

1

PORTABLE BREATHING APPARATUS FOR COAL MINES

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Although recent emphasis has been on breathing apparatus for space and deep underwater applications, the earliest interest in breathing apparatus was prompted by the need to protect miners engaged in mine rescue operations and underground firefighting. The first self-contained oxygen breathing apparatus for use in mines appears to have been developed in 1853 by Prof. Schwann (ref. 1); however, a really satisfactory oxygen breathing apparatus was not developed until 1906, by Draeger of Germany. By 1908, the Draeger apparatus had been introduced in U.S. coal mines, and the Technological Branch of the U.S. Geological Survey had purchased several. The Bureau of Mines inherited these upon its creation in 1910, and by 1911 it had acquired 150 self-contained oxygen breathing apparatus, including a second German model, the Westphalia, and the "Pronto" produced in England by Fluess. In 1912, the Bureau-sponsored Second National Mine Rescue and First Aid Conference (ref. 2) reported that instruction and training in the use of breathing apparatus had penetrated to every coal field and to several metal mining areas in the United States. At this conference also, it was resolved that "breathing apparatus used for mine rescue and mine recovery work should be of such types as passed the test of the Bureau of Mines" and that "the keeping of birds and mice at rescue stations for the purpose of detecting carbon monoxide is desirable." This last resolution was prompted by consideration for those older miners who preferred to wait until a bird or mouse toppled over before encumbering themselves with breathing apparatus.

Prior to World War I, only foreign-made oxygen breathing apparatus were used in this country, but by 1915, the Bureau was engaged in developing an apparatus that would be free of the "well-defined limitations" (ref. 3) of the imported models. Specifically, the new design was to meet the oxygen requirements of a man exerting himself to full physical capacity, to be lighter, to furnish more air, and to leave hands and arms free. This effort resulted in the Gibbs apparatus in 1916, the Paul apparatus in 1920, and the McCaa in 1926 (ref. 4). A somewhat improved version of the McCaa apparatus is still widely used in U.S. coal mines. These and similar self-contained oxygen breathing apparatus subsequently developed in this country and in Europe are based on the use of compressed oxygen.

From time to time, various other types of oxygen breathing apparatus have been developed. In the early 1940s a self-contained breathing apparatus supplied with chemically generated oxygen and giving 45-min protection (Chemox, ref. 4) was developed by the Navy. Used for firefighting in World War II, it was subsequently made available to industry and introduced into coal mines as auxiliary rescue equipment. A 2-hr liquid oxygen apparatus (ref. 5) and a 2-hr liquid air apparatus are also available (ref. 6). Nevertheless, most of the self-contained oxygen breathing apparatus used today in U.S. coal mines are but updated versions of a 45-year-old compressed oxygen design. Although heavy, bulky, and expensive, they have proved to be reasonably adequate for team rescue work.

In environments with sufficient (16 percent or more) oxygen, the universal gas mask (refs. 1,4,7) developed by the Bureau of Mines soon after World War I, has been widely used in mines, especially for recovery work. Although designed primarily to protect against carbon monoxide, universal gas masks, also known as Type N masks, afford protection against other toxic and noxious gases and vapors in concentrations up to 2 and 3 percent, and against smoke. They were approved for use in coal mines in 1925. Although gas masks are less cumbersome than the oxygen breathing apparatus, their dependence on an adequate oxygen concentration and their limited capacity for any one contaminant reduce their usefulness. The Federal Coal Mine Health and Safety Act of 1969 established a minimum oxygen concentration of 19.5 percent, further limiting the conditions for acceptable use of the universal gas masks. The National Fire Protection Association Subcommittee on Protective Equipment recently adopted a strong recommendation against the use of Type N gas masks by firefighters.

Another type of portable breathing apparatus, the one with which we are most immediately concerned, is the apparatus used under emergency conditions by miners escaping from a toxic environment. These are the carbon monoxide self-rescue respirators, more generally known as self-rescuers, which were first approved by the Bureau of Mines in 1924 (refs. 2,8). The self-rescuers are compact enough to be worn on the miner's belt; they are designed exclusively for protection against carbon monoxide, and like the universal gas mask are not intended for use in air containing less than 16 percent oxygen. Their operation is based on the catalytic conversion of carbon monoxide to carbon dioxide by hopcalite, which was first developed in the early 1920s at the University of California and Johns Hopkins University under a Bureau of Mines grant. A model providing at least 1 hr of protection is available. The use of self-rescuers is limited to reasonably low carbon monoxide concentrations because the heat generated by catalytic conversion to carbon dioxide increases with the carbon monoxide content of the intake air. With high concentrations, the inhaled air may become intolerably hot and dry, and since the mouthpiece is simply clamped between the wearer's lips and teeth, the urge to open the mouth for a breath of relatively cool but lethal air can be a very real hazard.

Certain other design features also limit the effectiveness of the self-rescuer. Moisture and organic vapors impair the activity of the catalyst, and the wearer has no way of determining whether it is functioning properly. Protection for face and eyes against dust and smoke is also lacking. All forms of voice communication by the wearer are precluded.

