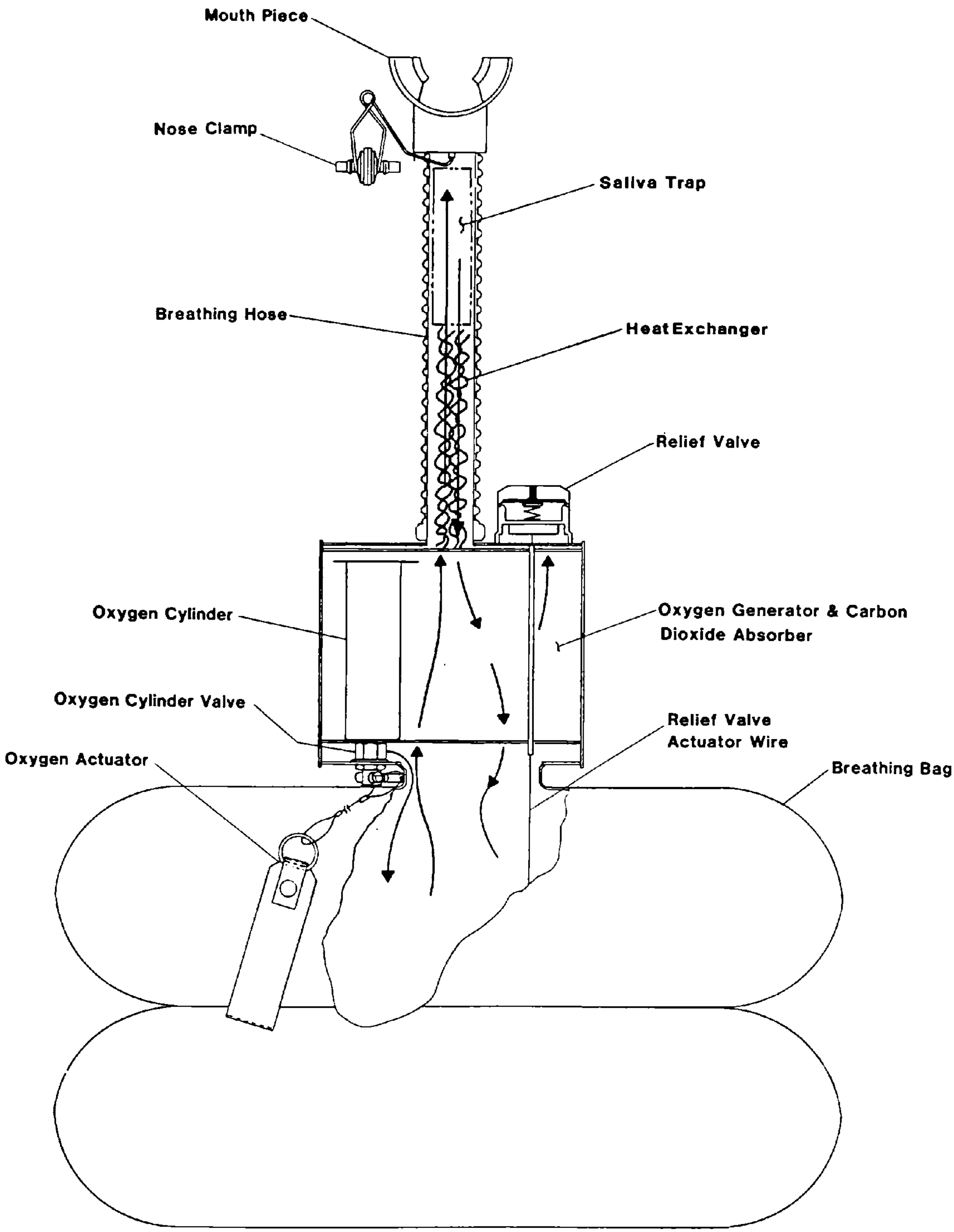

Mouth Piece
Nose Clamp
Saliva Trap
Breathing Hose
Heat Exchanger
Relief Valve
Oxygen Cylinder
Oxygen Generator & Carbon
Dioxide Absorber
Oxygen Cylinder Valve
Relief Valve
Actuator Wire
Oxygen Actuator
Breathing Bag

FIG. 1

the warmer heat exchanger and removes heat from the mesh. This heat is eventually lost through radiation, conduction and convection from the canister, breathing bag and through the relief valve (once the bag is full). The heat exchanger is then ready for the next inhalation and the gas cooling cycle starts all over.

The starter oxygen contained within a stainless steel bottle, is emptied into the breathing bag by simply pulling the oxygen release tab. This dumps about eight to nine liters of oxygen into the breathing bag in about one half minute. The oxygen bottle acts as a heat sink during use and lowers the inhaled temperature somewhat. The oxygen bottle contains a frangible disc that is in direct contact with the gas pressure in the cylinder. This protects the SR-100 with overpressure relief in the unlikely event that the cylinder and or the SR-100 is smashed or crushed. The cylinder is small enough that insufficient gas energy exists to fragment the cylinder but as a safeguard, a frangible disc is provided.

In the unlikely event that the on/off valve fails to operate properly and does not open to release the starter gas, the user can exhale four to five breaths into the SR-100 and start oxygen generation thru the KO_2 chemical reaction. After a few minutes of sedentary breathing into the SR-100 (during this time the inhaled oxygen content will never be less than 19%), the user can then commence his escape procedure. Eventually, in this scenario, the canister temperature will rise because of the various heats of reaction and the frangible disc will rupture. This will cause the contents of the starter oxygen bottle to be released into the breathing bag. The user will feel a temporary increase in exhalation pressure and a decrease in inhalation pressure. However, the bulk of the gas (depending upon how full the breathing bag is) will be vented through the relief valve.

The SR-100 supplies oxygen on demand through chemical reaction of the KO_2 and the user's breath. As work intensity increases and the user's oxygen demand increases, oxygen production increases accordingly. Actually, at some parts of the work cycle, the SR-100 will produce more oxygen than required by the user's oxygen uptake.

Figure 2 shows a size comparison of the SR-100 with two of the more commonly used filter self-rescuers. The SR-100 is roughly twice the volume and weight of the FSR.

Figure 3 shows the SR-100 with top and bottom covers removed and ready for use. Note that the SR-100 has a pair of goggles included within the bottom cover. With the exception of the plastic carrying case, which also serves as a heat shield during use, the SR-100 exterior components are constructed entirely of stainless steel. The stainless steel construction coupled with a high impact strength plastic carrying case, makes the SR-100 a strong, rugged self rescuer that can withstand the rigors of the mining industry. Additionally, the unit is totally sealed (gasketed) to protect the breathing circuit from dust, moisture and environmental factors that may impair the function of the SR-100.

