

IC

bureau of mines  
information circular 8458

PROCEEDINGS OF THE SYMPOSIUM  
ON RESPIRABLE COAL MINE DUST,  
WASHINGTON, D.C., NOVEMBER 3-4, 1969



UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

1970

PROCEEDINGS OF THE SYMPOSIUM  
ON RESPIRABLE COAL MINE DUST,  
WASHINGTON, D.C., NOVEMBER 3-4, 1969

Compiled by Richard M. Gooding

\* \* \* \* \* information circular 8458



UNITED STATES DEPARTMENT OF THE INTERIOR  
Walter J. Hickel, Secretary

BUREAU OF MINES  
John F. O'Leary, Director

This publication has been cataloged as follows:

**Symposium on Respirable Coal Mine Dust, Washington, 1969.**  
Proceedings, Nov. 3-4, 1969. Compiled by Richard M. Gooding.  
[Washington] U.S. Dept. of the Interior, Bureau of Mines [1970]  
p. (U.S. Bureau of Mines. Information circular 8458)

1. Coal mines and mining - Dust Control. 2. Mine ventilation.  
I. Gooding, Richard M., comp. II. Title: Respirable coal mine  
dust. (Series)

TN23.U71 no. 8458 622,06173  
U.S. Dept. of the Int. Library.

## FOREWORD

As a part of its continuing program in protecting the health and safety of the nation's coal miners, the Bureau of Mines, Department of the Interior, presented on November 3-4, 1969, a Symposium on Respirable Coal Mine Dust. The Symposium was cosponsored by the American Mining Congress, the National Coal Association, and the National Independent Coal Operator's Association.

Within recent years it has become evident that a large number of our coal miners develop a severe occupational respiratory disease commonly referred to as "black lung," but more appropriately designated as "coal worker's pneumoconiosis." Studies in the United States as well as in European countries clearly demonstrate that prevention of the disease is related to the control and suppression of respirable coal mine dust.

This Symposium dealt with the various engineering methods of controlling dust in underground coal mines including ventilation, water suppression, machine design, and dust collection; and a discussion of respirators and life support systems. The merits of these various procedures and their potential application to underground coal mining were examined. In every case attempts were made to secure outstanding talent in each of the major areas discussed. The proceedings of the Symposium should constitute a reference on current technology for dust control.

The Symposium helped to delineate those areas where additional research is needed and highlighted the necessity for concentrated efforts by both industry and Government for intensive research and investigative programs on engineering procedures to control respirable coal mine dust within prescribed hygienic limits. Hopefully, research will move so rapidly that within a reasonably short time this publication will be out of date in terms of dust control technology.

JOHN F. O'LEARY  
Director, Bureau of Mines

## CONTENTS

	<u>Page</u>
Foreword by John F. O'Leary, Bureau of Mines.....	iii
Program of Symposium.....	vii
Remarks of Honorable Russell E. Train, Under Secretary of the Interior, at Symposium on Respirable Coal Mine Dust, November 3, 1969, at the Statler Hilton Hotel, Washington, D.C. ....	1
Background and Objectives, by John F. O'Leary.....	3
The Measurement of Respirable Dust - The Basis for Gravimetric Standards, by W. H. Walton.....	5
Dust Concentration in the Mines, by Henry N. Doyle.....	27
Personal Respirable Dust Sampler, by M. Jacobson and J. A. Lamonica....	33
Assessing Respirable Dust in United States Coal Mines, by Murray Jacobson.....	42
Practical Problems in Implementing a Dust Control Program in Coal Mines, by W. G. Kegel.....	55
Future of Coal as an Energy Source, by David Freeman.....	67
Ventilation: Theory and Principle, by Donald S. Kingery.....	73
Face Ventilation Practices in Bituminous Coal Mines for Dust Control, The State of the Art, by K. M. Morse and R. R. Godard.....	78
Studies on the Control of Respirable Coal Mine Dust by Ventilation, by D. S. Kingery, H. N. Doyle, E. J. Harris, M. Jacobson, R. G. Peluso, J. B. Shutack, and D. P. Schlick.....	96
Water as a Control Method: Theory & Foreign Experience, by Dr. Ing. H. Breuer.....	111
Water as a Control Method: State of the Art, Sprays and Wetting Agents, by Thomas Kobrick.....	123
Parameters to be Considered in Water Infusing for Dust Control, by Maurice Deul.....	133

CONTENTS--Continued

	<u>Page</u>
Dust Control by Water Infusion on Longwall Face, No. 20 Mine, The Carbon Fuel Company, by U. A. Cobb.....	153
Principles of Machine Design and Operation Related to Dust Production and Control With Particular Reference to Longwall Mining in the U.K., by R. J. Hamilton.....	160
Machine Design: State of the Art, by Rolf F. Arentzen.....	178
Dust Collection Equipment - Theory and Operation, by Henning E. Soderberg.....	183
Dust Collecting Equipment, State of the Art, by A. Lee Barrett.....	207
The Dust Respirator Problem, by Robert H. Schutz.....	224
Life Support Systems, by William A. Burgess.....	229
Experience With Respirators in an Underground Coal Mine, by D. K. Flanagan.....	248
Appendix, List of Attendees.....	284

# PROGRAM OF SYMPOSIUM

November 3

## Session I

8:30 a.m. — 12:00 noon  
Senate & Congressional Rooms

### *Session Moderator:*

John B. Rigg, Special Assistant to Assistant Secretary—  
Mineral Resources, Department of the Interior

### Remarks

Russell E. Train  
Under Secretary  
Department of the Interior

The Symposium—Background and Objectives  
John F. O'Leary, Director, Bureau of Mines

Measurement of Respirable Dust—The Basis for a  
Gravimetric Standard

W. H. Walton, Institute of Occupational  
Medicine, National Coal Board, Edinburgh,  
Scotland

Dust Concentrations in the Mines  
Henry N. Doyle, Acting Assistant Director—  
Mineral Industry Health, Bureau of Mines

Personal Respirable Dust Sampler, by  
Murray Jacobson, Acting Chief, Pittsburgh  
Field Health Group, Bureau of Mines, and  
J. A. Lamonica, Pittsburgh Field Health  
Group, Bureau of Mines

Assessing Respirable Dust in United States Coal  
Mines

Murray Jacobson, Acting Chief, Pittsburgh  
Field Health Group, Bureau of Mines

Practical Problems in Implementing a Dust Control  
Program in Coal Mines

William G. Kegel  
Assistant General Manager  
Jones & Laughlin Steel Co.

Discussion



November 3

## Luncheon Session

12:15 — 1:45 p.m.  
Presidential Ballroom

Future of Coal as an Energy Source  
David Freeman, Director, Energy Policy Staff,  
Office of Science and Technology, Executive  
Office of the President

November 3

## Session II

2:00 — 5:00 p.m.  
Senate & Congressional Rooms

## Control Technology

### *Session Moderator:*

C. J. Potter, President, Rochester and Pittsburgh  
Coal Company

### Ventilation:

#### Theory and Principle

Donald Kingery, Acting Director, Health and  
Safety Technical Support Center, Bureau  
of Mines

#### State of the Art

Kenneth M. Morse, Director  
Environmental Health, U.S. Steel Corporation

#### Studies on the Control of Respirable Coal Mine Dust by Ventilation

Henry N. Doyle, Acting Assistant Director—  
Mineral Industry Health, Bureau of Mines

#### Water as a Control Method:

#### Theory & Foreign Experience

Dr. Ing. Hans Breuer, Chief of Central Office  
for Dust and Silicosis Control, Steinkohlengerg-  
bauverein, Essen, Federal Republic of Germany

State of the Art:

Sprays & Wetting Agents

Thomas Kobrick, Bethlehem Steel Company

Water Infusion:

Room & Pillar Operations

Maurice Deul, Research Manager, Bureau of  
Mines

Longwall Operations

U. A. Cobb, General Manager, Carbon Fuel  
Company

6:30 – 8:00 p.m. – Reception  
Presidential Ballroom

November 4

Session III

8:30 a.m. – 12:00 noon  
Senate & Congressional Rooms

Control Technology (Cont.)

Session Moderator:

William L. Crentz, Director of Coal Research,  
Bureau of Mines

Machine Design:

Theory

R. J. Hamilton, Head of Dust Group, National  
Coal Board, Isleworth, England

State of the Art

Rolf F. Arentzen, President, Lee-Norse  
Manufacturing Company

Dust Collection Equipment:

Theory

Henning Soderberg, Regional Sales Manager,  
American Air Filter Co.

State of the Art

A. Lee Barrett, Corporate Technical Consultant,  
Joy Manufacturing Company

Respirators and Life Support Systems:

Respirators—Their Use and Limitations

Robert H. Schutz, Supervisory Research  
Chemist, Safety Research Center, Bureau of  
Mines

Life Support Systems

Dr. William A. Burgess, Associate Professor of  
Environmental Health and Safety Engineering,  
Harvard School of Public Health

Experience with Respirators in an Underground  
Coal Mine

D. K. Flanagan, General Superintendent of  
Putnam Coal Mines, Union Carbide Corporation

November 4

Session IV

2:00 – 4:45 p.m.  
Senate & Congressional Rooms

Applying the State of the Art

A Panel Discussion

Panel Moderator:

James R. Garvey, President, Bituminous Coal Research,  
Inc.

Selected speakers from the previous Sessions

Closing Remarks

John F. O'Leary, Director, Bureau of Mines

*Symposium Chairman:* Henry N. Doyle, Bureau of Mines

*Symposium Arrangements:* American Mining Congress

*Program Committee:*

Henry N. Doyle, Chairman, Bureau of Mines  
Kenneth M. Morse, American Mining Congress  
Edmund M. Warner, American Mining Congress  
James R. Garvey, National Coal Association

PROCEEDINGS OF THE SYMPOSIUM ON RESPIRABLE COAL MINE  
DUST, WASHINGTON, D.C., NOVEMBER 3-4, 1969

Compiled by

Richard M. Gooding<sup>1</sup>

---

MR. RIGG: Gentlemen, I would like to welcome you all to the symposium this morning.

My name is Jack Rigg, and I am a special assistant to Hollis Dole, Assistant Secretary of the Interior for Mineral Resources. Hollis is not in town this morning, and I am here to pinch-hit for him.

The first order of business this morning is remarks by the Honorable Russell Train, Under Secretary of the Department of Interior.

Mr. Train.

MR. TRAIN: Thank you, Mr. Rigg.

Lest you think that Hollis Dole is not interested in this symposium, let me just say that he is flying back from Australia just to be here. He is heading up a United States delegation in Australia meeting on resource problems in the Pacific. And I believe he will be here about noon.

