Respiratory Protection and Respirable Dust in Underground Coal Mines

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I. INTRODUCTION

During the past several years, and especially as a result of the enactment of the Federal Coal Mine Health and Safety Act of 1969, much attention has been focused on respirable coal dust and various means of preventing the inhalation of such dust, including the use of dust respirators.

The use of respirators in coal mines is certainly not new and, in fact, almost 40 years ago the Bureau of Mines first established performance requirements under Schedule 21(1).* However, there was little information available about the usage of respirators in the field and, importantly, there was no information on how effective are dust respirators under actual working conditions. Consequently, the National Institute for Occupational Safety and Health sponsored a research project with Eastern Associated Coal Corp., with the Harvard School of Public Health acting as a subcontractor. The three major objectives of this project were:

a. To determine, by means of a field survey, the current status of respirator usage with regard to duration and frequency of use, types, and maintenance levels.

b. To determine protection factors provided by respirators worn by working miners.

c. To make recommendations on ways to improve existing units, or on research needed to develop new types of respiratory protective devices for coal miners.

II. FIELD SURVEY

A field survey (2), which was carried out in 1970 and 1971, involved visits to 47 mines and interviews with 511 supervisory and underground mining personnel; personnel interviewed included representation of all of the major job classifications found in underground mining operations.

Results from this survey showed not only was there rather widespread possession and usage of dust respirators (a small percentage of which, incidentally, were not Bureau of Mines approved) but the working miners expressed strong sentiments for the need for use of respirators, Table I.

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*Underlined numbers in parentheses refer to references at the end of this paper.

TABLE I. Need for Use of Respirators in Coal Mines

	Percent of Underground Work Force*
Generally Needed	42
Used Whenever Dust is Present	45
Used Only When Necessary	4
Needed, but are Hard to Wear	8
Prevent Dust to Make Usage Unnecessary	1

*428 people in various job classifications, plus 17 Section Foremen

It was also found that virtually all coal miners use respirators on an intermittent basis, i.e., putting the respirator on and taking it off a varying number of times during a work shift. Based on intermittent use, a significant number of miners found the presently available, approved respirators to be only marginally acceptable or unacceptable, Table II.

TABLE II. Respirator Acceptability Based on Intermittent Use

	Percent of Underground Work Force*
Completed	2
Generally	64
Marginally	24
Unacceptable	10

*See Note on Table I.

Major complaints about current dust respirators in use could be placed in two categories, namely, breathing difficulties and physical discomfort, Table III, and, consequently, the miners want respirators that are more comfortable and provide easier breathing, Table IV.

TABLE III. Problems Associated with Respirator Use

		Percent of Underground Work Force*
Cause Breathing Difficulties		37
Physical Discomfort		55
Generally Cumbersome and Uncomfortable	13	
Cause Perspiration	9	
Interfere with Tobacco Chewing	9	
Troublesome Head Harness	7	
Respirator Too Large	6	
Facepiece Troublesome	5	
Dust Inside Mask	5	
Improper Fit	1	
Interference with Work		9
Restricts Vision or Interferes with Wearing Glasses	5	
Exhalation Valve Troublesome	2	
Interferes with Communications	1	
Difficult to Carry	1	

*See note on Table I.

TABLE IV. Improvements in Respirators Desired by Mining Personnel

	Percent of Underground Work Force*	
Improvements	A	B**
Easier Breathing	19	28
Comfortable Facepiece	12	18
Smaller Unit	11	16
Comfortable Head Harness	11	16
Lighter Unit	6	9
Better Filter	5	7
Better Valves	2	4
Easier to Carry	1	2
Educate Men to Use Them	3	-
Cannot Be Improved	2	-
Do Not Know	28	-
	100	100

* See Note on Table I.

