

AN OVERVIEW OF OXYGEN SELF-RESCUER
TECHNOLOGY

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ABSTRACT

Federal regulations require that every person who goes into an underground coal mine in the United States be supplied with a Self-Contained Self-Rescuer (SCSR), a device capable of providing at least 60 minutes of oxygen regardless of ambient atmosphere. The development of oxygen self-rescuer technology suitable for in-mine use was a complicated engineering research and project management problem. The purpose of this paper is to trace the role which the Bureau of Mines played in the development of this technology in the United States from 1969 to the present.

INTRODUCTION

When a mine disaster occurs, the basic survival technique for a miner is to escape from the mine. Following a mine fire or explosion, the atmosphere inside a mine sometimes becomes oxygen-deficient or filled with toxic gases. Under these circumstances, escape is nearly impossible unless a miner is equipped with a self-rescue device which supplies oxygen without the need of breathing mine air.

Federal regulations (30 CFR 75.1714) require that every person who goes into an underground coal mine in the United States must be supplied with an SCSR. An SCSR is an emergency breathing apparatus designed for the purpose of mine escape. It must be capable of providing at least 60 minutes of oxygen, regardless of the ambient

atmosphere. Only SCSR's approved by the National Institute of Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) can meet the provisions of the regulations.

These regulations became effective on June 21, 1981, about two and one-half years after they were promulgated by the Mine Safety and Health MSHA. Their successful implementation depended crucially on two factors: (1) the commercial availability of approved SCSR's, and (2) acceptance by mine operators and mine workers that SCSR's were rugged enough to survive deployment underground and function reliably in the event of a mine disaster.

The purpose of this paper is to examine the role which the Bureau of Mines played in the development of SCSR technology. The development process, translating a conceptual design for an oxygen self rescuer into a workable SCSR technology, was a complicated engineering research and project management problem. What will be shown in this report is that the Bureau of Mines successfully developed prototype SCSR's approved for in-mine use. These prototypes, because they derived from proven, available technology, demonstrated the feasibility of the SCSR concept, encouraging manufacturers to adapt and modify this technology for commercial production.

SCSR DESIGN CONCEPTS

In 1969, the National Academy of Engineering established a Committee on Mine Rescue and Survival Techniques at the request of the Bureau of Mines. The purpose of this committee was to conduct a study program to assess technologies which could improve significantly a miner's chances for survival

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following a mine fire or explosion (National Academy of Engineering Committee on Mine Rescue, 1969).

Based on a survey of underground coal mine disasters from 1950 to 1969, the NAE committee believed that a miner's chances for survival following a mine disaster could be significantly improved if he were equipped with a new type of emergency breathing apparatus, one which supplied oxygen without the need for breathing ambient mine air. Such a device, they argued, was well within the reach of existing technology. Thus, the NAE committee recommended that the Bureau of Mines develop SCSR technology and described how an SCSR should optimally perform for mine escape purposes.

The SCSR design requirements which emerged from the NAE committee's recommendations defined how an SCSR should optimally perform for mine escape purposes. There were nine design requirements:

- (1) Provide respirable atmosphere, regardless of environment;
- (2) Permit intermittent voice communications between miners;
- (3) Supply 1 hour of oxygen at a work rate defined by 30 CFR 11, NIOSH Man Test 4;
- (4) Should be lightweight and compact;
- (5) Should be reliable and simple to operate, providing immediate safe oxygen levels at startup;
- (6) Should be acceptable to miners;
- (7) Should be rugged;
- (8) Materials and design should be within present state-of-the-art; and
- (9) Target costs should be less than \$50 per unit (in 1969 dollars) for 50,000 to 70,000 units produced within a two year period.

Besides defining how an SCSR had to optimally perform for mine escape

purposes, the NAE committee also described two conceptual designs for SCSR's, which they felt could potentially meet all nine design requirements.

There are two ways to obtain oxygen in SCSR's: by storing oxygen physically as a compressed gas or a cryogenic liquid, or by generating oxygen chemically. From the start, liquid oxygen SCSR's were ruled out because such a storage system represented a high development risk. Chemical oxygen sources were favored over compressed oxygen because available bottled oxygen technology could not meet the compact size and weight requirements. Another reason for favoring chemical oxygen sources was that even if a compressed oxygen SCSR could be built, it was believed that a chemical oxygen SCSR would have fewer moving parts and, as a result, have lower maintenance requirements and higher reliability.

Both NAE designs used chemical oxygen sources, and, in order to meet the requirements of a 1 hour oxygen supply and compact size, both used a closed-loop breathing circuit. In a closed-loop breathing apparatus, all inhaled and exhaled air is kept within the breathing circuit, conserving the available oxygen for reuse while requiring that the carbon dioxide produced by the body be absorbed. The NAE committee suggested that two different oxygen sources be considered:

- (1) a sodium chlorate candle plus a carbon dioxide scrubber, and
- (2) potassium superoxide.

SCSR'S DEVELOPED BY THE BUREAU OF MINES

The Bureau of Mines, successfully developed five different SCSR's through research contracts with private industries.

In the order in which they were developed, the five SCSR's are:

- (1) Westinghouse Electric Corp., Personal Breathing Apparatus (PBA) 1971,
- (2) Mine Safety Appliance Co., 10 Minute SCSR 1973,
- (3) Lockheed Missiles and Space Corp., PBA 1974,
- (4) MSA 10/60 1978, and
- (5) U.S. Divers Self-Contained Emergency Breathing Apparatus 60 (SCEBA 60 1981).

All five devices are shown in Figure 1. The size, weight, and operating characteristics of each device are listed in Table 1.

Westinghouse Electric Corp., PBA

The Bureau of Mines funded Westinghouse Electric Corp. to develop a 1 hour, sodium chlorate candle SCSR (Westinghouse Corp., 1971).