**REMARKS OF HONORABLE RUSSELL E. TRAIN, UNDER SECRETARY OF THE  
INTERIOR, AT SYMPOSIUM ON RESPIRABLE COAL MINE DUST, NOVEMBER 3, 1969,  
AT THE STATLER HILTON HOTEL, WASHINGTON, D.C.**

On behalf of Secretary Hickel and the Department of the Interior, it is my great pleasure to welcome you to what I believe will be a highly productive symposium. No subject could be more timely. President Nixon made improved coal mine health and safety a first order of business for his administration.

In attending this meeting I believe that you and I are indicating our recognition of a powerful new force on the American scene. The idea that each of our citizens has a right to a safe and healthful environment--as much right, let us say, as to an education--is now being voiced in many parts of our land. Environmental quality has already become one of the prominent public issues of our day, demanding the attention of industrialist, legislator, and President. The problem of how we get, and keep, an acceptable quality of environment touches all of the resources . . . air, water, and land . . . on which we depend for sustenance and survival.

<sup>1</sup> Chemist, Office of Director of Petroleum Research, Bureau of Mines, Washington, D.C.

Of this all-inclusive environment, the occupational environment is but one part. But, as President Nixon has pointed out, it is a part in which working Americans spend nearly a quarter of their lives. And in his words: "For them, the quality of the workplace is one of the most important of environmental questions."

The importance of occupational health, and the necessity for taking positive measures to assure it, have not found easy acceptance. For too many years, unhealthful working places and conditions have been countenanced as part of the price that must be paid for industrial progress. Too often, our occupational health problems have been rationalized away with the assertion that corrective measures would be economically insupportable. A fatalistic acceptance of the problem--a too easy readiness to live, or even die, with it--has been adopted even by those who suffer from it most directly. This, it seems, has been at least partly the case with coal miner's pneumoconiosis.

None of us here today has anything to be proud of in this respect. None of us can claim to have been sufficiently concerned, even a year or two ago, about the quality of the air going into the lungs of American coal miners. As with so many other kinds of environmental problems, both government and industry had legitimate responsibilities in the area and both defaulted.

It is to our credit, however, that, having recognized the problem and accepted our share of responsibility, we are attacking it with vigor and determination. I welcome your attendance here as evidence that coal miner's pneumoconiosis is now viewed as a serious matter by everyone connected with the coal industry. I apologize to our British and German guests, who have been hailed across the Atlantic on what must have seemed very short notice to share with us the benefits of their long experience in dust control. I offer industry the Department's complete cooperation in developing control measures that will give our coal miners the best protection that advanced technology can provide.

This protection, I believe, will become a demonstrably positive asset to the coal industry in a very short time. For coal's ability to help meet the expanding demand for energy is even now being hampered by a labor shortage. One obvious way to deal with the shortage is to raise the miner's working conditions to a level nearer those of other major industries.

In closing, I would like to express our appreciation to the cosponsors of this symposium, and particularly to J. Allen Overton, Jr., executive vice-president of the American Mining Congress; to Stephen F. Dunn, president of the National Coal Association; and to John L. Kilcullen, legal counsel for the National Independent Coal Operator's Association. Their help has made this meeting possible.

On your deliberations here, I wish you every success.

Thank you.

MR. RIGG: Thank you, Mr. Secretary.

The second presentation on the morning session will be, "The Symposium-- Background and Objectives," by John F. O'Leary, Director, Bureau of Mines.

## BACKGROUND AND OBJECTIVES

by

John F. O'Leary

---

---

Delegates to the Symposium and distinguished guests, I want to begin these brief remarks by expressing the Bureau's gratitude for the cooperation it has received from industry, not only in making arrangements for this symposium, but also in the intensive research and testing that we have been conducting cooperatively in recent months. These joint efforts are beginning to show promising results, about which you will be hearing more later on. We could not possibly have progressed so far so quickly without the wholehearted participation of management and labor at the various mines in which our studies have been underway.

I want to say also that regardless of the outcome of the pending legislation that concerns all of us here today, the Department of the Interior and the Bureau of Mines are dedicated to the elimination of dust diseases and the menace they represent to the health of this Nation's coal miners. We know that our determination is shared by all of you who represent the coal mining industry and that we will continue to enjoy the enthusiastic cooperation of other research establishments and the manufacturers of coal mining equipment.

In recent months, we have been working diligently to perfect engineering methods for substantially reducing the concentrations of respirable dust. In addition, we have reviewed the experiences of other countries, especially the United Kingdom and the Federal Republic of Germany, to determine if these countries had technology of which we were not aware. Our progress to date will be reported to you during the next two days, along with accounts of some of the work that industry has been carrying forward on its own.

Our first objective is to assure that all concerned parties have a common ground of knowledge regarding the various engineering methods for dust suppression and control and the effectiveness of each method in terms of the present state of technology. Proceeding from such a basis, we hope to identify those areas where both Government and industry can best direct their research efforts. The transactions, which will be sent to each registrant, should serve as a textbook on current technology; and incidentally, a textbook which we intend shall be out of date by this time next year.

The program has been planned with a definite sequence. Session I is designed to provide a baseline for the problem. It will therefore cover why and how respirable coal mine dust is measured, what dust concentrations are presently encountered in underground coal mines, and finally, some of the practical problems now confronting the industry.

Sessions II and III deal with the four principal methods for suppression and control of dust: ventilation, water, machine design, and dust collection. To this a discussion of respirators and life support systems has been added. Each method will be discussed in terms of its theory and, wherever possible, its effectiveness in present practice. Every attempt has been made to select the best qualified individual for each subject area.

There should be time for a short discussion after each presentation. However, to expedite the progress of the Symposium and to assure each speaker of his allotted time, we are asking that you limit your questions to matters of clarification. Each session moderator will determine whether a question is appropriate for an immediate answer or whether it should be held for the Panel Discussion on Session IV. In the latter case, the questions will be recorded and referred to the panel.

The Panel Discussion has been designed to respond to your technical questions and to explore significant subjects at more depth. We would prefer that you direct inquiries to the panel through written questions using the cards that have been provided. This will enable us to group related questions, and will permit the speakers to prepare more complete answers. Your questions may be either addressed to an individual or to the panel, and should be deposited in the boxes at each exit from the auditorium.

We do, however, ask that your questions be limited to the technical areas under discussion. We will not attempt to respond to questions which would encroach on decisions yet to be made by the Congress.

When there are substantive legislative questions that require discussion you can be assured that we will be consulting you.

Thank you.

Our first technical paper, "Measurement of Respirable Dust - The Basis for a Gravimetric Standard," is by Mr. W. H. Walton from the Institute of Occupational Medicine, National Coal Board, Edinburgh, Scotland.

PAPER TO SYMPOSIUM ON RESPIRABLE COAL MINE DUST  
WASHINGTON, NOVEMBER 3 - 4, 1969

## THE MEASUREMENT OF RESPIRABLE DUST - THE BASIS FOR GRAVIMETRIC STANDARDS

by

W. H. Walton

---

The airborne dust clouds found in coal mines are complex systems comprised of mixed particles, of varied size, density, shape, and state of aggregation. Because these particles settle at different speeds, and differ in their composition and toxicity, only a proportion of these particles are respirable. Moreover, the concentration and character of the cloud varies from place to place in the mine, and from time to time at the same place.

Some of the reasons for these variations are readily apparent. Mining operations are often discontinuous, and their site changes. These operations make, and scatter into the air, particles of all sizes. The larger, faster falling, particles tend to be deposited relatively near to the dust source; the small, slow-falling particles are carried long distances by the ventilation with little loss. The turbulence of the airflow keep some particles airborne longer than would otherwise be expected; therefore, the concentration falls logarithmically with time instead of linearly. The particles most persistent in the air, and most difficult to remove by dust control, are the "respirable" ones which, for similar reasons, are capable of penetrating into the depths of the lungs. This respirable dust is accompanied by variable, and possibly, large quantities of coarse non-respirable material. Different minerals when broken give rise to different amounts of fine dust; airborne dust composition may vary significantly at different particle sizes, and may also differ from that of the parent material. Many airborne particles are aggregates or clusters of smaller individual particles. All dust particles are weakly coherent, and the presence of small quantities of condensed water greatly increases their adhesion, therefore, the extent of aggregation in a cloud tends to depend on the violence of the dispersive process and humidity. The dust formed by the action of percussive tools on a hard rock may be relatively unaggregated; however, dust raised by debris falling from one conveyor belt to another may contain mainly aggregate particles. Aggregate particles, or particles of extreme shape, may have very low falling velocities in relation to their size.

The amount of dust in a given volume of air can be specified by the number of particles or by their weight; further distinction can be made between measuring all the dust or only that within a selected size range, and measuring with or without dispersion of aggregate particles. The relationships between these measures differ from one cloud to another. These differences may not be important in the early stages of a dust control program when there is a serious dust hazard obviously requiring attention. Practically any method of measurement

will show if the concentrations are being reduced. Setting up a sophisticated sampling program is unnecessary and is not a substitute for action to control dust. After the relatively easy first stages of dust control have been passed, progress becomes more difficult and expensive. If efforts are to be expended efficiently, it is desirable to use methods of measurement that closely reflect the dust hazard.

This precept has not always been followed. Indeed, the dust standards of different countries well illustrate the variety of ways in which dust concentrations can be measured. Some of these standards are summarised in table 1. The measures of concentration include numbers of particles determined in various ways; for example, between different size limits, with agglomerates counted as single units or dispersed (in liquid) into their component particles, with or without incineration or other chemical treatment to remove certain chemical constituents. In other cases, the standards are based on the weight of dust, sometimes including particles of all sizes, or in other cases within a selected size range. Yet other standards use an index derived from the amount of light scattered or absorbed by the dust. In some cases, no account is taken of the composition of the dust; in other instances, only one constituent, quartz, is measured; also, different weighting factors may be applied to different minerals.

There have been many investigations to compare and correlate dust measurements made by different instruments. Reference to a number of these have been given in an I.L.O. publication (I.L.O. 1967), where it is concluded "...No evaluation or comparison of dust contents ... has any significance unless the type of equipment, the method of sampling and the nature of the dust are precisely known ... Except in the case of homogeneous dust clouds with a constant particle size distribution, the correction factors will always vary with the particle size distribution or the nature, or both, of the dust examined". This publication also comments that standards derived by using particular dust sampling instruments and methods of examination are sometimes blindly accepted for use when the sampling and examination are done by quite different methods.