** Percentage Recomputed from Part A by eliminating last three items in Part A.

Further information on results of the field survey have been reported elsewhere.(2)

III. PROTECTION FACTORS

1. General

As mentioned previously, the field survey revealed that virtually all underground miners wear respirators only on an intermittent basis. This, coupled with the fact that the accumulated exposure of miners to respirable coal dust is considered to be of importance with respect to the incidence of coal workers pneumoconiosis, indicated two protection factors should be determined. One protection factor, entitled "Effective Protection Factor (EPF), represents the amount of protection obtained by working coal miners over the entire work shift when the respirators are used intermittently and worn according to the miner's training and work habits. Therefore, EPF was determined, in the field, by sampling separately, but concurrently, the ambient air and the air inside the respirator facepiece; over the entire working shift the concentration of respirable dust was determined for each sample. EPF was calculated as follows:

$$EPF = \frac{DC_A}{DC_M} \qquad 1)$$

where:

EPF = Effective Protection Factor

DC_A = Dust Concentration in the mine air

DC_M = Dust Concentration in the air in the respirator mask.

Since sampling was done over the entire working shift both DC_A and DC_M are time weighted average concentrations of respirable dust.

While EPF represents the protection provided to the working coal miner, it does not tell how much protection is provided by the half-mask respirator when the respirator is actually worn. Consequently, True Protection Factor (TPF), which is defined as the amount of protection the user receives when he is actually wearing the respirator and in accordance with the manufacturer's instructions, was determined by sampling separately but concurrently the ambient air and air inside the facepiece only when the respirator was worn; respirable dust concentrations were determined for both samples. TPF was calculated as follows:

$$TPF = \frac{DC_S}{DC_R} \qquad 2)$$

where:

TPF = True Protection Factor

DC_S = Dust Concentration in the Mine Air in the Vicinity of Miner wearing the respirator

DC_R = Dust Concentration in the air inside the respirator facepiece.

2. Equipment and Procedure:

a. Equipment

For determining EPF's, mine air sampling was done with conventional personal mass respirable sampling equipment (3) in use throughout the coal industry. Air inside the facepiece of the respirator was sampled using the same mass respirable sampling equipment, Figure 1, with the cyclone mounted on the respirator and connected to a sampling port inside the respirator (4). Also, located inside the facepiece, Figure 2, was a thermistor which is a part of a time-of-wearing device (4) that was used to determine the amount of time the respirator was actually worn.

In the case of TPF, sampling of the mine air and the air in the mask was done using two GCA RDM-101 Respirable Dust Monitors (5) both equipped with the same 10mm AEC Cyclone as used with the personal samplers. Figure 3 shows the sampling equipment in actual use underground.