The Westinghouse PBA was a straightforward feasibility demonstration of the SCSR concept using available technology as a starting point. It met most of the optimum design requirements. While the Westinghouse PBA was made as small as possible within the state-of-the-art for sodium chlorate candles, its overall size and weight made it impractical for miners to carry this SCSR constantly. Figure 2 shows the Westinghouse PBA in use on a miner.

Since the Westinghouse PBA was a closed circuit breathing apparatus, it used pure oxygen as the breathing medium, generating oxygen by burning a sodium chlorate candle. The sodium chlorate candle was ignited automatically when the SCSR was pulled from its carrying container.

The flow path through the Westinghouse PBA is shown in Figure 3. The wearer breathes oxygen to and from breathing bags. Exhaled gas passes through a canister containing a carbon dioxide absorbent - lithium hydroxide. Fresh oxygen from the sodium chlorate candle is constantly added to the breathing circuit. The amount of oxygen added will support a man working at the hardest work possible. Therefore, more oxygen is generated than is normally used by a man not working at maximum effort. The oxygen not used is vented through a one-way relief valve in the right breathing bag. This relief valve vents at a very low pressure build-up, and therefore, normally vents most of the time the apparatus is in use.

Separate tubes provide for inhalation and exhalation. Breathing check valves in the mouthpiece maintain one-way flow of the oxygen, preventing the wearer rebreathing gas from which carbon dioxide has not been removed. Rebreathing does not occur until the exhaled gas has been passed through the lithium hydroxide.

A plastic hood with a rubber neck seal and antifogging goggles is sealed around the mouthpiece to provide eye protection to the miner, to permit the miner to remove the mouthpiece without admitting contaminated air, and to ensure universal fit of the apparatus. A nose clip on the eye piece holds the nose shut to prevent breathing from the hood.

MSA 10-Minute SCSR

Because of the size of the Westinghouse PBA, the Bureau of Mines funded two separate contracts for the development of a 10-minute,

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belt wearable SCSR and a 1-hour SCSR using potassium superoxide as the oxygen source. The development of the MSA 10-minute SCSR will be discussed first (Mine Safety Appliances Co., 1972).

Figure 4 shows the MSA 10-minute SCSR deployed for use. In order to meet belt-wearability requirement, this SCSR was designed to use a pendulum breathing circuit.

Figure 5 is a drawing of the flow path through the MSA 10-minute SCSR. The exhaled air goes through the potassium superoxide bed where oxygen is produced and carbon dioxide is absorbed; then the exhaled air goes into the breathing bag. On inhalation, the gas from the bag returns by way of the same route. The split potassium superoxide bed design was chosen to make maximum use of the potassium superoxide while keeping overall breathing resistance low. The pressure relief valve on the breathing bag is necessary because the potassium superoxide produces slightly more oxygen than is needed. For safety, the potassium superoxide bed is designed to absorb all carbon dioxide, and thus, over produces oxygen. The relief valve is a one-way valve so that no toxic gases can enter the breathing bag.

Because potassium superoxide does not provide oxygen instantly, a supply of oxygen is provided by a sodium chlorate candle for the first 45 seconds. This helps inflate the breathing bag and provides the oxygen the wearer would need for the first minute or so. By that time enough breath moisture will have reacted with the potassium superoxide so as to provide the oxygen needed.

Inside the plastic carrying case, the MSA 10-minute SCSR is packed in

a double-sealed vapor bag. After opening the sealed bag, the SCSR is donned by putting the bag strap over the neck. The sodium chlorate candle is started automatically by pulling a firing pin which is attached to the goggles used to protect the eyes from smoke. The entire donning operation can be accomplished in less than 30 seconds.

The results of man tests of the MSA 10-minute SCSR showed that the device would last at least 10 minutes or longer depending on work rate.

LOCKHEED PBA

In a parallel effort, the Bureau of Mines funded a contract with Lockheed Missiles and Space Corp., to develop 1-hour potassium superoxide SCSR (Lockheed Missiles and Space Corp., 1974).

The Lockheed PBA is shown in Figure 6 and a flow path diagram is shown in Figure 7. In this SCSR, the wearer exhales through the exhalation breathing tube down through the potassium superoxide bed and into the breathing bag. On inhalation, oxygen enriched air scrubbed of carbon dioxide, bypasses the potassium superoxide bed by way of the return duct, then enters the inhalation breathing tube and passes into the mouthpiece, check valves at the mouth-piece assembly control the inhaled and exhaled direction of flow. Again, a relief valve on the breathing bag is needed to vent excess oxygen.

In order to keep inhaled air temperature within NIOSH requirements ($<115^{\circ}\text{F}$), the heat generated by the chemical reaction of potassium superoxide is removed by gas flow routed through the breathing bag by internal baffles. The large surface

area of the breathing bag exchanges heat with the ambient mine air.

A small sodium chlorate candle provides instant oxygen, similar to the MSA 10-minute SCSR. This candle supplies 2 liters of oxygen in the first 15 seconds and 8 to 10 liters during the 90 seconds that follow. Pulling the mouthpiece towards the wearer automatically fires the sodium chlorate candle.

The top and bottom covers on the Lockheed PBA are held in place with "O" ring seals and a band strap. The outer case and cover provide moisture and shock protection for the SCSR. The moisture indicator in the upper cover allows a wearer to determine if the outer case has leaked moisture.

When the latch mechanism is opened, the bottom cover falls away, and the breathing bag deploys from the bottom. The top cover is placed between the wearer and the unit in order to keep the hot outer cover from touching the wearer. This also allows mine air to surround the apparatus and keep it cool.

During a demonstration wear test of the Lockheed PBA, one unit had the breathing bag catch fire. This was caused by potassium superoxide escaping from the chemical bed and bypassing the potassium superoxide catcher, falling into the breathing bag. The combination of thermally hot potassium superoxide with a silicon/fiberglass breathing bag in the presence of about an 80 percent oxygen atmosphere was enough to start the fire.

Despite this serious problem and other design flaws, such as the need for protective goggles to be packaged inside the unit, the Lockheed PBA became the prototype for commercially available, NIOSH/MSHA approved SCSR's. Both MSA and Draeger

refined and successfully commercialized Bureau developed SCSR technology, producing the MSA 60 min SSR and the OXY SR 60 B, respectively.