Some examples of dust assessment given by different methods of measurements are provided by experience in British coal mines. If dust samples taken by thermal precipitator are counted in the range 0.5 to 5  $\mu$ m instead of 1 to 5  $\mu$ m, the concentrations are increased by a factor that varies from about 1.4 to 4 for underground dusts, or up to 9 if surface operations are included (Fay and Ashford, 1960). The relationship between the mass concentration of respirable dust (measured as described later) and the number of particles 1-5  $\mu$ m may vary fivefold, from about 6 to more than 30 mg/m<sup>3</sup> per 1,000 particles/cm<sup>3</sup> (Hamilton and others, 1967). If the respirable mass samples are dispersed in liquid and evaluated by Coulter Counter, the number of 1 to 5  $\mu$ m particles recorded may be up to 10 times greater than that found in the number count of corresponding thermal precipitator samples when agglomerate particles are assessed as single units. If the total mass of particles of all sizes is determined instead of the respirable mass, the concentrations are increased from 3 to 10 times. The composition of the dust in British coal mines is also quite variable; the ash percentages may differ tenfold and the quartz percentages twentyfold, the mean levels for coal face dusts being about 35 percent and 4 percent respectively. Thus the use of weighting factors for composition could

TABLE 1. - Mine Dust Standards of Various Countries

Country	Sampling Instrument	Sampling Procedure	Parameter Measured	Compositional Weighting	Dust Limits																												
Australia (N.S.W.)	Owen's jet	Not less than 12 (spot) samples taken over 1 hour period.	Particles/cm <sup>3</sup> < 5 μm	Dust limits vary according to % free silica in parent material.	Average concentration of 1-5 micron size not to exceed <table> <tr><td>% Silica</td><td>175 Particles/cm<sup>3</sup></td></tr> <tr><td>10</td><td>150</td></tr> <tr><td>10 - 20</td><td>125</td></tr> <tr><td>20 - 30</td><td>100</td></tr> <tr><td>30 - 40</td><td>75</td></tr> <tr><td>40 - 50</td><td>50</td></tr> <tr><td>&gt; 50</td><td></td></tr> </table>	% Silica	175 Particles/cm <sup>3</sup>	10	150	10 - 20	125	20 - 30	100	30 - 40	75	40 - 50	50	> 50															
% Silica	175 Particles/cm <sup>3</sup>																																
10	150																																
10 - 20	125																																
20 - 30	100																																
30 - 40	75																																
40 - 50	50																																
> 50																																	
Belgium and Netherlands (Coal Mines)	Soxhlet filter	Samples of at least 2 hr. duration taken in return airway 15 - 20 m. from face during actual mining operations.	Total airborne dust: mg/m <sup>3</sup>	Dust limits vary according to ash content of sample (interpolate between quoted values).	Dust Class <table> <tr><td>% Ash</td><td>I</td><td>II</td><td>III</td></tr> <tr><td>10</td><td>50</td><td>85</td><td>110 mg/m<sup>3</sup></td></tr> <tr><td>20</td><td>37</td><td>58</td><td>88</td></tr> <tr><td>40</td><td>24</td><td>35</td><td>55</td></tr> <tr><td>60</td><td>17</td><td>25</td><td>37</td></tr> <tr><td>80</td><td>13</td><td>19</td><td>28</td></tr> <tr><td>100</td><td>10</td><td>15</td><td>22</td></tr> </table>	% Ash	I	II	III	10	50	85	110 mg/m <sup>3</sup>	20	37	58	88	40	24	35	55	60	17	25	37	80	13	19	28	100	10	15	22
% Ash	I	II	III																														
10	50	85	110 mg/m <sup>3</sup>																														
20	37	58	88																														
40	24	35	55																														
60	17	25	37																														
80	13	19	28																														
100	10	15	22																														
Canada (Ontario)	Gathercole Konimeter	3 Spots at working place. Plus 1 in intake and 1 in return. 6 Month intervals.	Particles < 5 μm visible under x 150 dark field microscopy.	Incinerated and acid-treated before counting.	Low silica 500 Particles/cm <sup>3</sup> medium silica 300 high silica 200 (Mean of working place samples)																												
France	Soluble filter or membrane filter		A Logarithmic Index calculated from the concentration of particles/cm <sup>3</sup> , 0.5 - 5 μm	Only quartz is evaluated.	Index $i = 3.32 \log_{10} CQ - k$ . $C = P/cm^3$ , 0.5 - 5 μm; $Q =$ quartz % by weight in < 5 μm dust; $k = 10.6$ for soluble filter, or 8.9 for membrane filter. Threshold limit, $i = 5$ .																												
Germany (Federal Republic)	Tyndal Loscope and Bergbau Konimeter	Spot samples. Mean of measurements taken at different face positions over 2 hour period during work including normal short stoppages.	Total fine dust concentration, $k$ , measured by scattered light value corrected by calibration tables for ash content. (Coarse dust removed in settlement chamber before light readings are taken).	Dirt (ash) content, $b$ , determined from konimeter samples. Fine dirt concentration $k_b = k \times b$ . Separate limits for 'fine dust' and 'fine dirt'.	<table> <tr><td>Dust Class</td><td>Fine dust Concn., <math>k</math>, less than</td><td>Fine dirt Concn., <math>k_b</math>, less than</td></tr> <tr><td>I</td><td>25</td><td>5</td></tr> <tr><td>II</td><td>50</td><td>10</td></tr> <tr><td>III</td><td>100</td><td>20</td></tr> </table> No man may be employed in Class III dust conditions for more than 500 shifts in 5 years.	Dust Class	Fine dust Concn., $k$ , less than	Fine dirt Concn., $k_b$ , less than	I	25	5	II	50	10	III	100	20																
Dust Class	Fine dust Concn., $k$ , less than	Fine dirt Concn., $k_b$ , less than																															
I	25	5																															
II	50	10																															
III	100	20																															
India	Thermal precipitator		Particles/cm <sup>3</sup> 1 - 5 μm	According to free silica content (non-coal workings).	(a) For non-coal mines and stone drivages in coal mines:- Threshold value $\frac{8830}{\text{Free silica \%} + 5} \text{ Particles/cm}^3$ Shift average exposure not to exceed 50% of the threshold values. (b) For coal mines:- Average exposure during shift, < 500 Particles/cm <sup>3</sup> Average concn. of any operation, < 800 Particles/cm <sup>3</sup> . Threshold value (beyond which no work permitted). 1000 Particles/cm <sup>3</sup> .																												
Poland	Zeiss Konimeter or Membrane filter (Lower Silesia)		Particles/cm <sup>3</sup> < 5 μm	Dust limits vary according to quartz percentage	<table> <tr><td>% Quartz</td><td>Particles/cm<sup>3</sup></td></tr> <tr><td>&lt; 5</td><td>1,500</td></tr> <tr><td>5 - 15</td><td>1,200</td></tr> <tr><td>15 - 25</td><td>850</td></tr> <tr><td>&gt; 25</td><td>500</td></tr> </table>	% Quartz	Particles/cm <sup>3</sup>	< 5	1,500	5 - 15	1,200	15 - 25	850	> 25	500																		
% Quartz	Particles/cm <sup>3</sup>																																
< 5	1,500																																
5 - 15	1,200																																
15 - 25	850																																
> 25	500																																

TABLE 1. - Mine Dust Standards of Various Countries--Continued

Country	Sampling Instrument	Sampling Procedure	Parameter Measured	Compositional Weighting	Dust Limits
South Africa	Witwatersrand Konimeter  (modified thermal precipitator in coal mines)		Particles/cm <sup>3</sup> < 5 μm. (Counted by dark-field microscope at × 150)  Light obscuration of coal dust samples. (Coarse dust eliminated by selective sampling).	Acid-treated and incinerated to remove soluble and combustible material.	About 250 particles/cm <sup>3</sup> .
United Kingdom (a) To 1st April 1970.	Long-running thermal precipitator	Full-shift samples taken in return roadway 25 yds. from coal face.	Particles/cm <sup>3</sup> > 1 μm upper limit set by instrument elutriator.  (Approx. equivalent to particles 1 - 5 μm)  (Aggregate particles counted as single units)	All particles counted irrespective of composition but dust limits vary according to type of working place.	Type of place Stone drifts and scourings 250  All other locations in anthracite collieries 500  Ditto in other collieries 700  (Above shift - mean values not to be exceeded more frequently than 1 shift in 10).
(b) From 1st April 1970	M.R.E. Gravimetric Dust Sampler type 113A.	Continuous sampling throughout working shift. Position: Longwall coalfaces in return roadway 70 m. from face, other places at workplace.	Mass of respirable dust (M.R.C. Elutriator).	Standard varies with type of working place.	Stone drivages 3 mg/m <sup>3</sup>  All other locations 8 mg/m <sup>3</sup> .  Approval normally based on mean of last three monthly concentrations.
U.S.A. (Standards recommended by American Conference of Governmental Industrial Hygienists - A.C.G.I.H.)  Intended changes recommended by A.C.G.I.H. (May 1970)  Do.	Midget impinger  Gravimetric sampler  Do. with A.E.C. cyclone size-selector.	Continuous throughout working shift.  Do.	Dispersed dust counted in liquid cell at × 100 magnification after specified settlement time. Results usually expressed in millions of particles per ft <sup>3</sup> .  Mass of total dust  Mass of respirable dust.	Dust limit related by formula to silica percentage.  Do.  Do.	Threshold limit value  $= \frac{250}{\% \text{ quartz} + 5} 10^6$ particles/ft <sup>3</sup> .  (Average exposure over a normal workday, for workers repeatedly exposed, day after day).  $\frac{30}{\% \text{ Si O}_2 + 2} \text{ mg/m}^3$  $\frac{10}{\% \text{ Respirable Si O}_2 + 2} \text{ mg/m}^3$
U.S.S.R.	Gravimetric filter	Maximum permitted dust content in the atmosphere of work zones.	Mass concentration mg/m <sup>3</sup> (dust of all sizes)	According to free silica percentage.	70% free crystalline silica 1 mg/m <sup>3</sup> . 10-70 free silica 2 mg/m <sup>3</sup> . Coal or silicate dust < 10% silica 4 mg/m <sup>3</sup> . Coal dust not containing silica 10 mg/m <sup>3</sup> .

have a major effect on the "dust index". The above figures are derived mainly from measurements in the 25 collieries studied in the National Coal Board's Pneumoconiosis Field Research, and are intended to be illustrative rather than representative of conditions in British mines as a whole.

Dust measurements must also allow for the variation of concentration with time, both within the working shift and from day to day. An example of the variations in dust concentration experienced by a coal miner during a working shift is shown in figure 1. This relates to a longwall coal face worked by an Anderton shearer, which wins several strips of coal over the length of the face during the shift. The highest concentration is 3.5 times greater than the average value over the shift, and the lowest concentration is 0.3 of the average. The observed maximum and minimum values might have been quite different if the duration or phasing of the individual samples had been different. Clearly, if only a few short samples had been taken, covering a small part of the shift, their average might have differed markedly from the true value for the whole shift. Figure 2 gives an example of the different dust levels that may be found at the same working place on different, nonconsecutive days. The method of coal winning remained unchanged over the period of these observations. There is a difference of 3.5 times between the highest and lowest daily averages. Typically the day to day variation coefficient of the shift mean concentration is about 20 to 30 percent, but may be as high as 50 percent. Figure 3 shows the relationship between shift average and maximum concentrations for various coal face operations at a number of different coal mines. The maxima vary from about 2 to 6 times the average. The difference is greater on the preparation shifts (during which explosives were used) than on the hand-filling shifts which, in these examples were free from shot-firing. Thus it will be clear that recorded concentrations may vary by large factors depending on the choice of day, on whether average or peak concentrations are measured, and on the timing of short period samples. Dust concentration measurements made during a single short visit, or even over the whole of a single shift, can have little statistical significance. Moreover, there is little point in striving for the precise evaluation of individual samples when the statistical significance of each is low.