FIGURE 1 - TEST SUBJECT WEARING SAMPLING EQUIPMENT

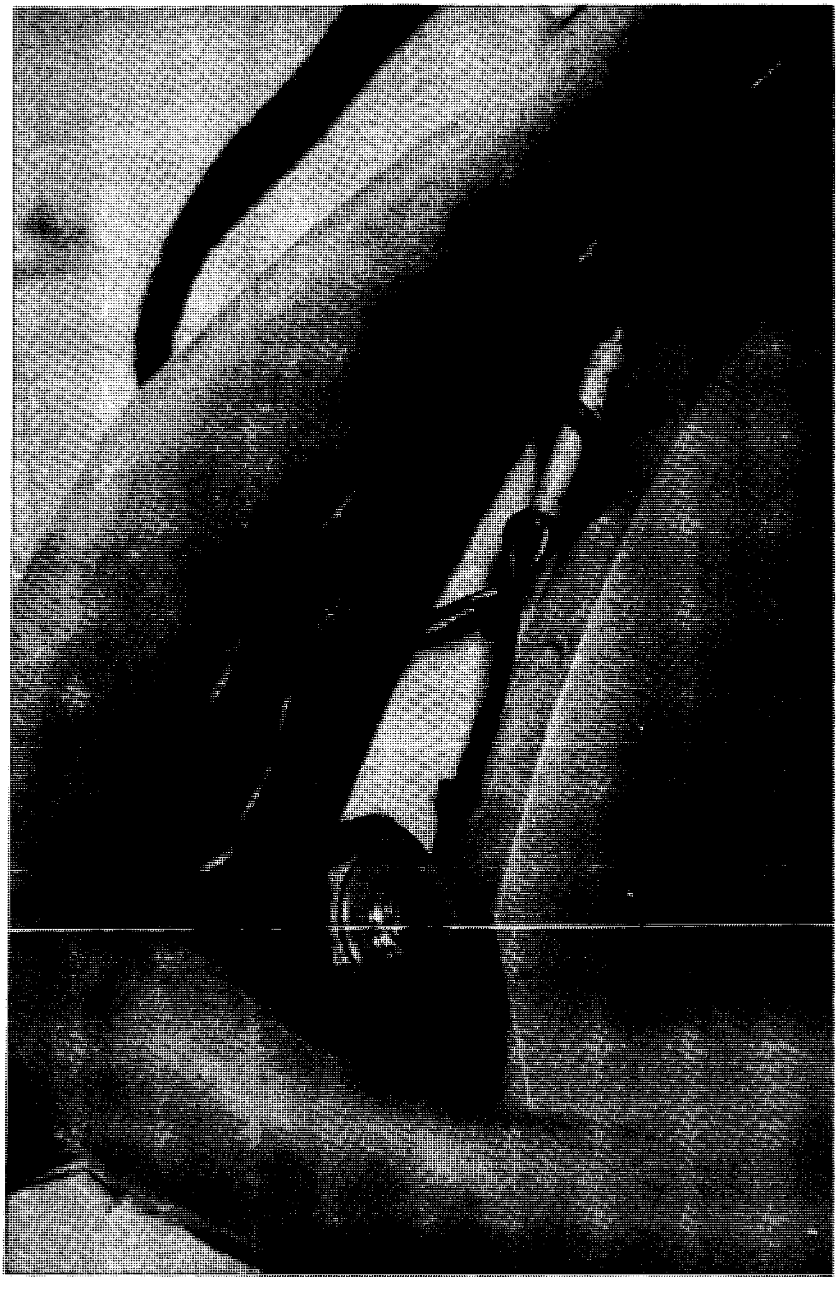

FIGURE 2 - INSIDE OF RESPIRATOR FACEPIECE SHOWING THERMISTOR

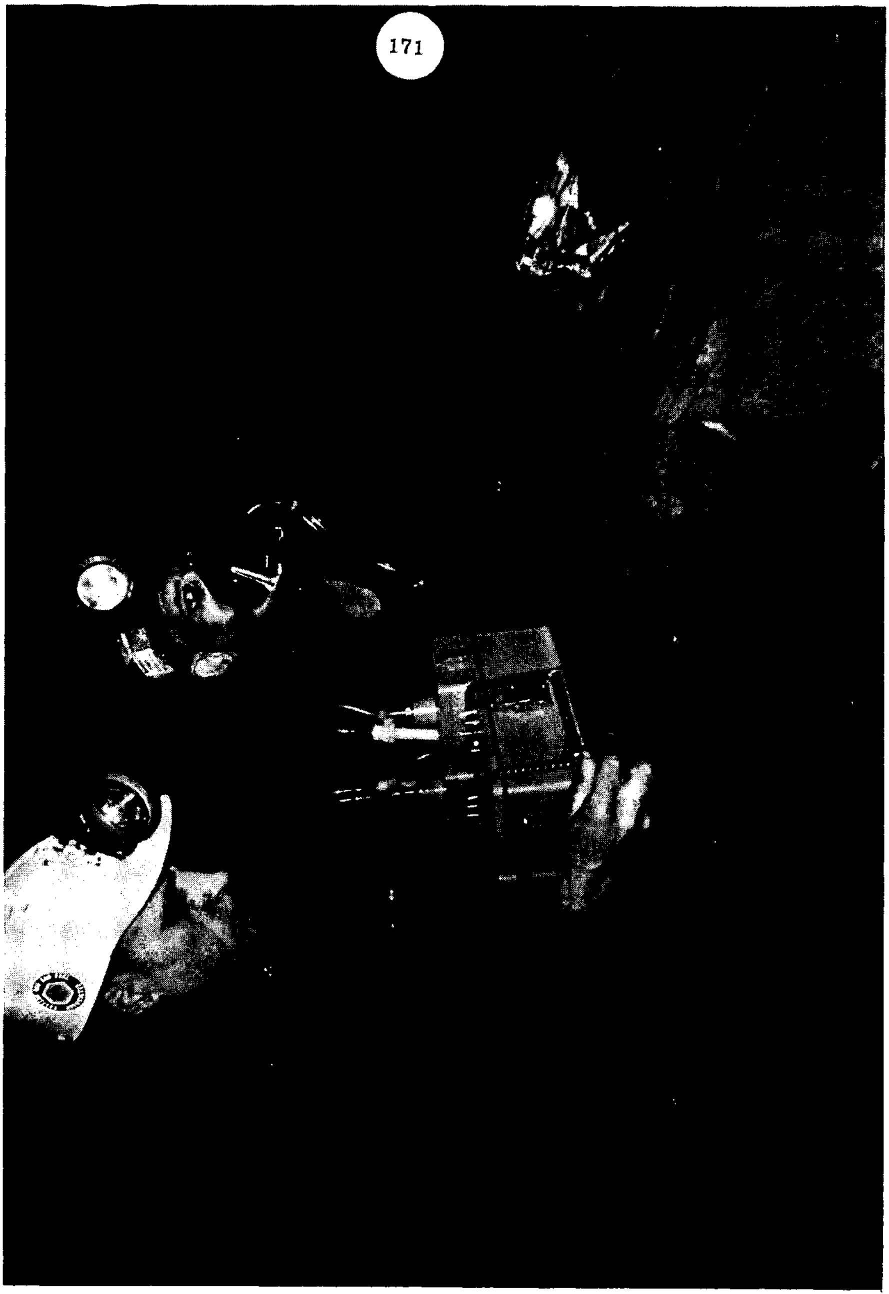

FIGURE 3 - TRUE PROTECTION FACTORS SAMPLING EQUIPMENT

b. Procedures

For EPF's, air and in mask sampling was done from the time each test subject miner started work until work ceased at the end of the shift, except for the lunch period. As shown in Table V, testing was done in five different mines and involved 208 man shifts and 13 different job classifications, mostly those at the working face. Five different models of respirators were used.

TABLE V. Scope of Testing - Effective Protection Factor

No. of Mines	5
Days of Testing	26
Man Shifts of Testing	208
Test Subjects (by job classification)	Number
Continuous Mining Machine Operator	5
Continuous Mining Machine Helper	1
Loading Machine Operator	6
Roof Bolter	3
Shuttle Car Operator	7
Bratticeman	2
Cutting Machine Operator	2
Coal Driller	2
Longwall Machine Headgate Operator	1
Longwall Machine Tail Operator	1
Longwall Machine Jack Machine Operator	2
Safety Technician	4
Rock Duster	8
Research Investigator	1
Total	45

For the TPF, 8 different face miners and one research engineer were used as test subjects. These people, which included 6 different job classifications of face miners, represented 8 different facial sizes as classified by the system set forth by Hyatt, et al (6); a diagram of this system is shown in Figure 4. Each of the test subjects wore 5 different respirator models over a 3 day period. During the period each respirator was worn, four sampling runs, each of four minutes duration, were made in which the mine air in test subjects' breathing zones and the air inside the respirator facepiece were sampled concurrently.

3. Results

While all of the data have been obtained, the analyses of the data had not been completed at the time this manuscript was prepared; consequently this should be considered in the nature of a progress report.

The distribution of EPF's for all the test subjects who were face miners is shown in Figure 5 and, similarly, the distribution for TPF's is shown in Figure 6. Some interesting differences can be observed.

Figure 4

Facial Size Classification Diagram

(Job Classification of Test Subjects put in appropriate block according to facial measurements)

Face Width, mm

FACE LENGTH, mm	129 - 139	140 - 145	146 - 155
136 126-	A Roof Bolter	B Cutting Machine Operator	C Continuous Miner Operator
125 116-	D Bratticeman	E Timberman Loading Machine Operator	F Roof Bolter
115 105-	G Research Engineer	H Loading Machine Operator	I None