The SR-100 was designed to minimize user training and to agree with the generally accepted 3+3 donning procedure put forth by MSHA and the BOM. For training purposes, and after considerable consultation with both the BOM and MSHA, reusable training devices are being prototyped so the training costs can be minimized. The 3+3 procedure is illustrated in Figures 4 through 11.

The SR-100 operates for one hour under the work regimes defined by NIOSH/MSHA 30 CFR 11 criteria. However, in emergencies where egress is denied to the user, the SR-100 will operate in an extended duration mode and will provide life sustaining oxygen for a period of five to six hours, depending upon the metabolism of the user. In this extended mode, the user minimizes any movement or exertion to decrease his metabolic oxygen requirements and breathes normally.

c. <u>THE CANISTER CHEMICAL</u>

A number of different chemicals were looked at, from a theoretical viewpoint, for minimizing the production of water within the canister thru chemical reaction. This was particularly true when considering the reaction of carbon dioxide with any absorption agent. Of the possible CO_2 absorption materials that could minimize weight and water production and still be an effective carbon dioxide scrubber, lithium peroxide was such a material. Not only was it feasible that this reagent would scrub carbon dioxide, but it would also generate oxygen. The problem with

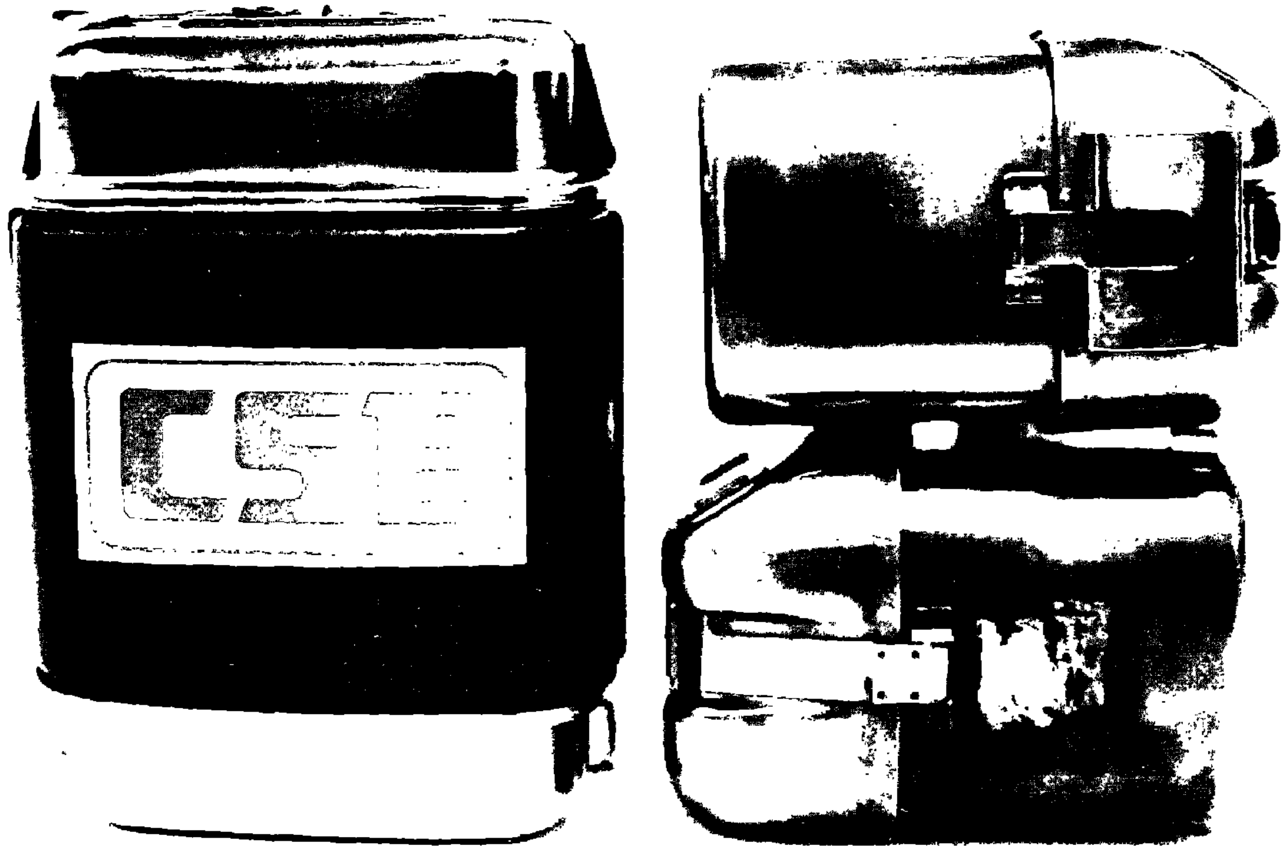


FIG. 2

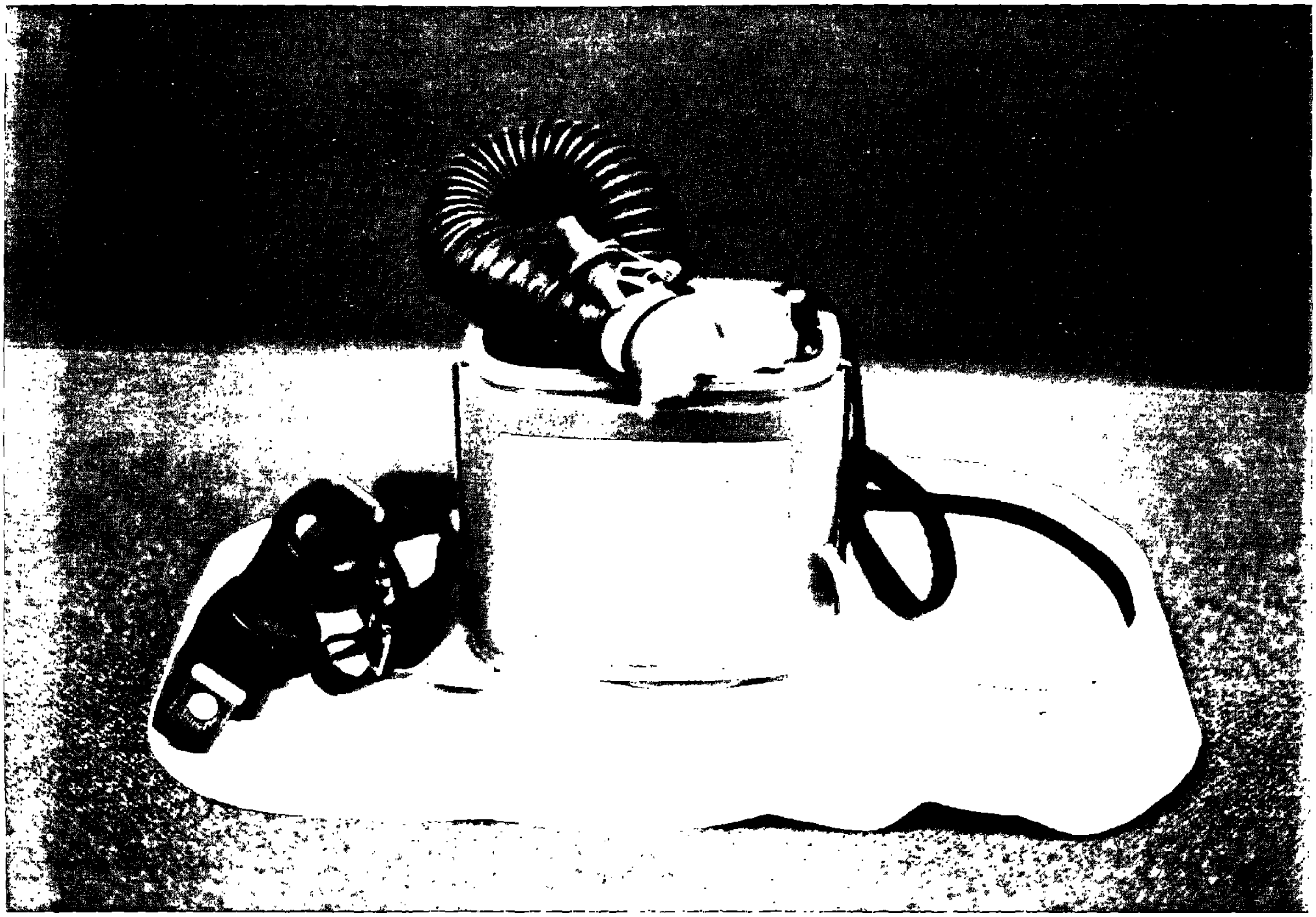
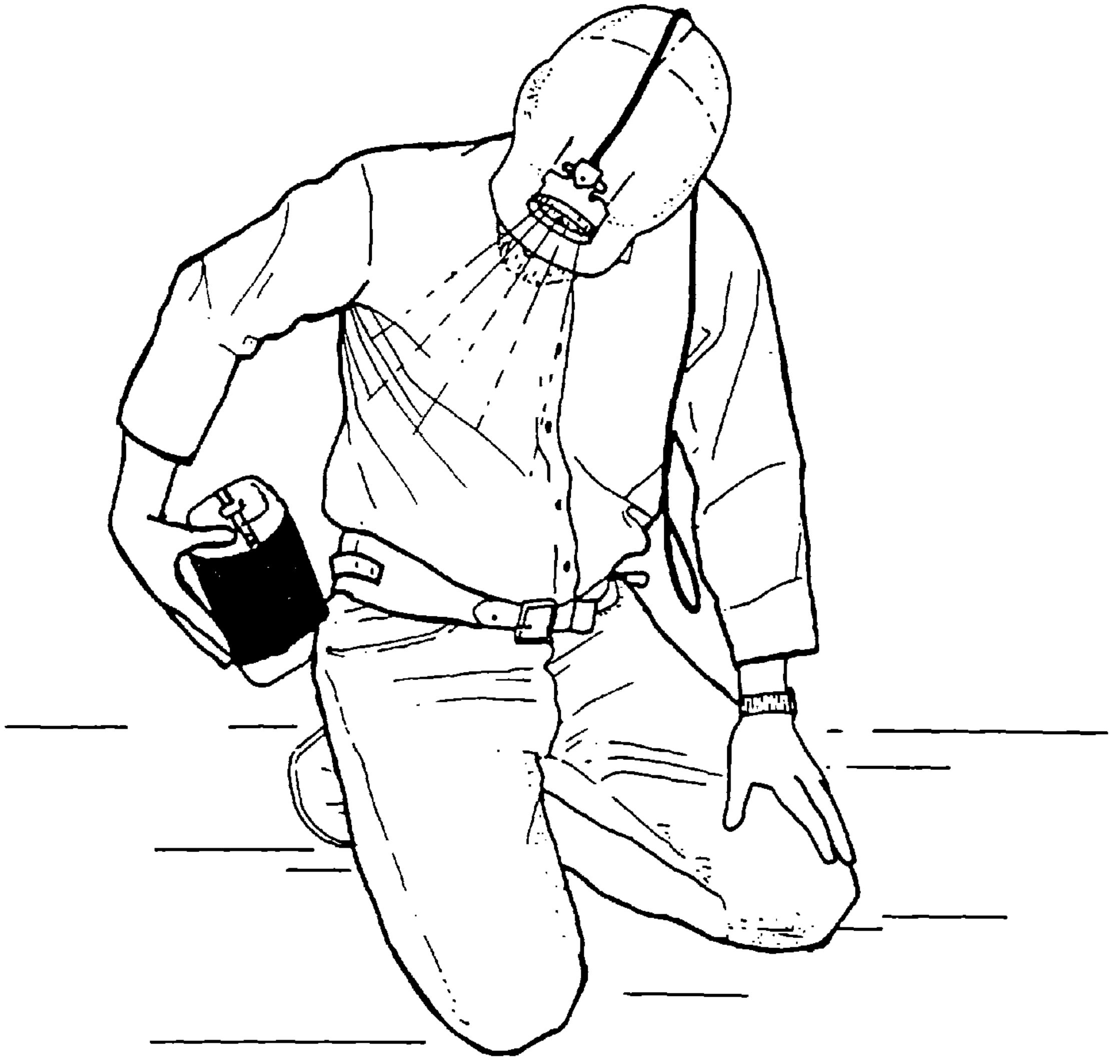