Consideration must also be given to spatial variations in dust concentration. In the well-ventilated roadways of a coal mine, the dust becomes well mixed over the cross-section, and the point-to-point differences in concentration tend to be less than those occurring in surface industries. Nevertheless, concentrations substantially different from those of the general body of the air may be found in the immediate vicinity of dust-producing machines or in cul-de-sacs. Furthermore, workmen may move from place to place, into different dust concentrations, during the shift.

It is hoped that the foregoing remarks will have illustrated the need to consider carefully just what information is wanted and to choose a sampling procedure that gives this in as direct a manner as possible before embarking on a dust measurement program. The method that I am expected to commend is indicated by the title of this paper, which was given to me by the organizers of this symposium. But before considering why one should adopt gravimetric (mass) sampling methods, it is perhaps pertinent to ask "why not?"

The dust hazard to miners was first specifically recognized and brought under intensive study in South Africa, during the early years of this century. According to Boyd (1930), systematic measurements of the mass concentration of dust, by sugar tube, were begun in 1911. Until 1913 all the dust found in the samples was regarded as dangerous. The research of Dr. J. McCrae then showed that only very fine dust was to be found in the ash of silicotic lungs, the particles ranging in size from  $12\ \mu\text{m}$  downwards. It therefore became necessary to devise some method of separating the coarse from the fine dust. A procedure of allowing particles above  $12\ \mu\text{m}$  in size to settle from a well-mixed suspension of the dust in water was introduced in 1915. However, the difficulty of separating the gravimetric sample into large and fine dust was so great that it was not practicable in ordinary routine work. Also, the sampling apparatus was cumbersome. To overcome some of these difficulties, a dust-count instrument, the konimeter, was devised by Sir Robert Kotze in 1916. Later, techniques of acid washing and incineration to remove soluble and carbonaceous particles were introduced. Thus the original gravimetric method was superseded by particle counting. Despite much criticism in recent years, the konimeter remains the standard dust sampling instrument in South African gold mines. Other dust count methods followed the konimeter, notably, the impinger (Greenburg and Smith, 1922); Owen's jet (1922), and thermal precipitator (Green and Watson, 1935). Counting methods based on the impinger became standard in the United States; and based on the thermal precipitator in the United Kingdom. Bulk collection of dust followed by size-separation by sedimentation in liquid has continued to be used, particularly for surface industry in Continental Europe.

In Britain, an extensive investigation of pulmonary disease among coal miners in the South Wales coalfield, conducted under the aegis of the Medical Research Council between 1936 and 1941, led to the recognition of "coalworkers' pneumoconiosis", as distinct from classical silicosis, as a compensable industrial disease (Hart and Aslett, 1942). From the concurrent environmental studies, Bedford and Warner (1943) concluded that standards of maximum permissible dustiness of the coal face in anthracite mines should preferably be based on the mass concentration of dust not exceeding  $5\ \mu\text{m}$  in size. However, it was considered that standards in terms of the mass of dust of a restricted range of size would cause administrative difficulties, because such concentrations could not be determined directly by gravimetric methods, and would require to be computed from counts and size distributions. Bedford and Warner, therefore, proposed that the standards be expressed in terms of the numerical concentrations of dust particles exceeding 1 micron in size. A close correlation between this parameter and the mass not exceeding  $5\ \mu\text{m}$  had been found in their studies. The dust standards introduced by the British coal mining industry in 1949 were based on, but not identical with, the recommendations of Bedford and Warner. The particle count was specified in the range 1 to  $5\ \mu\text{m}$  instead of greater than  $1\ \mu\text{m}$  and related to "periods of maximum dust production" rather than to an average concentration for the shift. The standards were adjusted to equivalent shift average values in 1965 to provide a better index of the hazard and avoid practical difficulties associated with the measurement of maximum concentrations. There was a further minor revision of the values for anthracite mines in 1966. The 1966 standards are quoted in table 1. It was originally intended that all shifts, day by day, should conform to the standard, but this proved difficult to implement because of the large day to day

variations in dustiness already noted. A "sequential" sampling procedure, based on the known statistical variability of the shift concentrations was therefore adopted (Tomlinson, 1957). This was designed to ensure that the dust level did not exceed the standard more frequently than 1 day in 10.

Particle counting methods for dust measurement came into use instead of gravimetric methods because, at the time, they provided a more convenient means of evaluating fine "respirable" dust in the presence of grosser material; not because they were considered to provide a better index of the hazard but, rather, despite the contrary view. It was felt, however, that if detailed size distribution counts were made, mass and other parameters could be calculated; in practice this approach was confined to research studies.

When the British standards were introduced in 1949, it was realized that further investigation was desirable into the relationship between dust exposure and disease in collieries outside the South Wales coalfield. Accordingly, in 1953 a large scale research project (the National Coal Board's Pneumoconiosis Field Research) was begun at 25 collieries that reflected dust conditions throughout British coal mines. The thermal precipitator was chosen as the main dust sampling instrument, because it was available and was considered to give a true sample of the fine dust without disruption of aggregate particles.

At about the same time, the problem of obtaining a bulk sample of the fine respirable dust, free from nonrespirable particles began to receive attention at a number of laboratories. The sample would be used for assessment by mass or other property, or for compositional analysis. This work received valuable impetus from the Dust Panels of the Medical Research Council which brought together research workers from various centres. By this time McCrae's early observations on the size of dust found in silicotic lungs had been followed by more comprehensive, theoretical, and experimental investigations of the particle desposition in the human respiratory system (Findeisen, 1935; Van Wijk and Patterson, 1940; Brown and coworkers, 1950; Landahl, 1952) and the general mechanisms were well understood. At first it was considered how particles smaller than  $5 \mu\text{m}$  might be separated (in accordance with the prevailing "standards"). The most practicable methods of separation were based on aerodynamic principles (elutriation or gravitational separation, cyclones, impingement, etc.). Such devices classify particles according to their mass-aerodynamic drag ratio (characterized by the falling speed in air) and not by size. This was seen to correspond with the separation mechanism operating in the human respiratory system. Neither devices based on areodynamic principles nor the human respiratory system can effect a sharp separation at a given size or falling speed. Thus there arose the concept of the selective sampling of respirable dust by providing the sampling instrument with a prefilter permitting the passage only of particles corresponding to those which have access to the respiratory region of the lungs. The following quotation comprises the recommendations made by the M.R.C. Panels in 1952:

- (i) For the purposes of estimating airborne dust in its relation to pneumoconiosis, samples for compositional analysis, or for assessment of concentration by a bulk measurement such as that of

mass or surface area, should represent only the "respirable" fraction of the cloud.

- (ii) The "respirable" sample should be separated from the cloud while the particles are airborne and in their original state of dispersion.
- (iii) The "respirable fraction" is to be defined in terms of the free falling speed of the particles, by the equation  $C/C_0 = 1 - f/F_c$  where  $C$  and  $C_0$  are the concentrations of particles of falling speed  $f$  in the "respirable" fraction and in the whole cloud, respectively, and  $F_c$  is a constant equal to twice the falling speed in air of a sphere of unit density  $5 \mu\text{m}$  in diameter.

It was noted that a selective sampling device meeting these requirements would have a 50 percent sampling efficiency for  $5 \mu\text{m}$  spherical particles of unit density and an absolute cut off for similar particles of size greater than  $7.1 \mu\text{m}$  diameter. It was considered that horizontal elutriators (of appropriate dimensions) possessed the desired characteristics.

These developments, together with practical aspects of elutriator design, have been discussed by Hamilton and Walton (1960); the theory of the elutriator was described by Walton (1954).

With the selective sampling of respirable dust now a practical possibility, attention was directed to the most appropriate method for measuring this dust. Bedford and Warner, as previously noted, had expressed the view that for coal the mass of respirable dust best represented the hazard. This might be expected since coal dust is a relatively inert material; when retained in the lungs it is sequestered in foci around the respiratory bronchioles, although it stimulates the production of comparatively little fibrous tissue. Thus the bulk quantity retained would seem to be significant. This view was reinforced by the results of post mortem studies of miners' lungs, which showed a relationship between the average weight of dust in the lungs and the radiological category of pneumoconiosis (Rivers and coworkers, 1960, Rossiter and coworkers, 1967). Silica (quartz) dust, on the other hand, is toxic to phagocyte cells which, when they die, appear to release substances that promote the growth of fibrous tissue, leading to the development of the characteristic silicotic nodules. It has been suggested that this activity might be associated with the surface, rather than with the mass, of the dust. In animal experiments, injected quartz dusts of different particle sizes produced pathological changes that were more closely related to the surface or mass of the dust than to the number of particles. These considerations led the M.R.C. Dust Panels in 1957 to endorse the view that mass might prove to be the best parameter for inert dusts such as coal and to urge the development of suitable measuring instruments. It was recognized, of course, that for mixed dusts the hazard might depend on the composition as well as on the total mass.

Another question debated at this period was whether peaks of dust exposure or the average dust level provided the best measure of the hazard. It was concluded by Wright (1953, 1957) that the "peak hypothesis" is not supported by any evidence and may lead to some misdirection of study in dust suppression. He argued that although it could not be stated with certainty that the "average" hypothesis is correct, it was simple and reasonable and did not conflict with anything known about the mechanism of dust inhalation and retention. Later, in experimental studies using rats, one group was exposed to dust for 20 hours per day, and the other was exposed to a concentration 10 times greater for only two hours per day. Wright found little difference between the amounts of dust accumulated in the lungs. The M.R.C. Panels, in 1956, concurred that the average concentration levels to which men are exposed provide the most important measure of dustiness in relation to pneumoconiosis; however, this study should be supplemented by a measure of variability if possible. One possibility considered in this connection was that periods of high dust concentration might coincide with peaks of high work rate and, consequently, with larger volumes of air breathed.

Gravimetric methods are, of course, well suited for the measurement of long term average concentrations, rather than of peak levels, because the possibility of obtaining "too dense" samples (as when particle counting) does not arise. Indeed it would be difficult to collect sufficiently large gravimetric samples for weighing and analysis in a short time.