MSA 10/60

The necessity of discarding the MSA 10-minute SCSR in order to don a one hour SCSR in a contaminated environment was considered by the Bureau of Mines to be design drawback. To overcome this limitation, it was decided that an optimum system would combine a 10-minute, belt-wearable SCSR with a stored, larger, one hour duration oxygen supply that could be plugged into the 10-minute unit without removing the mouthpiece. This 10/60 design concept was developed into a workable technology by Mine Safety Appliance Co., under contract to the Bureau of Mines (Mine Safety Appliances Co., 1976).

Figure 8 shows the MSA 10/60 SCSR as used by a miner for escape purposes. The one-hour oxygen supply is plugged into the 10-minute unit.

For the 10-minute unit, a breathing circuit was developed in which the air is passed through the potassium superoxide bed twice per respiration. The one-hour oxygen supply differs from the 10-minute unit in that air is drawn only once through the chemical bed per respiration. In other words, after connecting both components together, the breathing circuit is switched from a pendulum system to a simple closed loop system. This was necessary to keep the inhaled air temperature within NIOSH approval requirements.

A 6-cm finned aluminum cylinder located in the breathing tube acts as a heat exchanger in the 10-minute device. Location of the heat exchanger in the breathing tube also

prevents the breathing tube from closing. The breathing bag and the manifold in the 1-hour oxygen supply are used as the primary heat exchanger when both components of the MSA 10/60 are assembled together. These heat exchange mechanisms lower inhalation air temperature to less than 115°F, meeting NIOSH certification requirements. Both potassium superoxide canisters have a felt cover to protect the user from burns.

Operation of the MSA 10/60 SCSR involves connecting the 10-minute and one hour-components together. The drawing in Figure 9 shows the flow path through the assembled system.

The manifold system is designed to limit the inhaled concentration to less than 50 ppm of carbon monoxide if the coupling is performed in a mine atmosphere contaminated with 2.5 percent carbon monoxide. The potassium superoxide canisters have hermetic seals over their coupling ports. When the one-hour oxygen supply is pressed against the 10-minute unit, a metal-to-metal seal is made between the ducts prior to opening of either of the individual hermetic seals. Initial rotation of the handle on the latch assembly secures the metal-to-metal seal between the two components. Further rotation punctures the hermetic seals and activates the shutoff valve for the 10-minute unit.

The results of breathing machine and man tests indicated that the MSA 10/60 SCSR will last 60 to 270 minutes, depending on work rate.

SCEBA 60

Given the experience and technology of the late 1960's and early 1970's the development of compressed

oxygen SCSR's held little promise of success. This is the chief reason why the Bureau of Mines invested research and development resources in developing chemical oxygen SCSR technology.

In the late 1970's, however, it became clear that the state-of-the-art in compressed gas breathing apparatus had improved considerably over the past 10 years. This technology had advanced to the point where a compressed oxygen SCSR could be offered as a viable alternative to potassium superoxide SCSR's. Therefore, the Bureau of Mines awarded a contract to U.S. Divers to develop a 1-hour compressed oxygen SCSR suitable for mine escape use (USD Corp., 1983).

The SCEBA 60 as used by a miner for escape is shown in Figure 10. The apparatus includes a mouthpiece, noseclip, breathing hose and bag, a lightweight, single use high pressure oxygen vessel, lithium hydroxide absorbent canister, and a pressure reducing on/off valve.

The SCEBA 60 uses a pendulum flow circuit shown schematically in Figure 11, which provides a push/pull action through the carbon dioxide absorbent bed. Just as in the case of chemical oxygen SCSR's, to minimize size, the SCEBA 60 is a closed circuit breathing apparatus with an external breathing bag being used for gas storage. A compressed oxygen vessel and associated regulating valves control the addition of oxygen to the system.

In addition to these major components, the SCEBA 60 includes an easily reliable pressure gauge, a volume sensing relief valve, and a sealed carry case with quick donning waist and neck straps.

The SCEBA 60 has been approved by NIOSH.

Based on Bureau-developed technology, MSA and Draeger refined the design of the Lockheed PBA into commercial products; the Draeger OXY SR 60 B and the MSA 60 min SSR. These were the only two commercially available NIOSH/MSHA SCSR's at the time the SCSR regulations took effect.

STATE-OF-THE-ART IN SCSR TECHNOLOGY

Five models of NIOSH/MSHA approved one hour SCSR's are commercially available for U.S. use: CSE AU9-A1, Draeger OXY SR 60B, MSA 60 min SSR, OCENCO EBA 6.5, and PASS 700E. All five devices are shown in Figure 12. The size, weight, and operating characteristics of each SCSR are listed in Table 2.

In order to meet the one hour duration requirement, all of the SCSR's are closed circuit breathing apparatus. Both the Draeger OXY SR 60 B and the MSA 464213 use potassium superoxide to generate oxygen and remove carbon dioxide. The CSE AU9-A1, OCENCO EBA 6.5, and PASS 700E store oxygen as a compressed gas and use lithium hydroxide to absorb carbon dioxide. With the exception of the PASS 700E, all of the SCSR's can be worn by the miner as personal protective equipment; the PASS 700E must be carried or stored.

In 1983, the cost of an approved SCSR is about \$500. Taking inflation into account, the target cost of \$50/SCSR projected by the NAE in 1969 becomes about \$150/SCSR in 1982. So the projected and actual SCSR costs differ by about a factor of three.

CONCLUSIONS

The Bureau of Mines successfully pursued the development of SCSR technology, cooperating with private industry to produce three prototype SCSR's approved for in-mine use.

Manufacturers refined and adapted Bureau-developed SCSR technology for commercial production.