FIG. 3



KNEEL

1. BRING THE SR-100 IN FRONT OF YOU AND PLACE IT ON THE FLOOR.

2. LAY YOUR MINER'S CAP ON THE FLOOR AND SHINE THE LAMP ON THE SCSR.

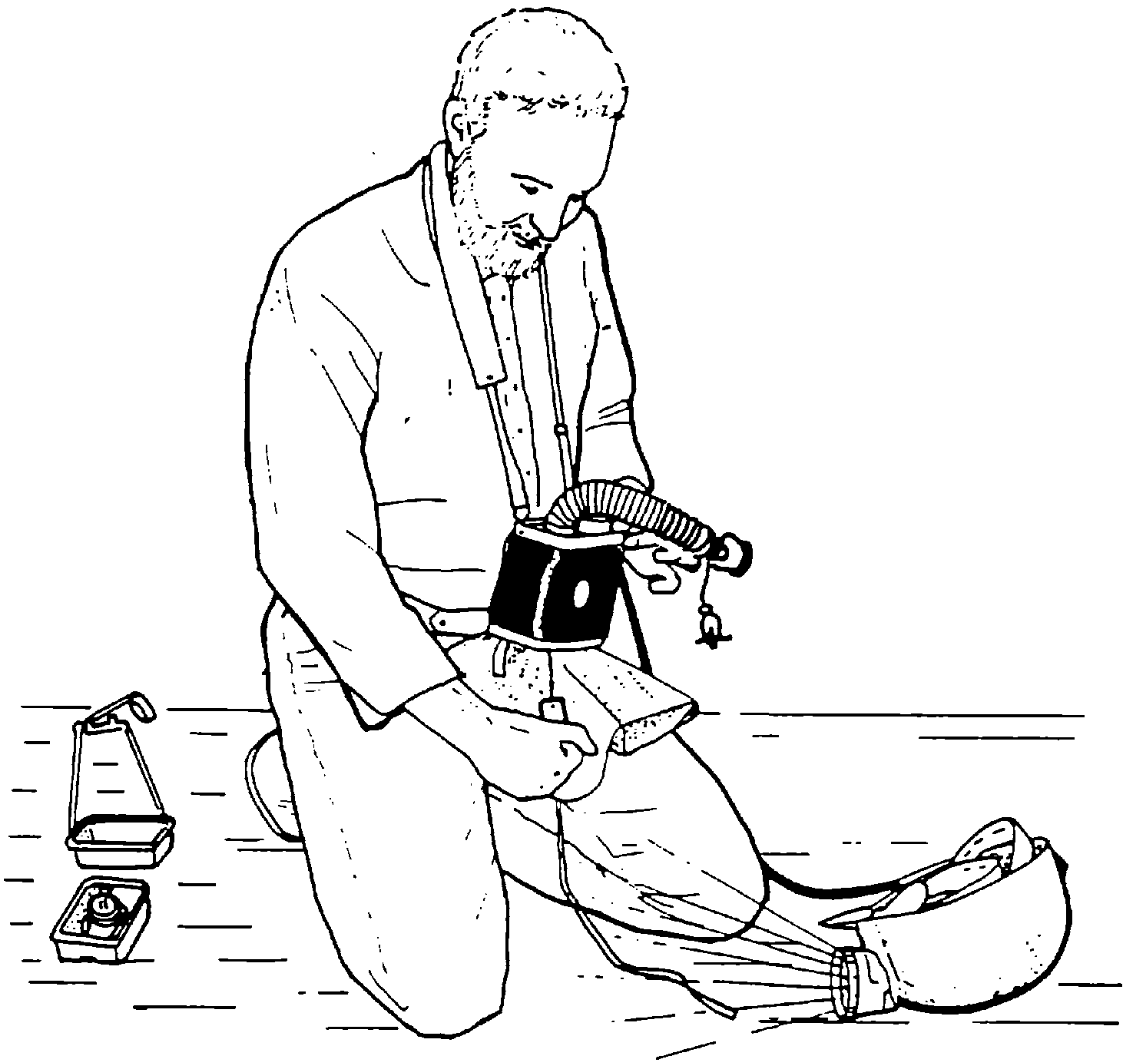
3. WORK WITH BOTH HANDS TO DON THE SCSR.

LOOP

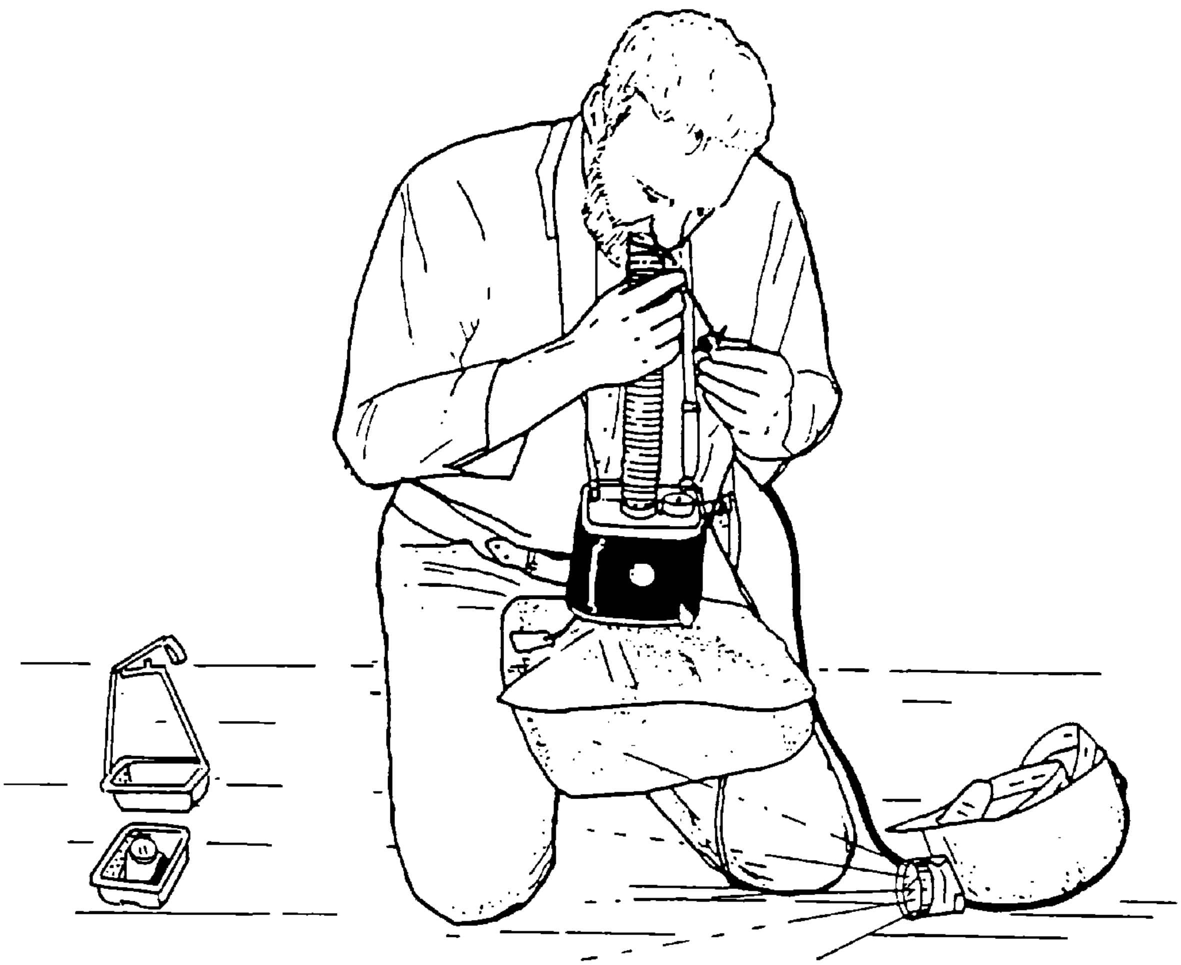
1. AFTER OPENING THE SR-100, QUICKLY LOOP THE NECKSTRAP OVER YOUR HEAD IN ORDER TO POSITION THE UNIT.