The selective sampling concept received further support from the 1959 Johannesburg International Conference on Pneumoconiosis, the recommendations of which are included the following quotation (Orenstein, 1960):

- (i) Measurements of dust in pneumoconiosis studies should relate to the "respirable fraction" of the dust cloud, this fraction being defined by a sampling efficiency curve which depends on the falling velocity of the particles and which passes through the following points: effectively a 100 per cent efficiency at 1 micron and below, 50 per cent efficiency at 5 microns, and zero efficiency for particles of 7 microns and upwards: all the sizes refer to equivalent diameters (the equivalent diameter of a particle is the diameter of a spherical particle of unit density having the same falling velocity in air as the particle in question).
- (ii) In the light of present knowledge, dust measurements to assess the health hazard should be expressed as the average level of dustiness over an appropriate period of sampling, such as a shift. This measurement may be made by averaging a number of samples, or by using an instrument which automatically averages the dust over the period. Exceptional peaks of dust concentration might also be recorded.

- (iii) In the light of present available evidence, the best single descriptive parameter to measure be considered: (sic)
- (a) in the case of coal dust to be the mass concentration of the respirable dust.
  - (b) in the case of quartz dust to be the surface area of the respirable dust.

With regard to (iii)(b) above, it may be noted that later research in South Africa has indicated that mass may be the more appropriate measure for quartz as well as for coal (Goldstein and Webster, 1966).

The M.R.C. and Johannesburg criteria for respirable dust represent something of a compromise. As previously noted, these criteria are based on the particle selection characteristics of the horizontal elutriator operated under conditions which bring the curve into reasonable accord with the human upper respiratory deposition. The shapes of the elutriator and lung curves are not the same, but it must be remembered that lung curves are neither known with certainty nor constant. The elutriation method of size selection is simple, it gives results in very close agreement with theory, and is readily adaptable to different sampling rates. These are desirable characteristics of a "standard" sampling method.

The first gravimetric selective-sampling instrument based on the horizontal elutriator was the Hexhlet (Wright, 1954). This required an external compressed-air power source, which is not usually available in British coal mines. Various portable instruments were subsequently developed and the NCB/MRE Gravimetric Dust Sampler Type 113A (Dunmore and coworkers, 1964) has been chosen for future use by the National Coal Board (fig. 4). This instrument has a sampling rate of 2.5 l/min and weighs 4.3 kg (9 1/2 pounds); it is intrinsically safe for use in coal mines.

In the United States, the Atomic Energy Commission proposed a somewhat different definition of respirable dust which approximates the pulmonary deposition curve of Brown and coworkers (1950). A family of air samplers based on the cyclone dust collector followed by an efficient filter to collect the respirable dust passing the cyclone has been described by Lippmann and Harris (1962). The cyclones (of commercial manufacture) and their flow rates were chosen, by experiment, to give samples in accord with the A.E.C. curve. Cyclones are essentially empirical devices, and other workers have found that the desired performance is most nearly attained at different flow rates from those recommended by Lippmann and Harris. Cyclones have, however, some practical advantages; notably, small size and insensitivity to orientation.

Cyclones have also been used by Breuer (1961, 1967), in Germany. Breuer uses a finer selection of characteristics matched to a dust retention curve derived from the post mortem examination of dust in the lungs of coalminers. Another cyclone device, described by Higgins and Dewell (1967) and used in the foundry industry in Britain, has been adjusted to give results similar to those obtained with the standard elutriator. This cyclone has been incorporated in

the "Simpeds" personal dust sampler designed by Harris and Maguire (1968), which is safe for use in coal mines (fig. 5). The pump unit is built into the (enlarged) top of a miner's cap lamp battery and communicates via a flexible tube attached to the electric cable with a sampling head mounted on the cap lamp. Underground trials with prototype instruments have shown departures from a 1-to-1 agreement with the M.R.E. sampler in certain dusts. These departures are probably due to differences between the selection curves of the cyclone and elutriator. The relationships between instruments with different characteristics cannot be expected to remain the same in different dust clouds.

Impingement (May and Druett, 1953) and mechanical centrifugation (Wolf and Roach, 1961) have also been used to reject nonrespirable particles. These devices also depend on experimental calibration against the desired selection curve.

Figure 6 shows the selection curves for respirable dust recommended by the Medical Research Council and Johannesburg Conference, the Atomic Energy Commission, and as used by Breuer in the BAT 1 instrument.

The development of the scientific view that the most suitable measure of the dust hazard for coal and other inert materials is the per-shift average mass concentration of respirable dust, selected aerodynamically, perhaps combined with a measure of composition, has been described. In the United Kingdom it was felt that such methods would also have operational advantages over existing procedures based on the thermal precipitator. The weight of dust is a more objective and reproducible measure than is particle count; and mineral composition can be more easily studied in gravimetric samples. Compared with short period sampling instruments, such as the standard thermal precipitator (used until 1966) or the impinger, the gravimetric can be left to run without attention, and there are fewer samples to be assessed per shift. (The long-running thermal precipitator introduced in 1966 also had this capability). Work, therefore, proceeded toward changing to gravimetric methods. Standards and sampling procedures have been agreed upon and will become effective on April 1, 1970.

The new British gravimetric standards for coal mines are based on the interim results of the Pneumoconiosis Field Research (Jacobsen and coworkers, 1969). At this stage, the correlation between the mean coalface dust concentrations at 20 collieries, and the corresponding progressions of pneumoconiosis in the coal face workers over a 10-year period, was examined. A more detailed analysis based on the exposures of the individual men will be made later.

Throughout the research the dust measurements were made by thermal precipitator, as previously stated, and had to be converted to gravimetric units. Preliminary studies using thermal precipitators and MRE gravimetric samplers side-by-side showed the relationship between the mass and number parameters (conveniently expressed as a mass-number index, MNI, with units  $\text{mg}/\text{m}^3$  per 1,000 particles/ $\text{cm}^3$ ) to be very variable; neither could the MNI be predicted from a knowledge of the number concentration, size-distribution, and other data recorded in the routine sampling. It was therefore necessary to conduct side-by-side sampling trials at each colliery and in different conditions within the

collieries. In this way colliery mean MNI's were derived, by which the colliery mean particle concentrations were converted to equivalent mass units.

The respective mass and number concentrations are shown in figure 7. The MNI's ranged from 7.8 to 38.2 mg/m<sup>3</sup> per 1,000 particles/cm<sup>3</sup>; the number concentrations from 110 to 520 particles/cm<sup>3</sup> 1-5 μ m, with a mean of 266 particles/cm<sup>3</sup>; the mass concentrations from 1.2 to 8.2 mg/m<sup>3</sup>, mean 4.14 mg/m<sup>3</sup>.

These concentrations relate to the whole underground working shift inclusive of time traveling to and from the coal face; they are averaged over all shifts sampled in the various coal face occupational groups at the respective collieries during the 10-year period between the first and third medical surveys. No direct comparison can be made between these values and concentrations determined by the routine system of dust sampling.

Statistical analysis showed a strong correlation between the overall radiological progression of pneumoconiosis for a colliery and the corresponding mean coal face dust concentration expressed as mg/m<sup>3</sup> of respirable dust. The correlation with particle number concentration was much weaker. The results demonstrated the expected advantages of the mass parameter: however, no firm conclusions concerning the role of composition could be drawn from the interim analysis. Jacobsen and coworkers next used the data for the 10-year period to estimate the probabilities of men contracting pneumoconiosis after 35 years' work at the coal face in collieries with various mean dust concentrations measured in the manner described. These probabilities constituted a basis for determining dust standards, but were not directly applicable.

In considering the nature of dust standards and the sampling procedures needed to enforce them, it must be borne in mind that dust concentrations vary from day to day and from place to place, and that some perhaps essential operations or work places may be especially dusty. Men may change their place of work within a shift or in the longer term. Also men differ in their response to dust so that, given equal exposures, some may contract pneumoconiosis while others are little affected. The proportion affected will decrease with decreasing exposure, but it may not be practicable to enforce standards so low that the more sensitive individuals would not contract the disease if they remained exposed for their whole working lives. In these circumstances, steps should be taken to identify the susceptible individuals at an early stage and to remove them from the hazard. The standards should, moreover, ensure that the risk is small for people in all occupations or places of work, not merely over the population as a whole.

The most common method of approach is to ensure that the dust levels nowhere exceed a specified maximum. This has some practical difficulties. A standard that is enforceable for the worst places must necessarily be higher than the general run of dust levels elsewhere, and may lead to a relaxation of effort to minimize dust at these places. On the other hand, if the limit is lowered and a percentage of unapproved places is considered to be acceptable, some individuals may be exposed to an excessive risk. The use of a standard to define only the average level over all work places would, of course, provide even less control of these cases. The specification of upper limits for both

average levels taken over all work places and local levels for individual places would overcome some of these difficulties. Time-averaged concentrations are meant in each case.

An alternative method is the control of employment to regulate the individual worker's cumulative exposure. This is not applicable to contaminants presenting a rapid, short-term, risk to life, but is logical for long-term cumulative diseases such as pneumoconiosis. Such a system would present difficulties in record-keeping and in other administrative areas, but it would also have some operational advantages. High dust concentrations at one working place, where essential operations present great difficulties in dust control, could be balanced against low dust concentrations at other places. From the medical point of view, the exposure control of the individual must be the aim, and a system that does just this has much to commend it. The records would also have considerable research value. A partial system of this type has been in use in German coal mines for some time. Dust conditions are subdivided into three classes, and no man may be employed in the highest class for more than 500 shifts in 5 years (this class has an upper limit above which no work is permitted). There are other restrictions on the employment of young people and persons with early symptoms of pneumoconiosis. More recently, Reisner (1967) has proposed that the summed product (dust concentration times number of months worked) should be recorded for each man; and that his employment should be regulated so that the total exposure does not exceed a given value in 5 years. With this approach it might still be prudent to specify an upper concentration limit.

In British coal mines, the coal is mined primarily from longwall faces. The dust concentrations normally increase along the face towards the return end, and, since 1949, the dust control standards have related to conditions in the return roadways. The aim is that all coal faces should conform to the standard, which is a maximum for any coal face rather than a colliery average. Since 1965, the standards have referred to the shift mean concentrations determined by continuous sampling during the time that men are at the face, including periods of mining inactivity, but excluding time traveling to and from work in the mine. It was decided that the new gravimetric standard should retain these features, but that it should specify the limiting mean concentration over a number of shifts rather than for individual days. This was to prevent frequent random changes in the approval status, and to reflect the hazard better.