BIBLIOGRAPHY

- Lockheed Missiles and Space Corp., (1974), "One-Hour Self-Rescue Breathing Apparatus," Bureau of Mines Contract H0220040.
- Mine Safety Appliances Co., (1972), "Design Report on Short Duration Self-Rescue Breathing Apparatus," Bureau of Mines Contract H0220071.
- Mine Safety Appliances Co., (1976), "Combined Short and Long Duration Rescue Breathing Apparatus," Bureau of Mines Contract H0252079.
- National Academy of Engineering Committee on Mine Rescue and Survival Techniques (1969), Mine Rescue and Survival, Final Report, Bureau of Mines Contract No. S0190616.
- USD Corp., (1983), "Compressed Oxygen Self-Rescuer," Bureau of Mines Contract J0100092.
- Westinghouse Electric Corp., (1971), Manual of Operating Instructions Personal Breathing Apparatus (PBA) for Coal Mine Rescue and Survival System, Bureau of Mines Contract H0101262, March 1971.

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TABLE 1. - Specifications of Bureau developed SCSR's

SCSR	Duration (min)	Weight carried (kg)	Volume (ℓ)	Oxygen source
Westinghouse PBA.	60	3.95	8.60	chlorate candle
Lockheed PBA	60	2.04	3.28	potassium superoxide
MSA 10 min SCSR..	10	1.09	1.64	potassium superoxide
MSA 10/60	10	1.91	2.79	potassium superoxide
	60	3.86	-	
		(both deployed)		
SCEBA 60	60	2.82	5.80	compressed oxygen

TABLE 2. - Specifications for commercially available,
approved 1-hour SCSR

SCSR	Carrying weight (kg)	Deployed weight (kg)	Volume (ℓ)	Oxygen source
CSE AU9-A1	5.00	4.32	5.80	compressed oxygen
Draeger OXY SR 60B.	3.81	3.36	6.00	potassium superoxide
MSA 60 min SSR	3.14	3.04	5.90	potassium superoxide
OCENCO EBA 6.5	3.50	3.09	7.41	compressed oxygen
PASS 700 E	8.64	6.59	12.41	compressed oxygen



FIGURE 1. - Bureau developed SCSR's.



FIGURE 2. - Westinghouse PBA as worn by a miner for escape.

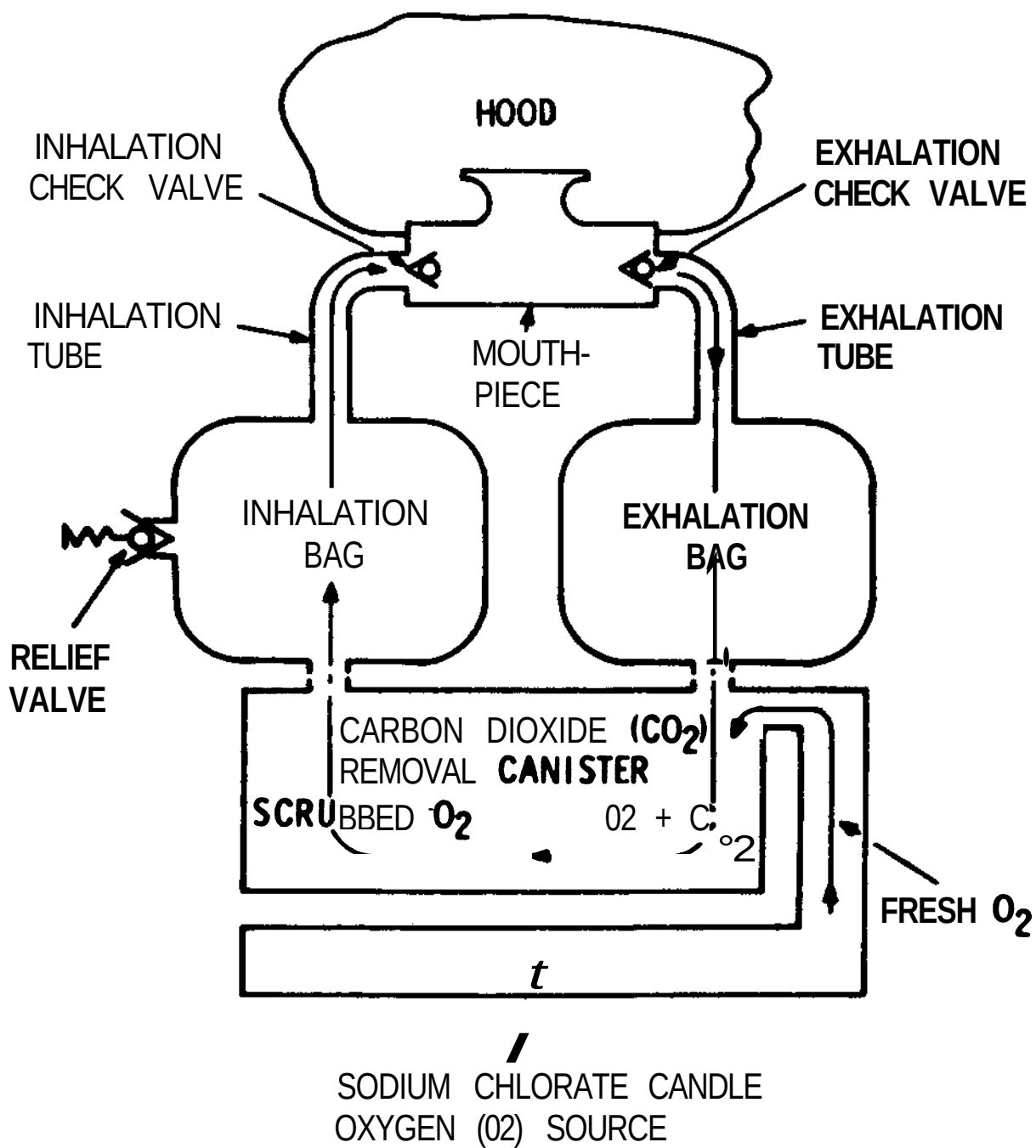


FIGURE 3. - Flow path through the Westinghouse PBA.



FIGURE 4. - MSA 10-minute SCSR as worn by a miner for escape.