2. LEAVE THE STRAP ADJUSTMENT UNTIL YOU HAVE ISOLATED YOUR LUNGS.

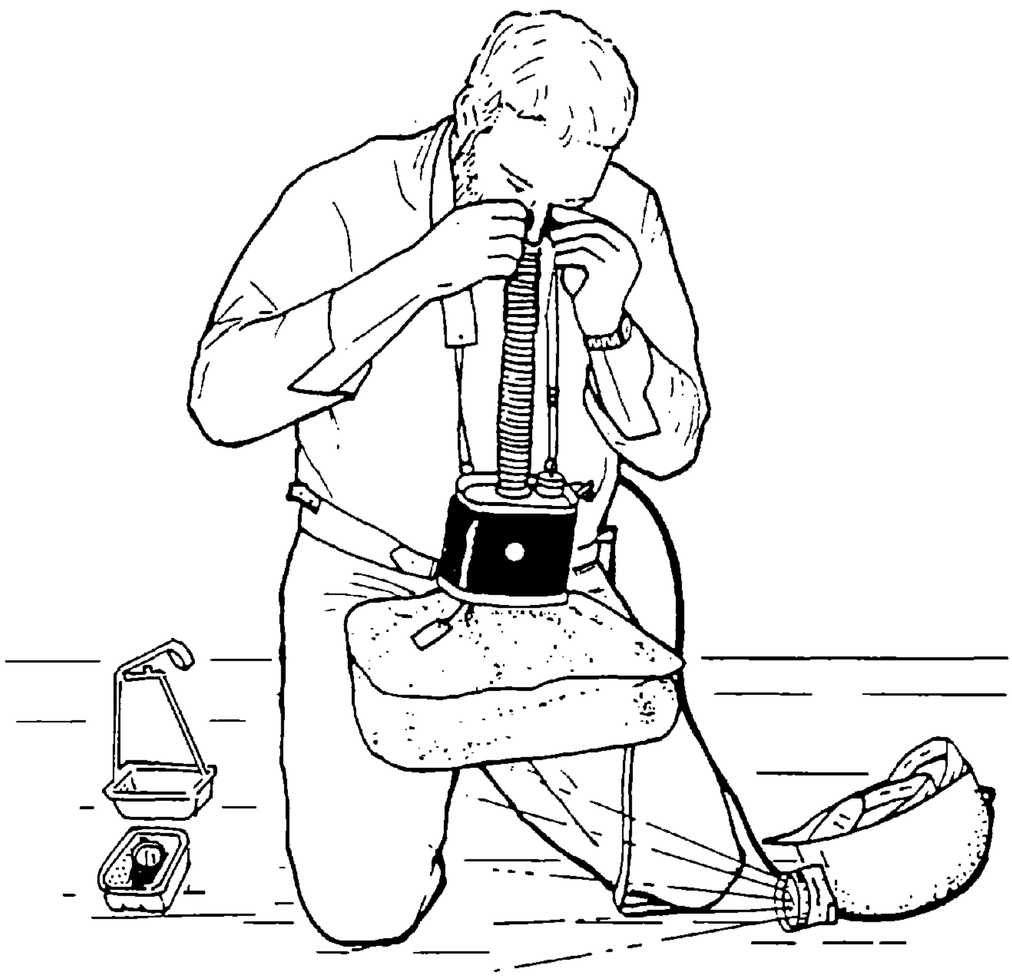
3. NOW YOU ARE READY TO BEGIN THE "3+3" DONNING PROCEDURE.



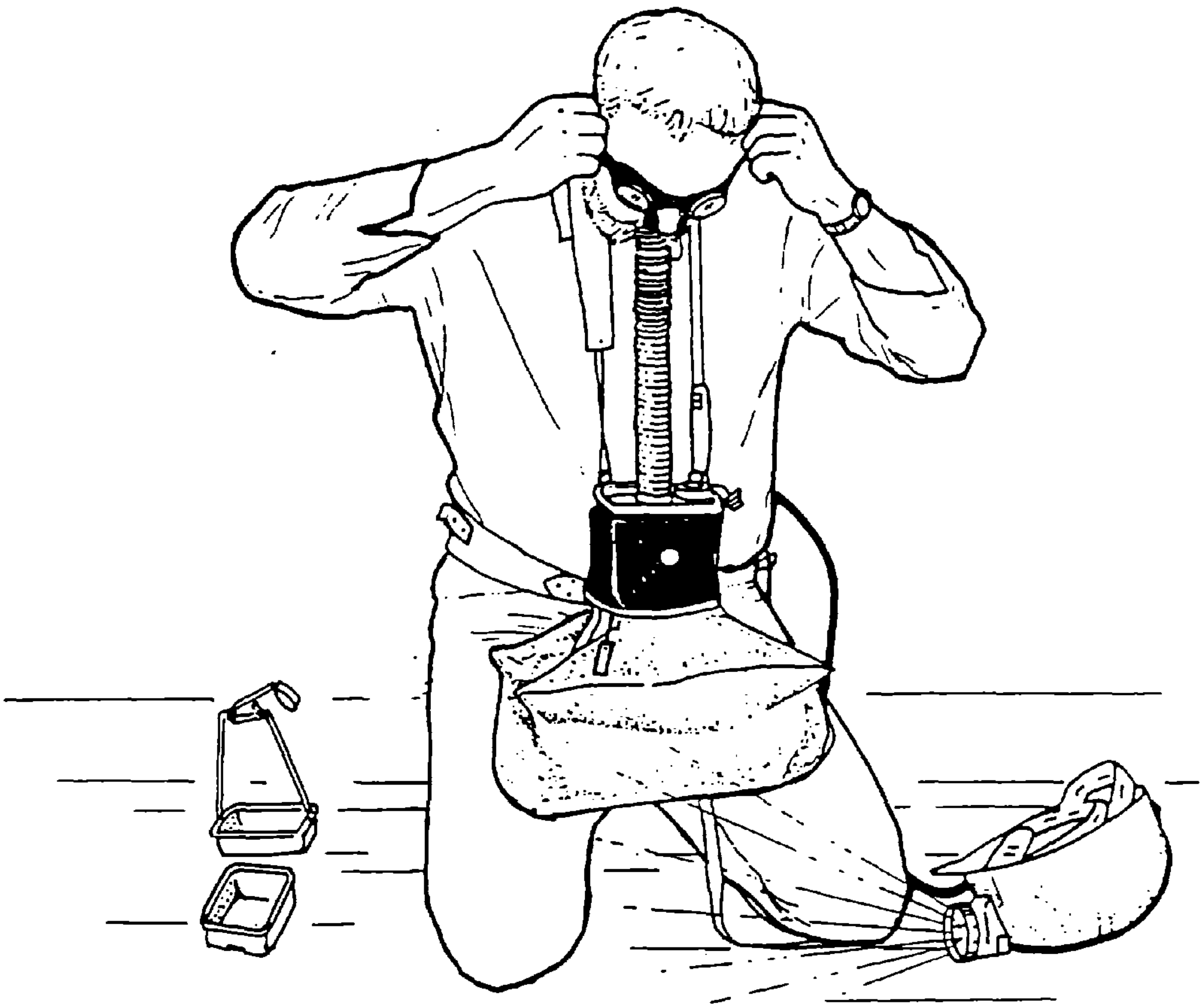
STEP 1 -- ACTIVATE THE OXYGEN.