To derive such a standard from the results of the pneumoconiosis field research, it was necessary to examine the relationship between the mean concentration of a coal face as determined by the P.F.R. method and as measured (over a somewhat shorter shift period) in the return roadway. The average ratio was found to be 1:1.4. The distribution of face concentrations within collieries was also studied, and it was found that the concentration on the most dusty face (in a colliery with about six coal faces) was 1.32 times greater than the mean of all faces. Thus the highest return concentration, taken during the time that men are at the face, on a number of shifts, can be expected to be  $1.4 \times 1.32$ ; that is, 1.85 times greater than the corresponding P.F.R. mean face concentration for the whole colliery.

The value of the new gravimetric dust standard is  $8 \text{ mg/m}^3$  of respirable dust, as measured by the MRE instrument over the time that men are at the face (Jacobsen and coworkers, 1969). The normal sampling point for longwall coal faces will be in the return roadway 70 meters from the face (to avoid damage to instruments from shotfiring at the ripping lip). It is intended to sample faces monthly, and to classify them as approved if the mean of the last three monthly concentrations does not exceed the  $8 \text{ mg/m}^3$  value.

Adoption of the gravimetric standard will hopefully achieve for all face workers an overall mean dust concentration not exceeding  $8/1.85$ ; that is,  $4.3 \text{ mg/m}^3$ , portal to portal. Few people at any given time would be exposed to levels as high as  $8 \text{ mg/m}^3$  at their places of work, and none should be so exposed consistently over a long period. Data on the distribution of long term individual exposures corresponding to a given colliery mean will be available later from the pneumoconiosis field research.

As indicated by Jacobsen and coworkers, this standard does not eliminate all risk of contracting pneumoconiosis during a 35-years exposure to coal mine dust. However, it should be remembered that many face workers would not, in the normal course of events, remain on the coal face for as long as 35 years. Moreover, it is anticipated that any workers who do show evidence of radiological change due to dust would be identified at an early stage by the periodic X-ray examinations.

The new British gravimetric standard for stone drivages will be  $3 \text{ mg/m}^3$ . This is intended to preserve the previous differential between the standards for stone and coal pending further information from the pneumoconiosis field research concerning the relative hazards of these dusts.

In coal and stone drivages, and at other "elsewhere underground" work places, samples are taken in the vicinity of representative workmen throughout the shift. Hitherto, in places other than stone drivages, the standard applied has been the same as for longwall coal faces; this is now being reconsidered.

The normal British system of sampling the return air from longwall coal faces is not applicable to "room and pillar" methods of mining. Here, a number of headings will be worked in a given district. They will have been driven various distances from the through-ventilated galleries, and the dust concentrations may vary correspondingly. Machine crews may work in a number of different headings during their shift, while workers engaged in transporting the coal may also traverse a variety of dust conditions. Similar considerations will apply during pillar extraction. Under such circumstances, sampling in the vicinity of representative workmen, perhaps with personal sampling instruments, would seem to be the best way of assessing dust exposure. The formulation of appropriate sampling schedules and dust standards to ensure that no individuals or groups receive long-term mean dust exposures exceeding an agreed "safe" level would require some knowledge of the statistical distribution of dustiness between shifts, between men and between operations. The relationships given by Jacobsen and coworkers (1969) between mean respirable dust concentration and the probabilities of contracting pneumoconiosis after a 35-year exposure, although derived under different conditions, should provide guidance.

## REFERENCES

1. Bedford, T., and C. G. Warner. Med. Res. Council, Sp. Rept. Series No. 244 (London, H.M.S.O.), 1943.
2. Boyd, J. Methods for Determining the Dust in Mine Air as Practiced on the Witwatersrand. Silicosis: Records of the International Conference held at Johannesburg, (Geneva, I.L.O.), August 1930, p. 141.
3. Breuer, H. A Filter Device for the Selective Sampling, in Coal Mines, of Respirable Fine Dusts. Inhaled Particles and Vapours, ed. by C. N. Davies, (Oxford, Pergamon Press), 1961, p. 453.
4. \_\_\_\_\_. Investigation on the Suitability of Cyclones for the Selective Sampling of Respirable Fine Dusts. Inhaled Particles and Vapours II, ed. by C. N. Davies, (Oxford, Pergamon Press), 1967, p. 523.
5. Brown, J. H., K. M. Cook, F. G. Ney, and T. Hatch. Am. J. Public Health, v. 40, 1950, p. 450.
6. Dunmore, J. H., R. J. Hamilton, and D. S. G. Smith. J. Sci. Instr. v. 41, 1964, p. 669.
7. Fay, J. W. J., and J. R. Ashford. Br. J. Appl. Phys., v. 11, 1960, p. 1.
8. Findeisen, W. Arch. Ges. Physiol., v. 236, 1935, p. 367.
9. Goldstein, B., and I. Webster. Br. J. Ind. Med., v. 23, 1966, p. 71.
10. Green, H. L., and H. H. Watson. Med. Res. Council, Sp. Rept. Series No. 199 (London, H.M.S.O.), 1935.
11. Greenburg, L., and G. W. Smith. A New Instrument for Sampling Aerial Dust. BuMines Rept. of Inv. 2392, 1922, 3 pp.
12. Hamilton, R. J., G. D. Morgan, and W. H. Walton. The Relationship Between Measurements of Respirable Dust by Mass and by Number in British Coal Mines. Inhaled Particles and Vapours II, ed. by C. N. Davies, (Oxford, Pergamon Press), 1967, p. 533.
13. Hamilton, R. J., and W. H. Walton. The Selective Sampling of Respirable Dust. Inhaled Particles and Vapours, ed. by C. N. Davies, (Oxford, Pergamon Press), 1961, p. 465.
14. Harris, C. W., and B. A. Maguire. Ann. Occup. Hyg., v. 11, 1968, p. 195.
15. Hart, P. D'arcy, and E. A. Aslett. Med. Res. Council, Sp. Rept. Series No. 243 (London, H.M.S.O.), 1942.
16. Higgins, R. I., and P. Dewell. A Gravimetric Size - Selecting Personal Dust Sampler. Inhaled Particles and Vapours II, ed. by C. N. Davies, (Oxford, Pergamon Press), 1967, p. 575.

17. International Labour Organization. Dust Sampling in Mines. Occup. Safety and Health, Ser. No. 9 (Geneva, I.L.O.), 1967.
18. Jacobsen, M., S. Rae, W. H. Walton, and J. M. Rogan. Gravimetric Standards for Airbourne Dust in British Coal Mines. 1969 (To be published).
19. Landahl, H. D., T. N. Tracewell, and W. H. Lassen. A.M.A. Arch. Ind. Hyg. Occup. Med., v. 6, 1952, p. 508.
20. Liddell, F. D. K., and D. C. Lindars. Br. J. Ind. Med., v. 26, 1969, p. 89.
21. Lippmann, M., and W. B. Harris. Health Phys., v. 8, 1962, p. 155.
22. May, K. R., and H. A. Druett. Br. J. Ind. Med., v. 10, 1953, p. 142.
23. Orenstein, A. J. Proceedings of the Pneumoconiosis Conference, Johannesburg, (Churchill, London), 1969.
24. Owens, J. S. Proc. Roy. Soc. A., v. 101, 1922, p. 18.
25. Reisner, M. T. R. Pneumoconiosis and Dust Exposure - Results of an Investigation of Miners with a Definite Dust Exposure for Periods of 7-10 Years. Inhaled Particles and Vapours II, ed. by C. N. Davies, (Oxford, Pergamon Press), 1967, p. 453.
26. Rivers, D., M. E. Wise, E. J. King, and G. Nagelschmidt. Br. J. Ind. Med., v. 17, 1960, p. 87.
27. Rossitor, C. E., D. Rivers, I. Bergman, C. Casswells, and G. Nagelschmidt. Dust Content, Radiology and Pathology in Simple Pneumoconiosis of Coalworkers. Inhaled Particles and Vapours II, ed. by C. N. Davies, (Oxford, Pergamon Press), 1967, p. 419.
28. Tomlinson, R. C. Instr. Pract., June 1957, p. 578.
29. Van Wijk, A. M., and H. S. Patterson. J. Ind. Hyg. Toxicol., v. 22, 1940, p. 31.
30. Walton, W. H. Br. J. Appl. Phys., Supp. No. 3, 1954, p. S29.
31. Watson, H. H. Trans. Inst. Min. Metal, v. 46, 1936-37, p. 155.
32. Wolff, H. S., and S. A. Roach. The Conicycle Selective Sampling System. Inhaled Particles and Vapours, ed. by C. N. Davies, (Oxford, Pergamon Press), 1961, p. 460.
33. Wright, B. M. Br. J. Ind. Med., v. 10, 1953, p. 235.
34. \_\_\_\_\_. Br. J. Ind. Med., v. 11, 1954, p. 284.
35. \_\_\_\_\_. Br. J. Ind. Med., v. 14, 1957, p. 219.

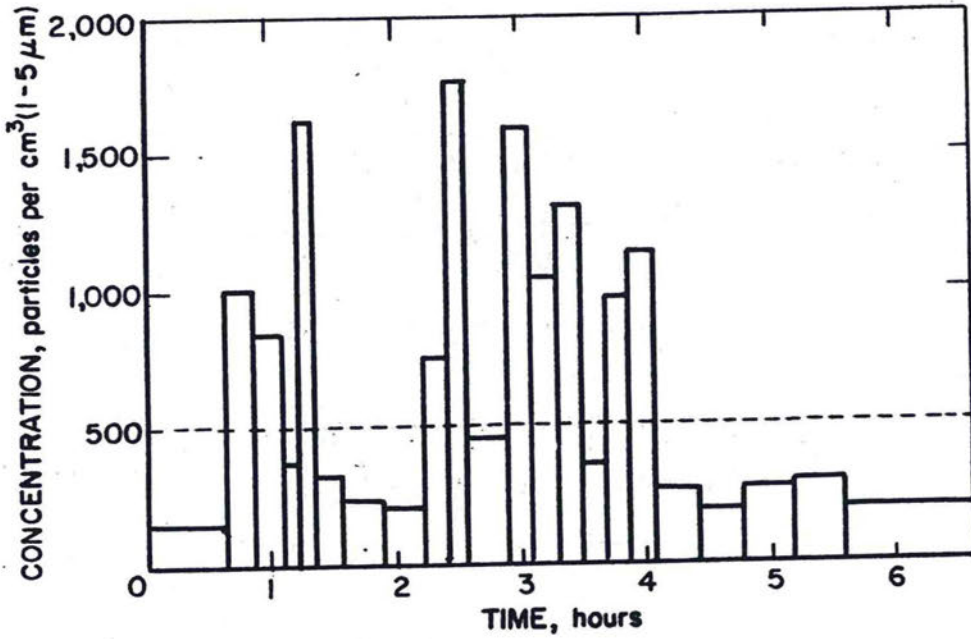


Figure 1.—Variability of Dust Concentration During a Working Shift.