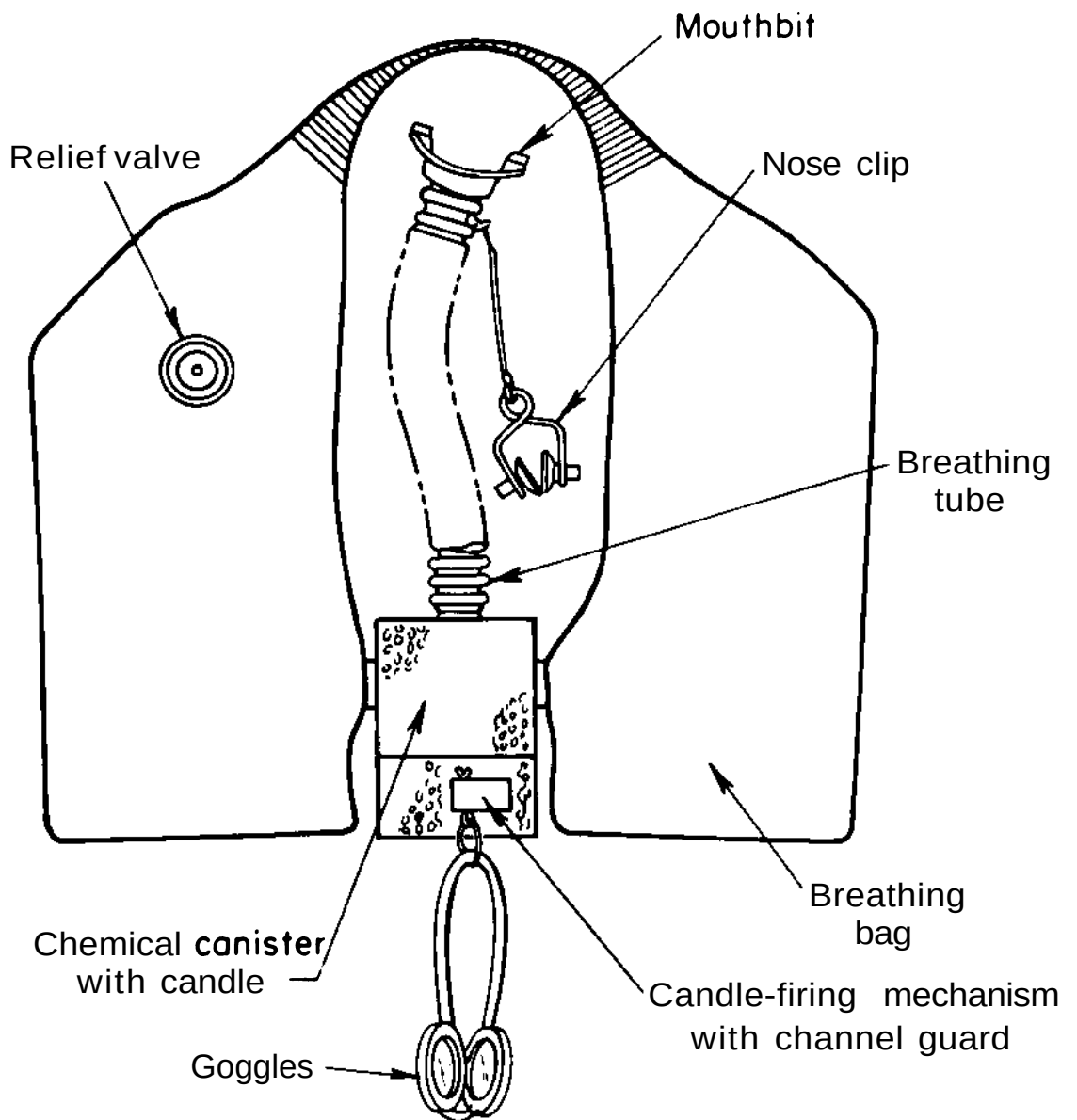


FIGURE 5. - Flow path through the MSA 10-minute SCSR.