STEP 2 -- INSERT THE MOUTHPIECE.



STEP 3 -- PUT ON THE NOSECLIPS.



STEP 4 -- PUT ON THE GOGGLES.

STEP 5 -- ADJUST STRAPS.

STEP 6 -- REPLACE MINER'S CAP.

this chemical was that it is not readily available commercially. Consequently, after a few tests, this effort was abandoned.

The test work then settled on lithium hydroxide in combination with KO_2. Because of its scrubbing efficiency and low grams of chemical absorbent to grams of CO_2 absorbed ratio, LiOH was most likely to satisfy the volume and weight constraints for the self rescue device. Lithium hydroxide suffered from the fact that its reaction with carbon dioxide produced water via the following reaction:

$$2LiOH + CO_2 = Li_2CO_3 + H_2O$$

To overcome the fact that the water produced by this reaction would result in oxygen overproduction, means were instituted to control the water that could be introduced into the system. This resulted in the introduction of a saliva trap (capable of trapping liquid water plus some water vapor in the breathing hose) and calcium chloride into the breathing bag. The net effect was that sufficient water (either in liquid or vapor form) was trapped to prevent excessive oxygen overproduction.

To comply with 30 CFR 11 requirements (with regard to exhalation and inhalation pressures at a minute volume of forty liters), a particle size for the KO_2 of -2.5 + 6 mesh was selected. Similarly, the lithium hydroxide particle size was set at -4 + 8 mesh.

d. STARTER OXYGEN

Considerable thought was given to the choice of using compressed oxygen or a chlorate candle for supplying the initial oxygen into the SR-100. The choice was made in favor of a small compressed oxygen cylinder for the following reasons:

1. The oxygen bottle was considered to be more reliable for delivering the initial oxygen.
2. Chlorate candles produce excessive amounts of heat because of the exothermic oxygen generating reaction. This additional heat tends to raise inhaled gas temperatures. Consequently, the chlorate candle was rejected on this point.
3. The steel oxygen cylinder, contained within the canister, would act as a heat sink and also provide a

small amount of additional cooling by the release of the compressed oxygen. These factors tend to reduce the temperature of the inspired gas.

The on/off valve of the oxygen cylinder is turned on by pulling a large fluorescent orange tag that is located on the bottom of the canister right above the breathing bag. The large, readily seen tag, is pulled down and forward to activate the oxygen cylinder.

An additional subjective influence for choosing an oxygen bottle for the starter gas was the fact that the oxygen (8 to 9 liters) is released within a half minute and inflates the bag. It was felt that this would have an assuring effect as the user is able to see the bag quickly inflate.

e. BREATHING BAG AND RELIEF VALVE

The breathing bag, made from polyurethane-coated nylon, is attached to the bottom of the canister by means of a urethane grommet. This material passes the NIOSH gasoline permeability test. The location of the bag at the bottom of the canister eliminates convective heating of the bag by the rising hot air that surrounds the working canister. The net effect is that there is an overall lowering of the inhaled gas temperature.

The breathing bag is connected to a relief valve (located on the top of the canister and next to the breathing hose) by means of a stainless steel cable. This makes the relief valve a volume rather than a pressure actuated device. Volume actuation and location of the relief valve has two desirable features:

1. The volume actuated valve, precludes the possibility of the user accidentally dumping the contents of the breathing bag.
2. When the breathing bag is full, the relief valve discharges excess gas from the breathing hose before it enters the chemical bed. This gas is higher in CO_2 and lower in oxygen than the gas in the bag, conserving oxygen and minimizing the amount of reagent required to absorb CO_2.

f. PACKAGING

CSE's goal for packaging the SR-100 was to make the unit resemble, as nearly as possible, existing filter self-rescue devices so that familiarization time would be minimal. In addition, the package had to have the following characteristics:

1. It is to be at least as strong and durable as existing FSR's that have proven their utility in the field over many years of use.
2. The SR-100 must have high visibility.
3. It must meet the constraints imposed by the BOM with regard to volume and weight, i.e., about twice the volume and weight of existing FSR's.
4. It must be easy to open-- but not accidentally.
5. It must be tamperproof.
6. Inspections for maintaining usability must be simple and straightforward and not require time-consuming procedures.
7. The unit must be corrosion resistant and waterproof.
8. It must be compact and ergonometrically designed for easy carrying and handling.

Durability was achieved by using stainless steel for the construction of all major components. The thickness of the steel is the same as that used in FSR's which have been field proven for durability. High visibility is assured by using a safety-orange-colored, high-impact plastic, carrying case/scuff shield. The carrying case/scuff shield is an integral part of the SR-100 and provides additional heat protection during use.

The top and bottom covers are attached to the canister by means of a steel band. This band is opened by means of a pull tab much in the same way as opening existing FSR's. Pulling on the tab causes the top and bottom covers to fall away leaving the unit ready for use. Both covers are gasketed to the canister which provides water, moisture and dust protection.

B. NIOSH/MSHA-APPROVAL TEST PROGRAM

As part of the add-on contract requirements, the SR-100 had to become NIOSH/MSHA approved. This required that CSE submit a document package containing quality control procedures, classification of defects, drawings and twenty-two SR-100's for testing. Testing is defined in 30 CFR 11 and consists of a number of bench tests as well as man tests. Before submitting the SR-100 to NIOSH/MSHA, CSE conducted its own testing in a manner that duplicated the official tests as closely as possible. Once these tests were done, the SR-100's were released to NIOSH/MSHA for man tests. Our first submittal resulted in a rejection due to:

a. difficulties in firing the starter oxygen bottle;

b. insufficient oxygen during the early time periods if the starter oxygen bottle failed to empty.

The difficulty in firing the starter oxygen bottle was corrected by a mechanical change in the oxygen valve configuration. The second problem was corrected by the introduction of catalyzed KO_2 into the canister bed. The modified SR-100's were then resubmitted to the approval authorities and successfully passed the approval process.

A summary of the tests is presented in the following:

<u>Bench Tests</u>

Relief valve operation
Breathing resistance
Carbon dioxide dead space
Ro-Tap vibration test

<u>Man Tests</u>

Service Life--- Man Test 1 through 4
Extended duration--- Man Test 5
Cold Temperature operation
Isoamyl Acetate leak test

a. <u>Bench Tests</u>

1. <u>Relief Valve Test</u>

The relief valve serves the function of reducing breathing bag pressure to a preset level. This prevents excessive gas pressure buildup in the system. The relief valve is tested for proper operation and is required to relieve pressure when the breathing circuit pressure is one-half inch of water pressure above the minimum pressure required to fill the bag. The relief valves passed both CSE and NIOSH testing. NIOSH test results are presented in Table 1.