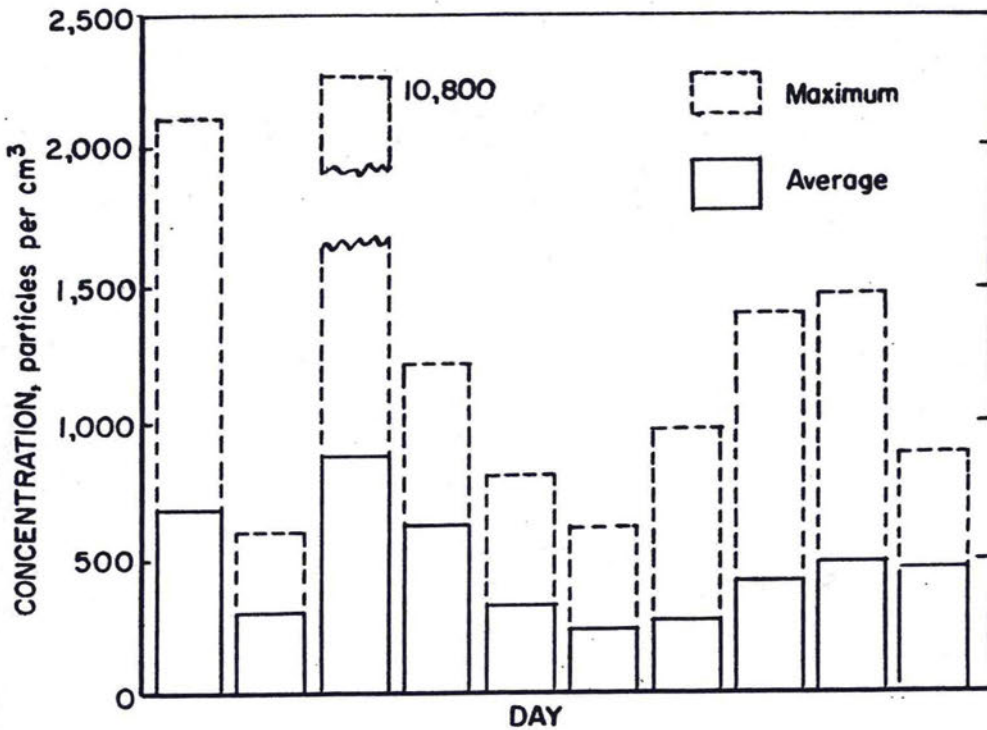


Figure 2.—Variability of Dust Concentration at Same Working Place.

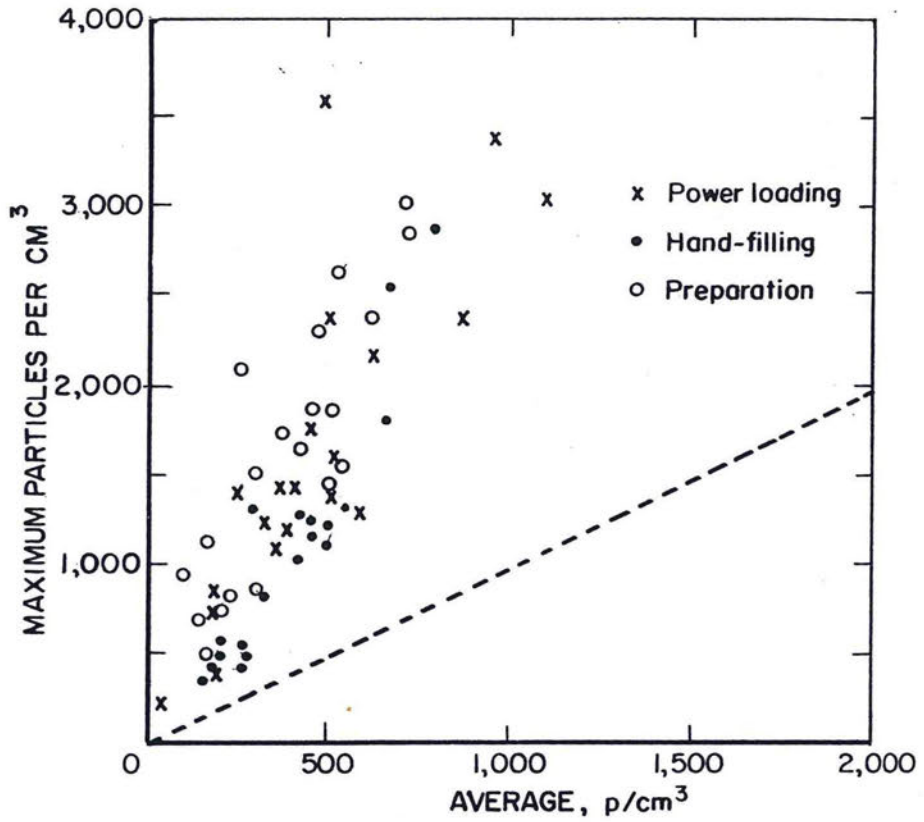


Figure 3.—Shift Average Versus Maximum Concentration.

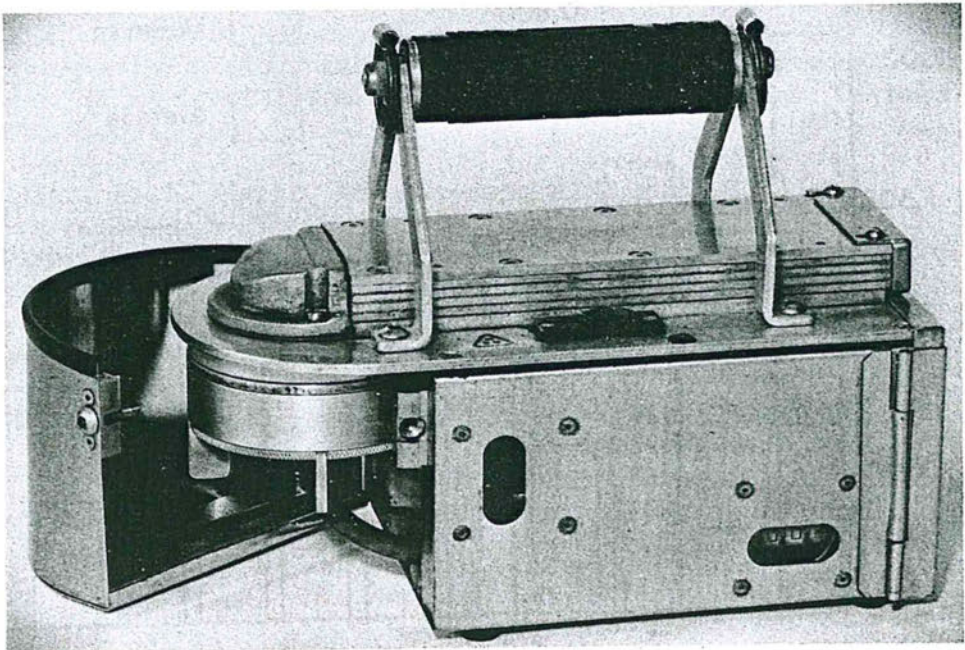


Figure 4.—NCB/MRE Gravimetric Dust Sampler Type 113 A.



Figure 5.—“Simpeds” Personal Dust Sampler.

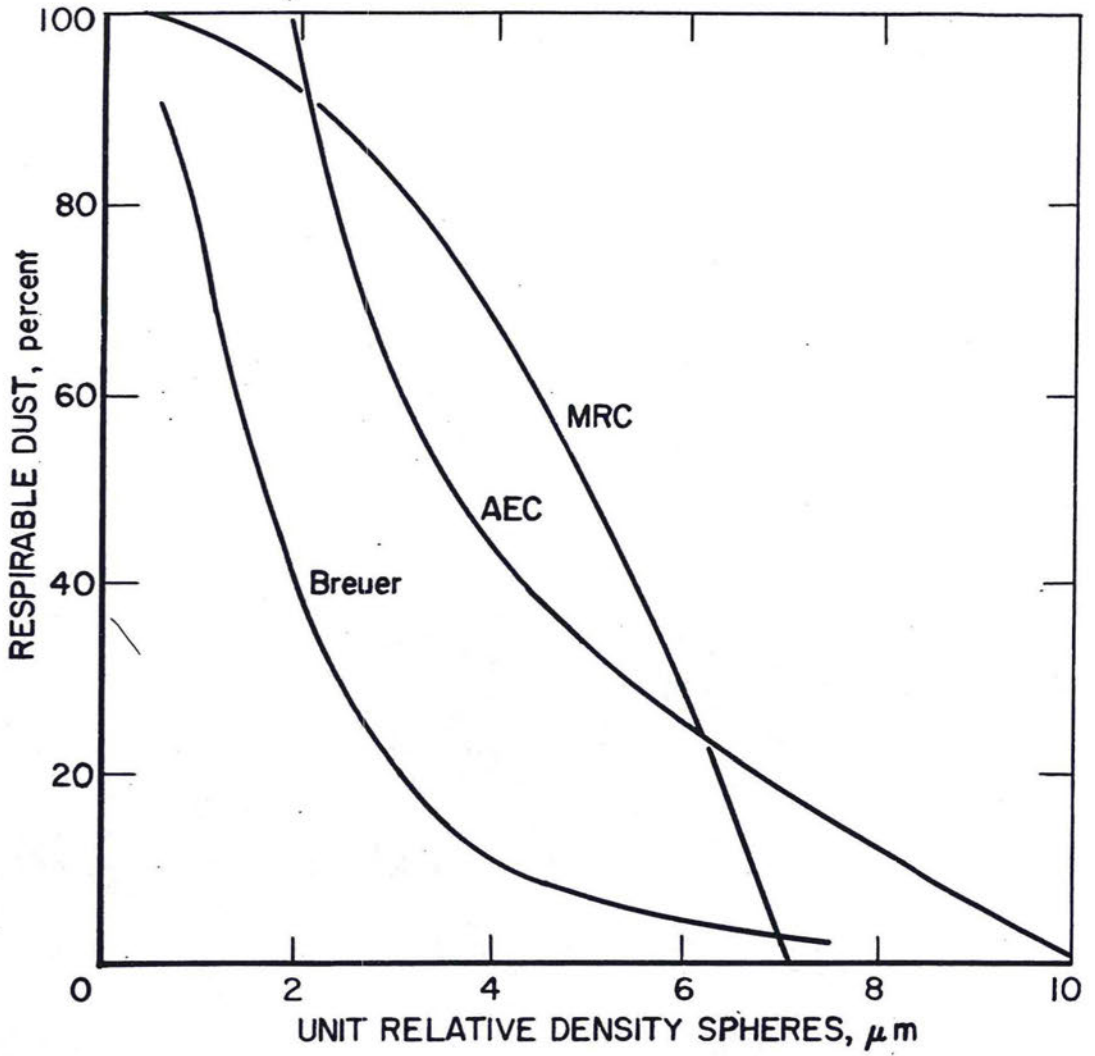


Figure 6.—Selection Curves for Respirable Dust.