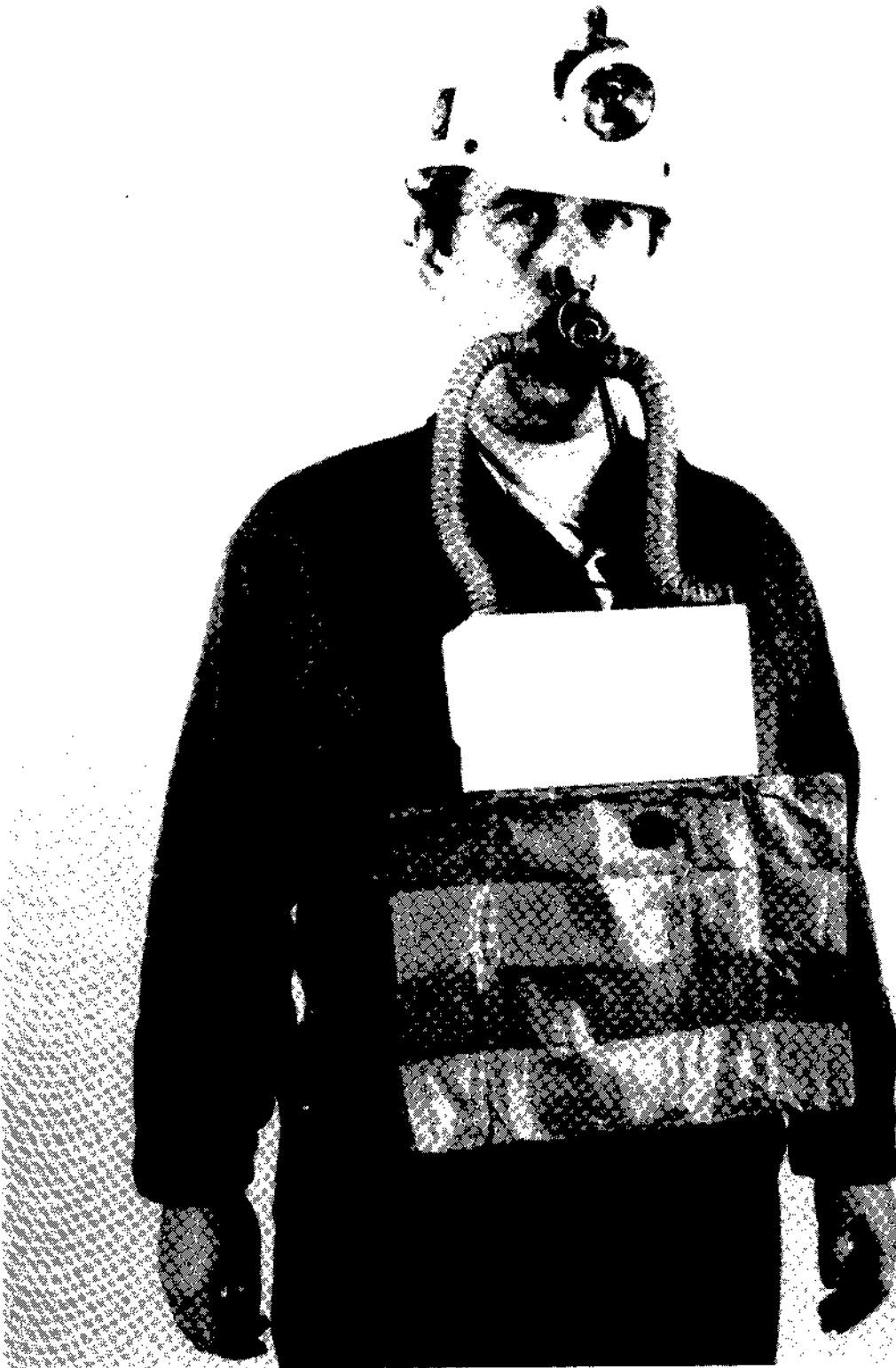
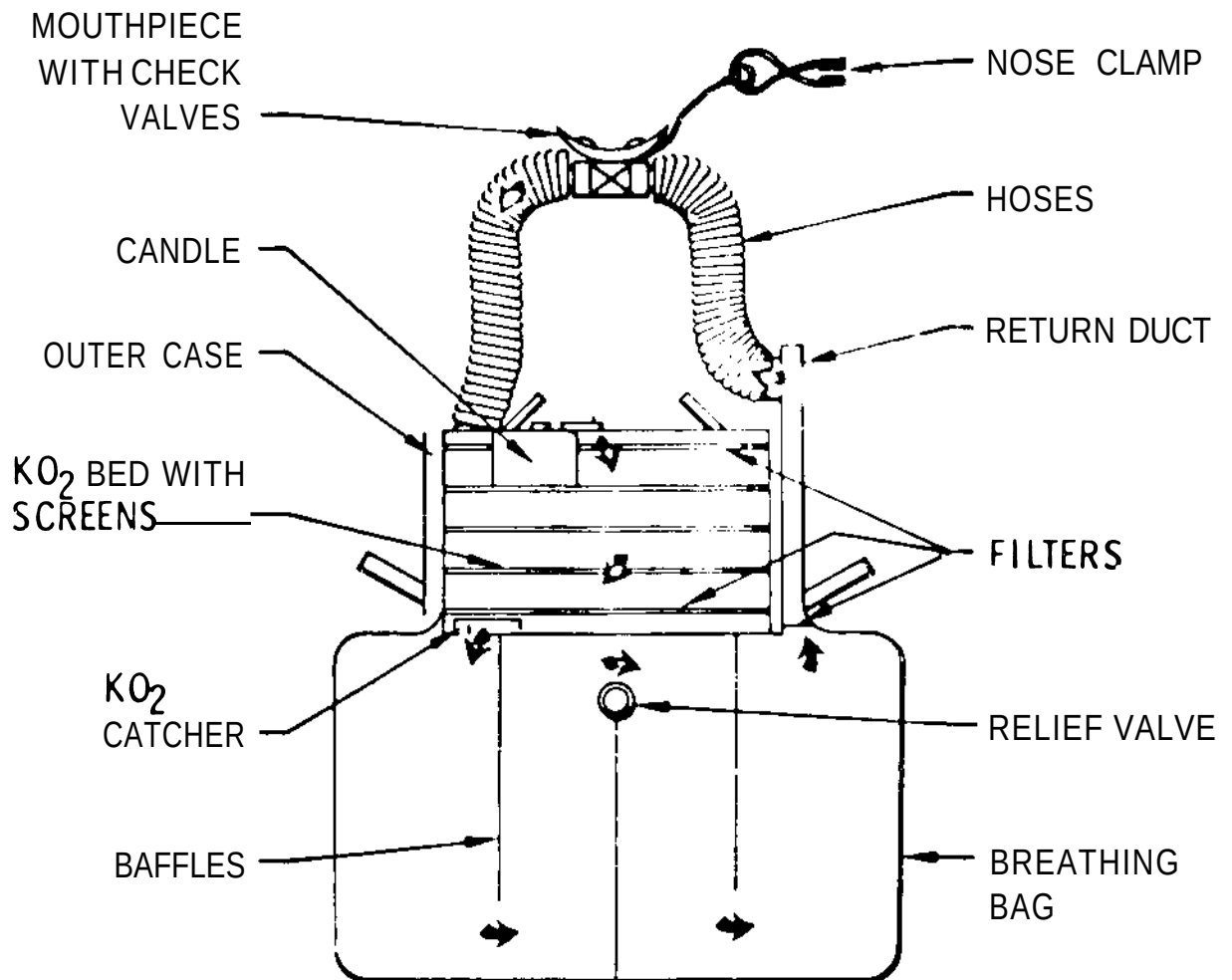


FIGURE 6. - Lockheed PBA as worn by a miner for escape.



DIAGRAM

FIGURE 7. - Flow path through the Lockheed PBA.