TABLE 1 RELIEF VALVE OPENING PRESSURES (inches of water)		
UNIT NO.1		
BAG FULL	RELEASE	DIFFERENCE
0.09	0.42	0.33
0.11	0.42	0.31
0.10	0.44	0.34
0.12	0.45	0.33
0.12	0.46	0.34
0.10	0.44	0.34
UNIT NO. 2		
0.14	0.46	0.32
0.12	0.44	0.32
0.14	0.44	0.30
0.14	0.46	0.32
0.14	0.46	0.32
0.16	0.46	0.30

2. Resistance Tests

The breathing resistance test is conducted on a standard breathing machine using 622 kg-m/min cam and operated at a cycle speed of twenty-four revolutions per minute. The minute volume of the apparatus is forty liters per minute. Pressure is measured at the mouthpiece by means of a transducer whose output signal is fed to a strip chart recorder. Maximum allowable exhalation pressure is 51 mm of water column. Peak to peak (exhalation/inhalation) pressure cannot exceed 100 mm. The test results obtained by NIOSH are given in the following Table 2.

TABLE 2 BREATHING RESISTANCE TEST		
UNIT NUMBER	inches of water INHALATION	EXHALATION
1	-1.40	+1.80
2	-1.40	+1.90

3. CARBON DIOXIDE DEAD SPACE TEST

The concentration of carbon dioxide in the inspired gas in a closed circuit apparatus is measured at the mouth while the parts of the apparatus contributing to dead-air space are mounted on an anthropomorphic dummy head and are operated by a breathing machine. The breathing machine uses a sedentary cam to produce a 10.5 liter minute volume when operated at 14.5 revolutions per minute. A mixture of 5% carbon dioxide in air is fed into the breathing machine and into the SR-100 during the exhalation cycle. The gas is flushed during the inhalation cycle. Carbon dioxide levels during the inhalation segment of the cycle are recorded and the average inspired CO_2 content is calculated. The average inhaled CO_2 content cannot exceed 2.5%. The NIOSH SR-100 test result showed an average of 1.22% inhaled carbon dioxide.

4. RO-TAP TEST

A special vibration test is conducted by NIOSH on all apparatus. In this test, the SR-100 is mounted on a Ro-Tap sieve shaker and vibrated for forty hours. The vibration test is administered to the unit by vibrating it on each of its three axes for 800 minutes. At the same time, hammer blows are applied at the rate of 150 impacts per minute at a peak acceleration of 15 +/- 1 G for the entire test. After completion of the forty hours, the unit is removed from the test device and then is man tested under the protocol of man test number 1. The SR-100 successfully passed this test with no evidence of dust generation or bed degradation. The results of the NIOSH testing are presented in Table 3.

TABLE 3
RESULTS OF MAN TEST NO. 1 AFTER RO-TAP TEST

schedule limits	test results
O_2 > 19.5%	63.5 to 83.6%
CO_2 < 1.5%	0.11 to 0.45%
max. inh. temp 115 °F	80.2 to 96.1

5. GASOLINE PERMEATION TEST

The urethane coated nylon breathing bag material used in the SR-100 is the same material that was previously used in approved escape apparatus. Consequently, a new gasoline permeation test was not made. The material is approved by NIOSH.

b. MAN TESTS

CSE performed a treadmill equivalent of NIOSH man testing prior to submission for certification and approval. These equivalent tests were completed for man tests one through four. The extended duration and cold-temperature tests were completed in the same manner as done at NIOSH. The SR-100 was found to meet all requirements.

Each of the tests, as completed by NIOSH, are summarized in the following paragraphs. In each of these tests, oxygen and carbon dioxide concentrations, inhaled temperature and breathing resistance were monitored. In general, these tests are designed to:

1. Familiarize the wearer with the apparatus during use,
2. Provide for a gradual increase in physical activity,
3. To evaluate the apparatus under different work loads and physical orientation and
4. Provide information on the operating and breathing characteristics of the apparatus during actual use.

1. MAN TEST NO. 1

The SR-100 successfully passed the requirements of man test number one. The results of NIOSH testing are presented in Table 4.

TABLE 4
MAN TEST NO. 1 RESULTS

VARIABLE MEASURED	UNIT #1 MIN/MAX	UNIT #2 MIN/MAX
O_2 content %	73.8 to 90.5	76.5 to 92.4
CO_2 content %	0.0 to 0.07	0.0 to 0.0
temperature °F	81.3 to 94.6	85.3 to 102.8
pressure in. H_2O	-0.58 to +0.63	-1.48 to +1.13

2. <u>MAN TEST NO. 2</u>

Man test number two was successfully passed. The results of NIOSH testing are presented in Table 5.

TABLE 5 MAN TEST NO. 2 RESULTS		
VARIABLE MEASURED	UNIT #1 MIN/MAX	UNIT #2 MIN/MAX
O_2 content %	76.3 to 90.5	80.8 to 92.3
CO_2 content %	0.0 to 1.07	0.0 to 0.21
temperature °F	88.1 to 104.7	84.6 to 107.5
pressure in. H_2O	-4.34 to +2.17	-1.87 to +1.56

3. <u>MAN TEST NO. 3</u>

Man test number three was successfully passed. The results of NIOSH testing are presented in Table 6.

TABLE 6 MAN TEST NO. 3 RESULTS		
VARIABLE MEASURED	UNIT #1 MIN/MAX	UNIT #2 MIN/MAX
O_2 content %	71.1 to 93.1	76.0 to 93.4
CO_2 content %	0.0 to 0.10	0.0 to 0.45
temperature °F	85.6 to 91.0	84.1 to 94.7
pressure in. H_2O	-0.64 to +0.54	-0.75 to +0.59

4. <u>MAN TEST NO. 4</u>

Man test number four was successfully passed. The results of NIOSH testing are presented in Table 7.

TABLE 7 MAN TEST NO. 4 RESULTS		
VARIABLE MEASURED	UNIT #1 MIN/MAX	UNIT #2 MIN/MAX
O_2 content %	80.5 to 93.7	81.7 to 94.3
CO_2 content %	0.0 to 0.61	0.0 to 0.25
temperature °F	84.2 to 101.4	88.7 to 101.7
pressure in. H_2O	-2.51 to +1.03	-2.17 to +1.05

5. MAN TEST NO. 5

Man test number five is the extended mode of operation. There are no pass/fail criteria. The purpose of the test is to determine the maximum length of time the apparatus will supply the respiratory needs of the wearer while at rest. Samples of inspired air are taken at two and five minutes and every fifteen minutes thereafter until the unit no longer supplies the respiratory needs of the user. At no time will the oxygen content be less than 19.5% nor will the carbon dioxide content be greater than 1.5%. NIOSH test data after 120 minutes are shown in Table 8.