DISTRIBUTION OF PROTECTION FACTORS

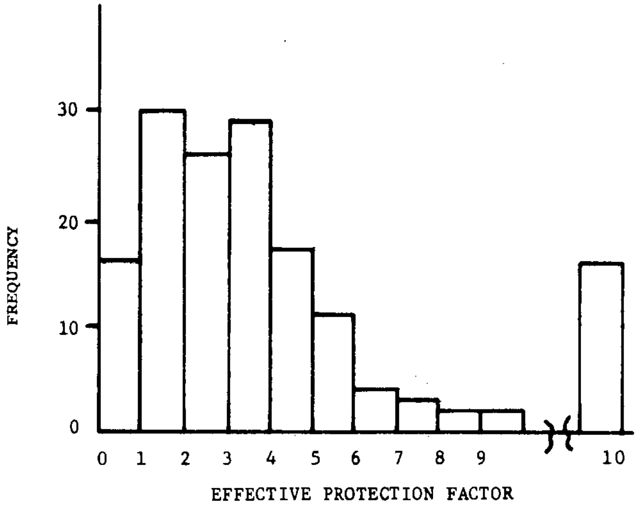

FIGURE 5

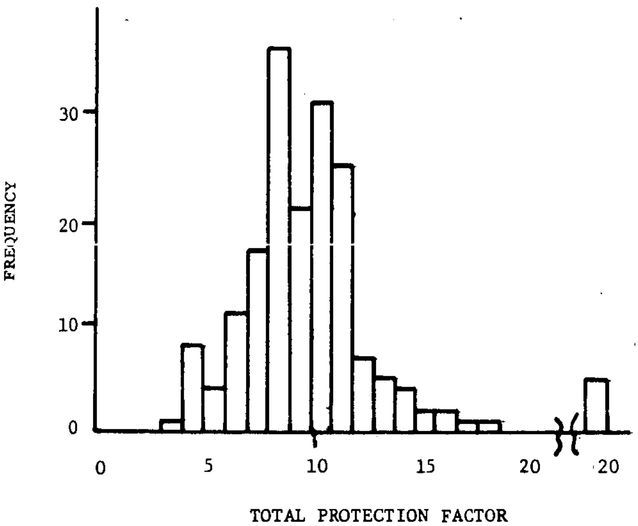

FIGURE 6

For the EPF's, values ranged from less than one to as high as 40 and above; however, most of the values were in the one to four range. Of the 151 values obtained, 16, were less than 1.0. While it may seem surprising that on occasion a respirator user is, either getting no protection at all or is possibly inhaling more respirable dust than is present in the ambient air, field observations indicate such is the case. For example, it is quite possible that respirable dust collected on the miner's clothes could be brushed off or knocked loose and be collected in the mask, which was worn hanging loose on the wearer's chest, thereby creating the higher dust concentrations found in the mask.

Unlike the EPF's, the TPF's showed a reasonably normal distribution and with little difference between mean and median values.

As shown in Figure 7, during the EPF test work the time the respirators were actually worn during the work period by the test subjects varied from a low of about 10 percent of the time to almost 90 percent; the mean average was about 46 percent of the time. It might be expected that a relationship should exist between the length of time the respirator is actually worn and the level, or effectiveness, of the protection obtained; in other words, the longer the respirator is worn, the better the protection (higher EPF) obtained. However, so far we have found no relationship to exist between the time the respirator was worn and the protection obtained. This suggests there are probably other factors that obviate the effect of time of wearing.

Test results for the five different models of respirators tested (for EPF) is shown in Table VI. It should be noted that the data shown include some very high values and values, as mentioned previously, where the EPF is less than 1.0. Both can, of course, influence the mean average and, consequently, the median value is also shown. Although we have not completed a statistical analyses of the data, it does appear there are differences among the respirators tested with respirators B and E being less effective than the others.

TABLE VI. Comparison of Different Respirator Types Tested

Respirator	No. of Test Subjects	Effective Protection Factor (EPF)	
Model		Mean Avg.	Median
A	8	4.9	3.4
B	11	5.0	2.6
C	11	6.8	3.7
D	6*	8.5	3.9
E	4	3.2	2.0

* Actually 3 different test subjects.

The TPF's obtained for the same five respirators is given in Table VII. While, in each case, the TPF obtained was substantially higher than the EPF, the TPF is still somewhat less than that theoretically possible based on filter efficiencies.