FIGURE 8. - MSA 10/60 SCSR as worn by a miner for escape.

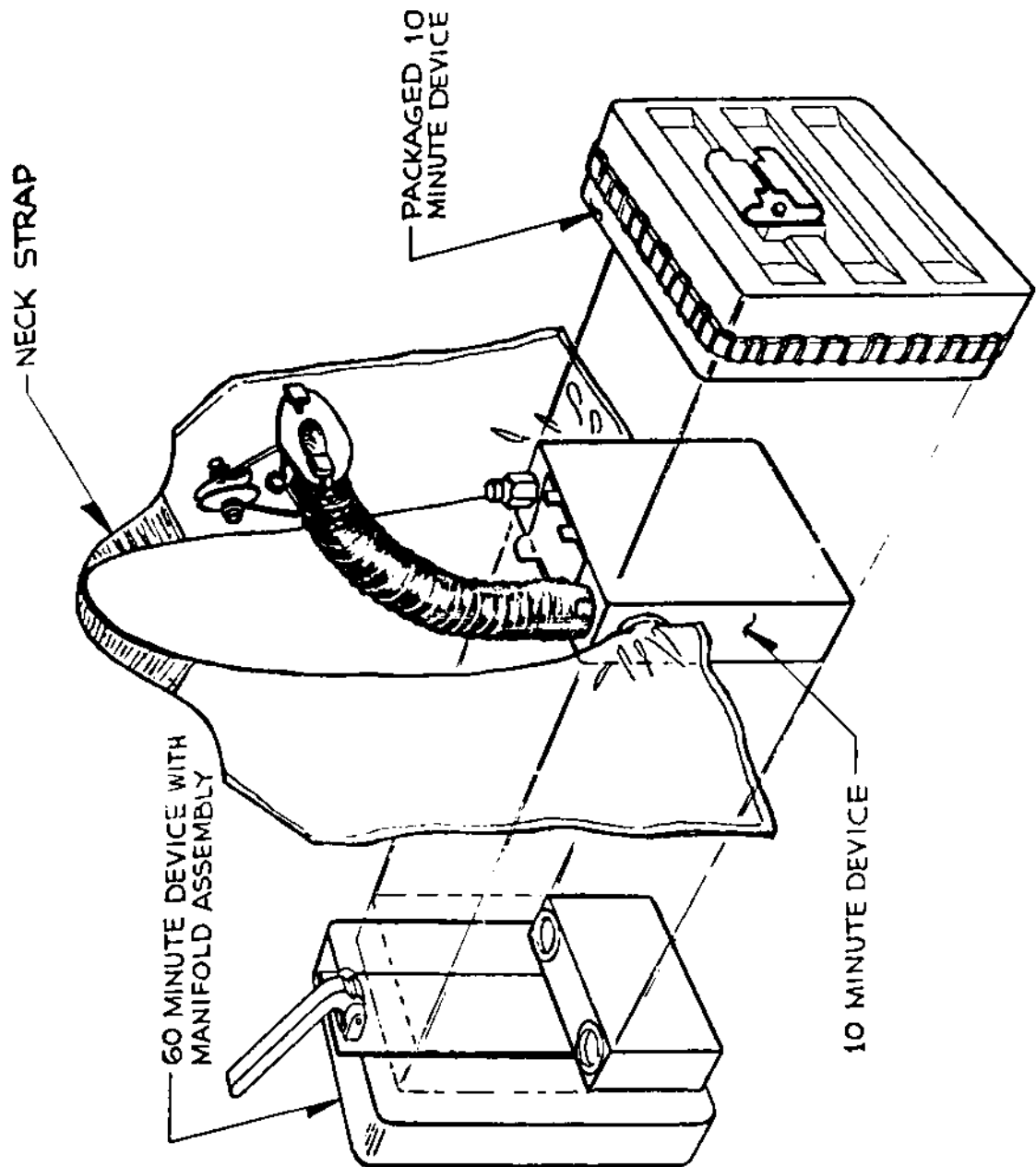


FIGURE 9. - Flow path through the MSA 10/60 8C8R.



FIGURE 10.- SCEBA 60 as worn by a miner for escape.