In the official report of the test, NIOSH stated that "the test was terminated after 120 minutes when it became evident that the data collected was correlating with the data graph supplied by CSE. This graph shows the duration to be between 300 and 400 minutes."

TABLE 8
MAN TEST NO. 5 RESULTS

VARIABLE MEASURED	UNIT #1 MIN/MAX	UNIT #2 MIN/MAX
O_2 content %	78.3 to 89.9	68.6 to 75.6
CO_2 content %	0.0 to 0.15	0.0 to 0.66

6. COLD TEMPERATURE TEST

In this test, the applicant specifies the minimum operating temperature of the apparatus. During NIOSH testing, the unit is precooled at this minimum temperature for four hours. The apparatus is then worn by the test subject while inside of the cold-test chamber. During the test period, alternate one-minute periods of exercise and rest will be completed. The exercise period consists of stepping on and off a box 21.5 centimeters high at a rate of thirty cycles per minute. The user shall not experience undue discomfort and the apparatus shall function satisfactorily at the specified temperature in duplicate tests.

CSE specified a minimum operating temperature of 32 °F. The results of the NIOSH tests are presented in Table 9.

TABLE 9 COLD TEMPERATURE TEST RESULTS		
VARIABLE MEASURED	UNIT #1 MIN/MAX	UNIT #2 MIN/MAX
O_2 content %	56.4 to 71.7	50.0 to 62.8
CO_2 content %	0.0 to 0.34	0.0 to 0.15

7. ISOAMYL ACETATE TEST

This test is used to determine the gas tightness of the unit to the external environment. The atmosphere surrounding the user wearing the apparatus contains about 1000 ppm of isoamyl acetate vapor. If the apparatus is gas tight, the user detects no odor of the isoamyl acetate. No odor was detected by six test subjects.

c. SR-100 SPECIFICATIONS

Table 10 presents a list of the operating specifications of the SR-100 person wearable self-rescuer.

TABLE 10 OPERATING SPECIFICATIONS	
Deliverable oxygen supply (liters)	100
Rated duration (minutes)	60
Extended duration (hours)	5 to 6.6
Carrying weight (Kgs)	2.6
In-use weight (Kgs)	2.2
Dimensions (centimeters)	19.7x14x10.1
Starter (compressed oxygen, liters)	8 to 9
Breathing bag capacity (liters)	9 +/- 0.5
Storage temperature (°F)	32 to 130
Oxygen supply rate (liters per minute)	On Demand
Oxygen supply for continuous use	Chemical
Construction	Stainless Steel
Eye protection	Goggles

*** CONCLUSIONS

The completion of this contract has resulted in the development of the smallest (volume) and lightest one-hour, person-wearable self-rescuer that has been approved (TC-239) to date. This apparatus, called the SR-100, is approximately twice the volume and weight of existing filter self-rescuers as required by the contract.

By using innovative heat transfer techniques, low inhalation temperatures were achieved without adding excessive weight to the apparatus. Careful control of water, generated either by the user or through chemical reaction, resulted in more nearly matching the user's metabolic requirements to the theoretical oxygen contained within the oxygen generating chemical---potassium superoxide.

The carbon dioxide scrubber is sized to exceed the equivalent of the CO_2 produced by the user's metabolic conversion of available oxygen. Thus the user will run out of oxygen before high levels of inhaled carbon dioxide are realized.

A rugged unit was developed to withstand the rigors of the mining industry. All external components (with the exception of the heat/scuff shield) that may see excessive wear and tear are constructed of stainless steel. The heat/scuff shield, which adds protection against the heat generated during use, is made of high-impact, abrasion-resistant plastic.

EPILOGUE

Once the SR-100 received NIOSH/MSHA approval and certification, the Bureau of Mines then conducted field trials on the SR-100. These trials consisted of deploying the SR-100 at selected mine sites to evaluate their durability and miner acceptance under actual mining conditions. Following a six-month period of use, the units were recalled from the field and were then used in simulated mine escape at the Bruceton, Pa. facilities. Videotape studies, user discussion group analysis and laboratory evaluation uncovered a number of mechanical problem areas associated with donning procedures and serviceability. The more important problems and their solutions were:

a. The location of the SR-100 security strap was such that it tended to rub the thigh of the user. The problem was resolved by changing the security strap position from front-to-back to a side-to-side location.

b. During the simulated escape from the Bruceton experimental mine, it was observed that the on/off starter oxygen bottle activator strap was causing some difficulty during pulling. Additionally, some cylinders were completely empty due to leakage. A redesign of the valve was made to eliminate leakage and to permit easy valve actuation.

c. The mine escape simulation also uncovered another problem area that arose as a result of the method used to pack the SR-100. Once the top cover was removed and the miner attempted to insert the breathing hose into his mouth, there was a tendency for the miner to twist and kink the breathing hose. Although the SR-100 was still functional, this had the undesirable effect of increasing breathing resistance. The tendency to twist or kink the breathing hose during donning was eliminated by repositioning the relief valve on the top of the absorption canister. This allowed the breathing hose to be packed in a different manner.

d. During the escape trials, most of the miners had difficulty adjusting the web waist strap to their waist size. To overcome this problem, the waist strap was changed from an adjustable web strap to an elastic strap. Since the web strap needed adjustment to accommodate the user, the substitution of an elastic strap eliminated this problem for most cases. However, for a miner having a small waist, some belt adjustment is still necessary.

e. A second waist strap problem existed that made it difficult for the miner to differentiate between the front and the back of the SR-100. This caused some miners to don the unit such that it did not fit snugly against their body. The problem was solved by relocating the waist straps so that the unit is always held securely to the body, regardless of its orientation.

f. The breathing bag was also redesigned to withstand higher burst pressures. Analysis of the videotapes showed that it may be possible for the miner to impact or compress the breathing bag when traveling through tight passages. As the relief valve is volume activated, no gas is vented if the bag is compressed under certain conditions. Consequently, through a redesign of the geometric configuration of the breathing bag, the burst strength of the breathing bag was increased to a minimum of 1750 mm of water column. At pressures far below this value, the user would naturally vent the gas through the mouthpiece to relieve excessive pressure.

g. To accommodate the possibility that the breathing bag could be compressed or impacted in such a direction that the wire connecting the relief valve to the breathing bag could be stretched and broken, the wire was made stronger.

h. Some miners had difficulty removing the top and bottom covers from the SR-100 because the opening pull-tab broke. This problem was corrected by sewing the pull-tab rather than gluing it together.

Once all of these problems were corrected, a second mine escape study was conducted and the tests proved successful. The only reported problem during this second test was that some fogging of the goggles occurred. This problem was also corrected by the inclusion of an anti fog lens into the goggle.

The field trials proved to be of substantial value in that the performance of the SR-100 with regard to comfort and ease of donning was greatly enhanced. Without field trials, the reported problems would not have been readily uncovered.