PORTION OF WORK PERIOD THAT RESPIRATORS WERE WORN

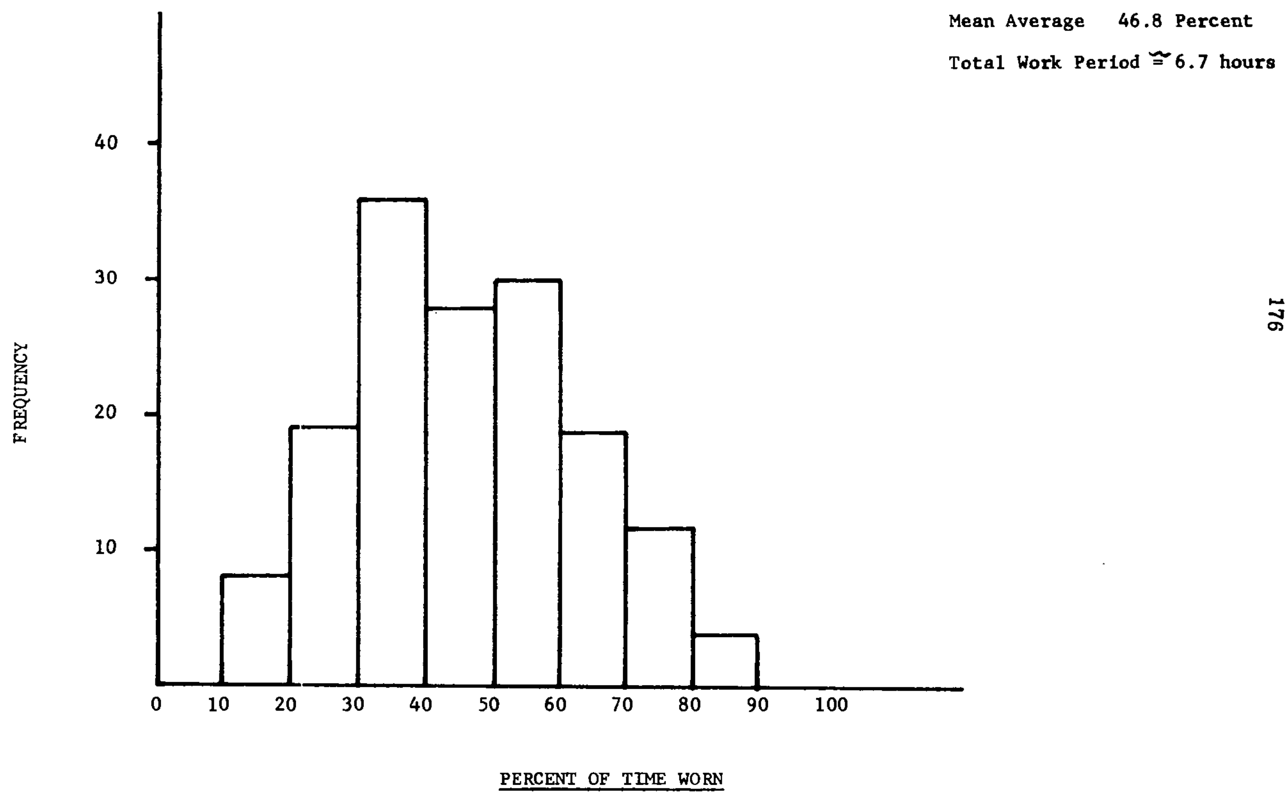

FIGURE 7

TABLE VII. Comparison of Different Respirator Models

Respirator	No. of Test Subjects	True Protection Factor (TPF) Mean Avg.	Median Avg.
A	9	11.1	10.6
B	9	9.2	8.9
C	9	11.4	10.8
D	9	8.7	8.4
E	9	8.7	8.5

(Penetration of filter media by particles 0.8 to 1.0 micron in size is usually less than 4 percent.) We feel this loss in respirator effectiveness is primarily caused by the lack of an ideal fit or seal between the facepiece and the subject's face. Not only is a proper face seal disturbed by facial and body movement, but undoubtedly the facial size and shape affects the seal obtained. This is indicated by the range of values obtained for the different test subjects, Table VIII, each of whom wore all the different respirators.