In a recent survey of disasters in U.S. coal mines from 1950 to 1969, a National Academy of Engineering committee (ref. 5) estimated that at least 20 percent of those who died could have been saved if adequate postdisaster survival systems had been available. Of 451 fatalities in 28 major mine disasters (disasters resulting in five or more deaths), 83 were attributed to asphyxiation by smoke or carbon monoxide or both, and five to suffocation by carbon dioxide. In the same period 115 men died in so-called "minor disasters" (involving fewer than five deaths); 35 of these deaths were attributed to carbon monoxide and smoke, and three to carbon dioxide.

These findings demonstrate what has been known for many years—that the hazards of a mine disaster are not limited to its violent phase. They underline the importance of postdisaster procedures. As early as 1928, S. H. Katz and J. J. Forbes (ref. 8) wrote: "More miners have probably been killed by carbon monoxide than by fires or the violence of explosions . . . it seems that the half-hour of protection given by a self-rescuer would in most instances have assured their escape."

The Federal Coal Mine Health and Safety Act of 1969 requires that mine operators provide every miner with a self-rescue device offering 1 hr or more of protection; at present, only the

hopcalite self-rescuers are available. The Act also established a greatly expanded program of research and development in all phases of coal mine health and safety. Clearly, improved breathing apparatus should be a part of this program.

The National Academy of Engineering report (ref. 5) proposed a complete system for postdisaster mine survival and rescue. One element of the survival subsystem was to be a portable breathing apparatus (PBA), light enough and small enough to be carried by the miners, to replace the present self-rescuers. The Bureau of Mines funded a contract with Westinghouse Electric Corporation for the entire system, and required, as part of the survival subsystem, a 1-hr PBA. Frank Martin describes the development of the PBA in paper 6. However, problems still remain. The PBA developed under the hurried contractual effort required by the Bureau is so bulky and so heavy that it is unrealistic to expect the miner to wear or carry it constantly.

The requirements for PBAs in coal mines have much in common with those for other hostile environments, such as space or underwater. In all cases oxygen must be supplied and carbon dioxide removed at rates appropriate to the metabolic load. However, there are important differences. For a lunar backpack, bulk is a nuisance in egressing the lunar module, but in the lunar environment the bulk and the weight of the backpack become less significant. Underwater, bulk can again cause inconvenience but weight is relatively unimportant. In a coal mine, bulk and weight assume commanding importance, probably in that order, but there are other special requirements that must be imposed on any PBA designed for self-rescue. The apparatus must be capable of easy and rapid donning because a toxic atmosphere may descend on the miner with little warning. Eye protection against smoke and dust is very desirable, and because visibility may be reduced, voice communication should be possible without exposing the wearer to a toxic atmosphere. Further, in the United States, some 50 percent of coal is mined from seams 4 ft thick or less. Except in a few locations, the height of the work space is the height of the coal seam, sometimes less. Under this low roof, the miner must carry out arduous work, operate machinery, or drive a shuttle car, while already encumbered by a caplamp battery and at times by a respirable dust sampling pump and battery. Some miners also carry other instruments or equipment.

As Dr. Alan Chambers has pointed out (ref. 9), the probability of success for a surface-stationed rescue device is just the probability of its proper functioning. On the other hand, the probability of success for a self-rescue device is the product of probability of its proper functioning and the probability of its timely use by the miner. The probability of timely use will approach unity only if the device is worn by all miners constantly; this means providing the miner with a small and lightweight PBA that he will accept as one more thing to wear on his belt.

Existing technology does not seem capable of producing such a PBA that will function for 1 hr at a high metabolic rate. According to the 1969 Act, a 1-hr self-rescue device "shall be made available to each miner . . ."; wearing is not required. As a result, the Bureau has recently published its search for R&D sources for a 10-min device that is believed feasible within reasonable constraints of bulk and weight. Ten minutes should provide ample time for miners to reach a fresh air base or a cache of longer duration PBAs, or to escape from a small mine or even a large one if they are near a portal or shaft. The cache of longer life PBAs in each section could be moved as the mine workings advance or retreat. Even in a large section, miners should not be more than a few hundred feet from a conveniently located cache.

The longer duration PBA could provide 1 hr of protection, which should allow escape from most mines under most circumstances. However, a 2-hr device might be necessary if the distance to an exit is great, if injured miners are to be assisted, or if progress is impeded by detours

necessitated by fires, roof falls, and the like. With a certain percentage of the weight and cost fixed, perhaps a 2-hr PBA might not be an unrealistic goal.

A study of the time required to rescue survivors or locate fatalities from carbon monoxide asphyxiation revealed an interesting breakpoint. Of 87 that were rescued, 82 were rescued in 6 hrs or less after the fire or explosion, and the bodies of about 20 percent of those who succumbed from asphyxiation were recovered within the same elapsed time. The other miners were rescued or recovered one to many days later. Although they represent a rather small sample, these data suggest the desirability of a 6-to 8-hr PBA (with a corresponding loss in portability).

Bureau personnel with experience in mine rescue and recovery, or in reopening operations, believe that rescue apparatus of longer duration than the most common 2-hr apparatus would be extremely valuable. Along with increased duration, a reduction in bulk and weight made possible by improved technology would be welcome.

For the necessary improvements in rescue and self-rescue portable breathing apparatus, the Bureau of Mines seeks to take advantage of the expertise of the members of this conference and their colleagues to advance life support technology and provide greater protection to miners in underground "space."

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