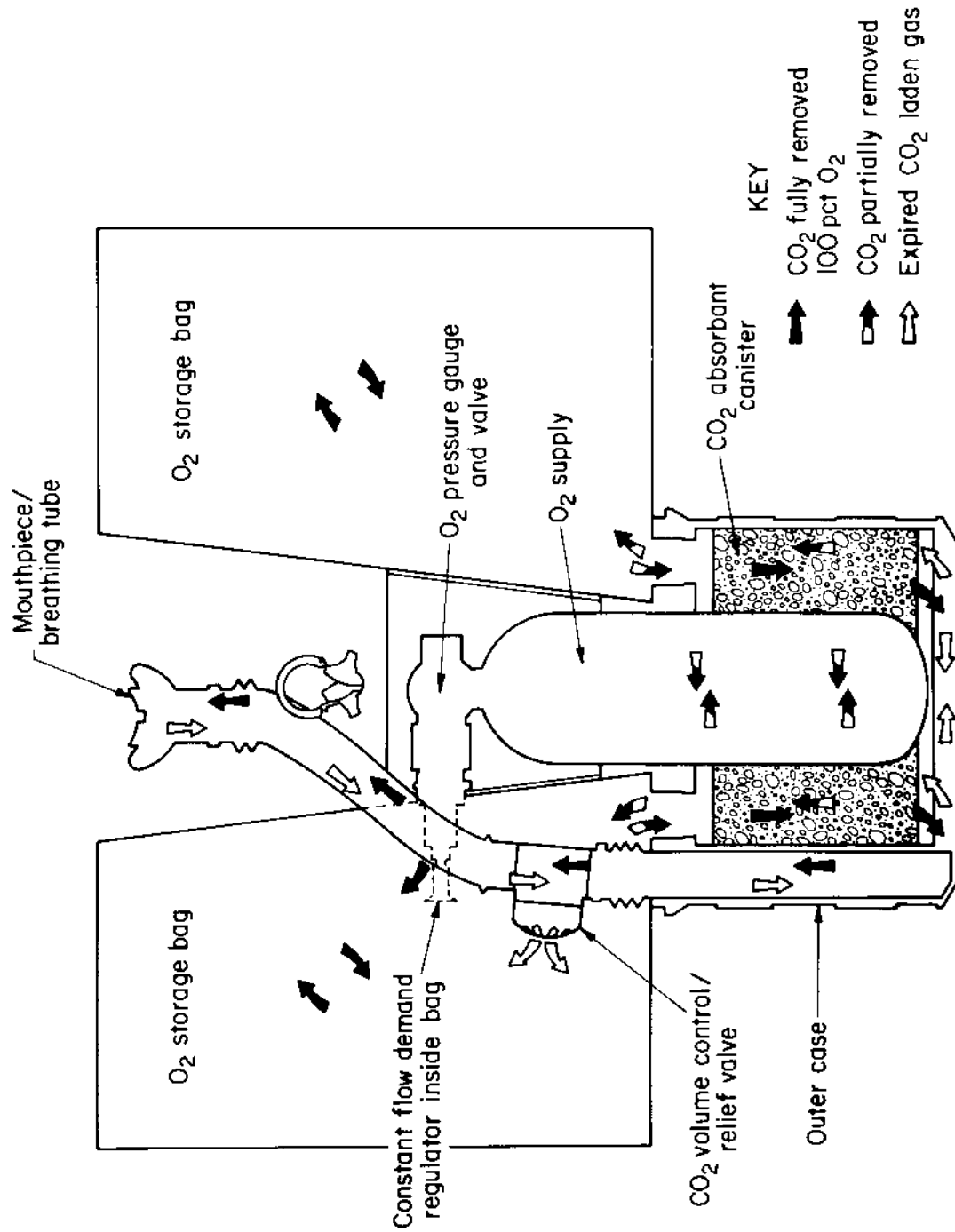


FIGURE 11.- Flow path through the 8CEBA 60.

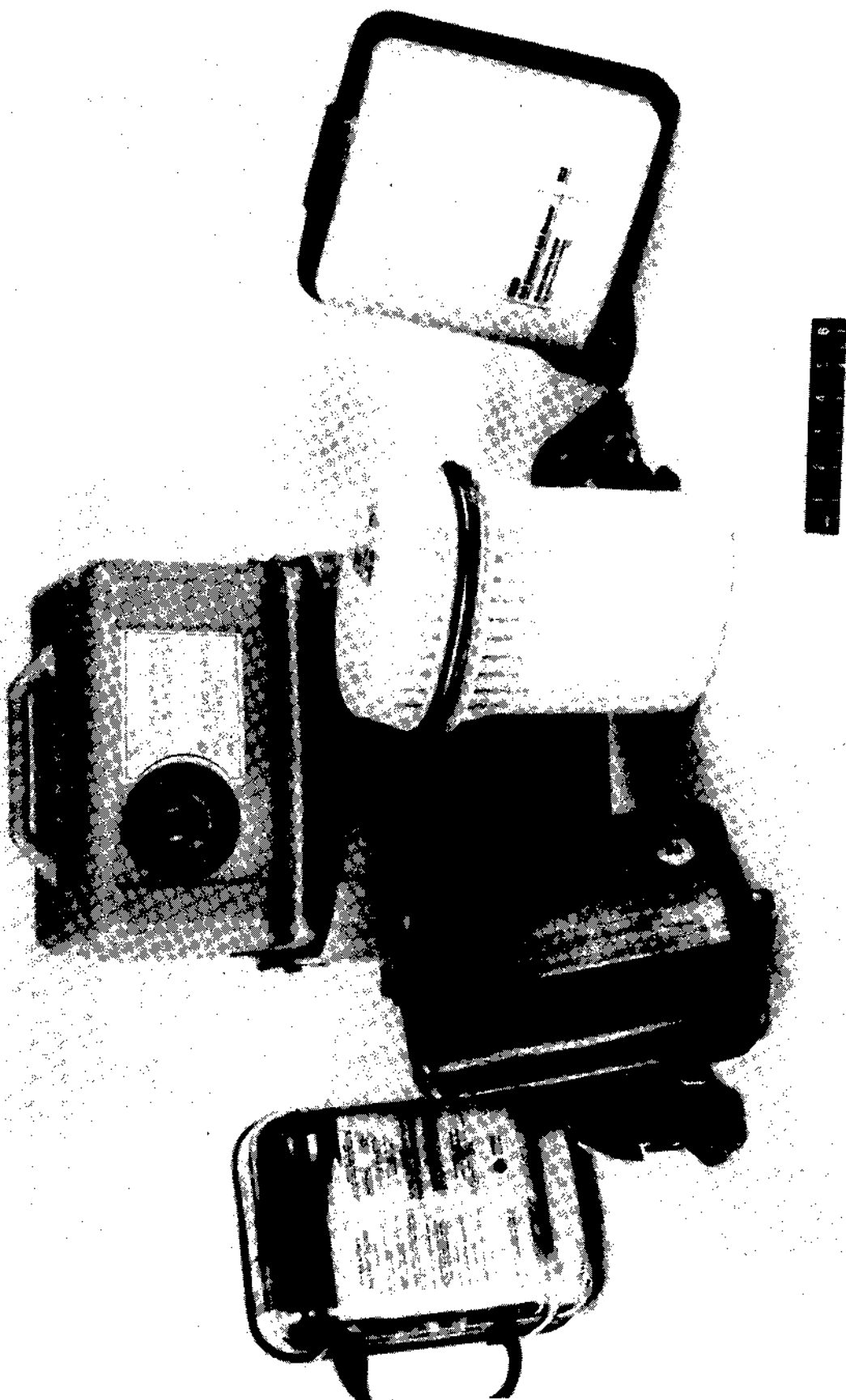


FIGURE 12.- Commercially available approved SOSR's.