TABLE VIII. Range of TPF's

Test Subject	TPF* High	Low
1	12.3	6.6
2	13.5	5.8
3	14.2	4.0
4	11.4	8.2
5	15.4	7.2
6	19.5	8.3
7	10.2	6.6
8	11.9	9.6
9	10.0	5.9

* Average of four values obtained for one respirator worn.

It is probably this difficulty of easily achieving and maintaining a good fit and face seal that accounts for much of the difference between EPF and TPF. In this connection and in the case of EPF the fit problem becomes more difficult because miners find it impractical to wear a two-strap respirator head harness in the prescribed manner. Therefore, the miners wear the two straps in a single-strap configuration below the ears. The development of a more appropriate head harness is an area wherein research is much needed. In addition, there is need for better materials of construction and better designs which will provide both a more comfortable respirator and better face seal.

V. CONCLUSIONS

1. Half-mask dust respirators are in general use in underground coal mines and working miners feel there is a definite need for respiratory protective devices.

2. Most miners feel presently available approved respirators are acceptable for intermittent use but over a third of the miners feel the current units are unacceptable or marginally acceptable.

3. Discomfort to wear and breathing resistance are cited by miners as the major disadvantages of present day half-mask respirators.

4. As used in the field, presently available respirators provide the working miners a reasonable level of protection against the inhalation of respirable dust. However, the level of protection obtained is significantly lower than possible under ideal conditions. Difficulty in maintaining the proper seal between facepiece and face is one of the major reasons for reduced protection levels under actual working conditions.

5. There is a need for more comfortable respirators with reduced resistance to breathing. Likewise, there is a need for better materials of construction and better designs so that a good fit between facepiece and face can be secured and maintained with half-mask type respirators.

6. In the development of improved respiratory protective devices for coal miners a system approach should be used.

VI. FURTHER OBSERVATIONS

It is evident that improved respiratory protective devices for underground coal miners are needed. In the development and design of such devices, a systems approach should be used because of the need to integrate protection requirements of different kinds with the constraints of the work requirements and work environment. In the case of the coal miner, there is, as a minimum, a need, all or part of the time, for the following, each of which can be considered a system:

a. head protection
b. illumination
c. eye protection
d. noise protection
e. others, e.g., carrying of special equipment or tools

At the same time, the miner needs to have the maximum amount of mobility and the work environment often imposes severe constraints in terms of space and size and weight limitations. Consequently, it will be necessary, for example, when developing and designing improved respiratory equipment to take into account the miner's need for such things as head, eye, and noise protection and illumination, and to integrate these systems.

An example of the lack of systems approach are the present difficulties associated with respirators with the two-strap head harness and the miner's use of the hard hat (7). Clearly, such difficulties must be eliminated in newer and improved designs.

REFERENCES

1. Schutz, R. H., "The Dust Respirator Problem", Proceedings of the Symposium on Respirable Coal Mine Dust, Washington, D. C. November 3-4, 1969.

2. DeSieghardt, W. C., H. E. Harris, W. A. Burgess, and P. C. Reist, "Respirator Usage in Underground Bituminous Coal Mines", Mining Congress Journal, pp 43-48, August 1971.

3. IC 8503, "Sampling and Evaluating Respirable Coal Mine Dust," U. S. Bureau of Mines, February 1971.

4. Harris, H. E., W. C. DeSieghardt, W. A. Burgess and P. C. Reist, "Respirator Usage and Effectiveness in Bituminous Coal Mining Operations." American Industrial Hygiene Conference, San Francisco, Calif. May 18, 1972.

5. Lilienfeld, P. and J. Dulchinos, "Portable Instantaneous Mass Monitor for Coal Mine Dust,"AIHA Journal, Vol. 33, No. 3, pp 136-145 (1972)

6. Hyatt, C. C., A. L. Hack, T. O. Moore, and C. P. Richards, "LASL Respirator Test Panel - Representative of U. S. Male Facial Sizes.

7. Harris, H. E., W. A. Burgess, and W. C. DeSieghardt, "Effectiveness of Dust Respirators in Underground Coal Mines", AIME Annual Meeting, Feb. 25 - Mar. 2, 1973, Chicago, Ill.