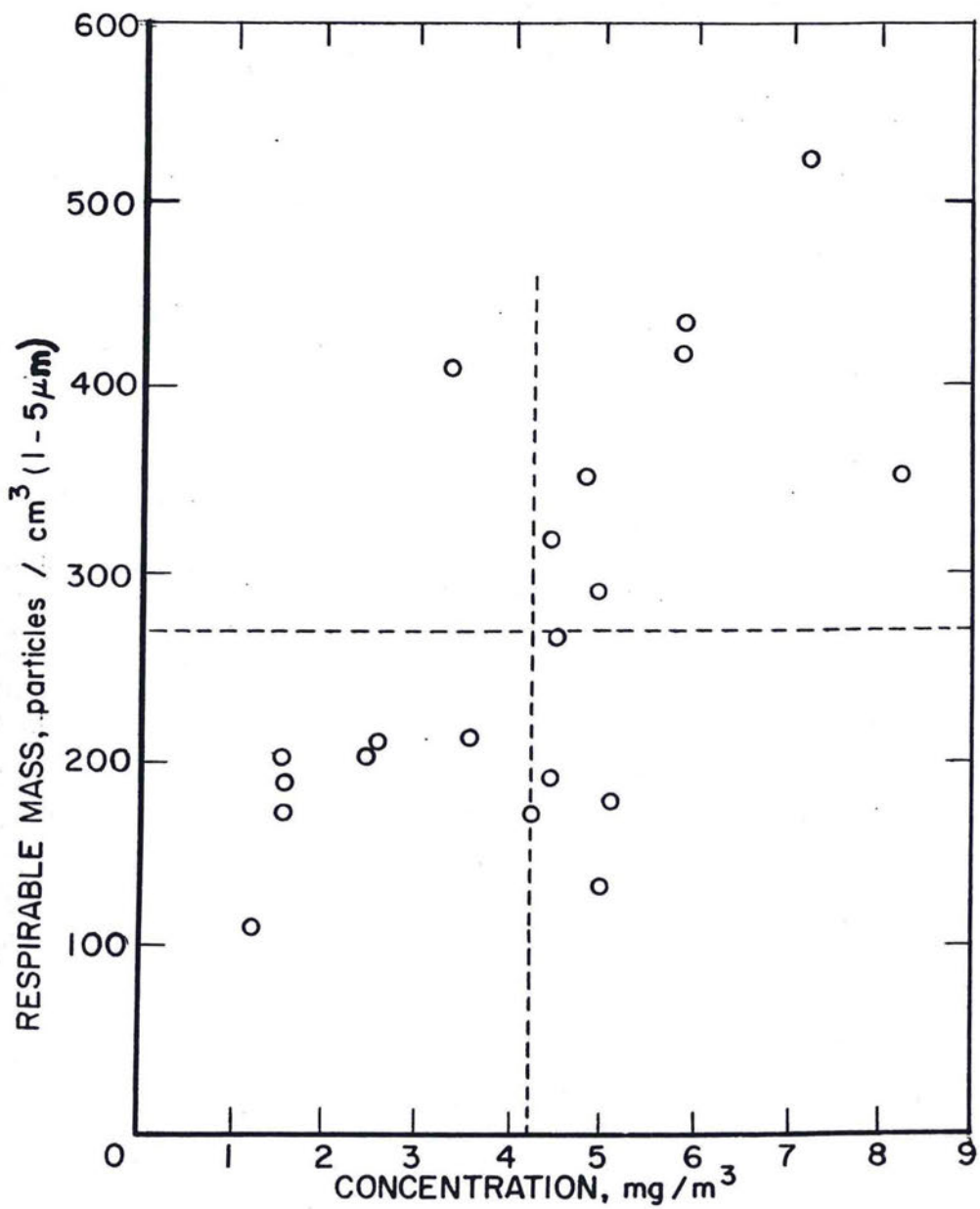


Figure 7.—Colliery Mean Coal-Face Concentrations by Number and by Respirable Mass.

MR. RIGG: Are there any questions for our speaker?

QUESTION: On what basis do you determine the percent of silica in the dust samples?

MR. WALTON: We measure quartz by infrared absorption spectrometry. The dust is washed from the membrane filter using ultrasonics (recovery is normally about 90 percent), and the ash percentage of the recovered material is determined. A known weight of ash is then mixed with potassium bromide and pressed into a disk whose infrared transmission at the quartz absorption doublet (780 and 800  $\text{cm}^{-1}$ ) is recorded and compared with that of standard preparations. Alternatively, the dust and membrane filter can be ashed together. Samples containing as little as 50 micrograms of quartz can be evaluated in this way or to 1 microgram using micromethods.

QUESTION: What is your standard for the probability of contracting pneumoconiosis based on?

MR. WALTON: The results of the Pneumoconiosis Field Research over 10 years were projected to give estimates of the probabilities of men contracting Category 1 or Category 2 pneumoconiosis after 35 years' exposure to various concentrations of colliery mean coal face dust. The curves will be given in a paper by Jacobsen, Rae, Walton and Rogan, to be published shortly. At a colliery mean concentration of 4.3  $\text{mg}/\text{m}^3$ , the probability of contracting Category 2 or more pneumoconiosis in 35 years is, I believe, a little over 3 percent, but I must remind you that many men will not work on the coal face as long as this and that any developing cases of pneumoconiosis should be detected by the periodic X-ray examinations before Category 2 is reached.

QUESTION: You indicated that portal-to-portal sampling was not done. You have about 15 percent .....

MR. WALTON: The colliery mean coal face concentrations, measured in the Pneumoconiosis Field Research, were based on portal-to-portal sampling. The corresponding concentrations, measured only over the time that men were at their places of work, would be on average about 15 percent greater. This difference is embraced within the factor used to derive the standard for return roadway sampling over the time that men are on the face from the research data.

QUESTION: Does that mean that your standard corresponds to a mean working place concentration of 4.9 to 5  $\text{mg}/\text{m}^3$ ?

MR. WALTON: Yes, about that for the colliery mean face concentration, if measured over time at the working place instead of portal-to-portal.

QUESTION: In weighing the filters, did you dry them first or not?

MR. WALTON: It is necessary to take precautions against changes in the moisture content of the filters. We do not dry them but use controls from the same batch. Both sample filters and controls are conditioned in the same laboratory atmosphere before and after sampling. It is of course desirable that there should be no large difference in atmospheric humidity between the two sets of weighings.

MR. RIGG: Our next speaker, on "Dust Concentrations in the Mines" is Henry N. Doyle, Acting Assistant Director, Mineral Industry Health, Bureau of Mines.

## DUST CONCENTRATION IN THE MINES

by

Henry N. Doyle

---

By 1966, based on work of British and European investigations and a Public Health Service study, it was abundantly clear that coal pneumoconiosis was a major health problem in the American coal mines. The cause of the disease was, without doubt, the inhalation of coal mine dust. In U.S. mines about 10 percent of active coal miners had X-ray evidence of the disease: 6-1/2 percent had evidence of the early stage of pneumoconiosis, and 3-1/2 percent showed signs of the complicated stage. Furthermore, evidence pointed to a growing problem if corrective action were not taken.

In November 1968, the Bureau of Mines established as one of its goals the development of engineering procedures for the prevention of coal pneumoconiosis, in the shortest possible time frame. To attain an objective of this nature, the following three criteria must be fulfilled: First, the problem must be defined; secondly, the magnitude of the problem in some definable parameter must be known; and thirdly, procedures for its solution must be developed.

Through the efforts of many investigators, the problem had been defined in clear and concise terms as the prevention of a chronic respiratory disease caused by the inhalation of coal mine dust. Although scientists may not be in full agreement on the relative importance of coal and quartz dust in its etiology, this fact was only of academic interest since all biologists would agree that coal mine dust should be controlled to the maximum limit possible to minimize worker exposure.

To meet the second criteria, it was necessary to establish a health standard for a safe concentration of coal mine dust and to evaluate dust conditions in the mines relative to this standard.

Based on the best available epidemiologic evidence, the Public Health Service in December 1968 recommended the value 3 mg/m<sup>3</sup> of respirable coal mine dust as a hygienic standard. The gravimetric standards are based on the Mines Research Establishment (MRE) instrument, also known as the Isleworth sampler.

In April 1968, the Bureau had initiated a study to measure the exposure of various occupations in underground coal mines. The original measurements were to have been taken in 34 mines (32 bituminous and two anthracite) selected from various mining areas. The criteria for selection were that (1) the mine employ more than 20 men underground and (2) the productive life of the mine be in excess of 10 years. The objective of the original study was to develop exposure data on various occupational groups for correlation with medical information on individual workers; this information was to be obtained by the Public Health Service. This was a long range study planned to develop a hygienic standard and to determine the effect of coal mine dust

on the development and progression of pneumoconiosis. In view of the need for additional data, the study was altered to some extent so that meaningful data in terms of other parameters could be obtained.

Two basic instruments used in conducting this investigation were as follows: The Mines Research Establishment instrument (MRE), an instrument developed by the National Coal Board (United Kingdom) and used primarily to evaluate dust conditions in the environment; and the personal sampler, another gravimetric instrument, but one that could be used to evaluate the exposure of the individual. Both instruments will be described in more detail in a later paper by Mr. Jacobson. Laboratory studies have demonstrated the reliability and comparability of the two instruments. The difference, in relationship to this data, is that under identical dust conditions the MRE instrument will collect 1.88 times more dust than the personal sampler. In other words, the value of  $3 \text{ mg/m}^3$ , when measured by the MRE, is equivalent to  $1.6 \text{ mg/m}^3$  when measured by the personal sampler.

The significant findings from this study were as follows:

1. A large portion of the underground occupations had exposures in excess of the recommended Public Health Service standard of  $3 \text{ mg/m}^3$ .
2. The mining machine operators and helpers generally had the highest exposure to respirable coal mine dust.
3. Higher environmental dust levels were associated with the continuous mining machines.
4. Control measures in general use were limited to ventilation and water sprays.
5. Some mines were using dust-laden air for ventilation.

Detailed exposure data was obtained on 16 underground occupations, resulting from 1,976 samples obtained in 29 mines. This data is shown in abbreviated form in table 1. The concentration of respirable coal mine dust to which the underground worker was exposed during a single shift ranged from  $.36 \text{ mg/m}^3$  to  $103 \text{ mg/m}^3$ . The mean dust concentrations measured over an 8-hour period was in excess of  $3 \text{ mg/m}^3$  for 13 of the 16 underground occupations.

Another parameter of the investigation was to compare the dust generating characteristics of the various underground coal mining machines. The limitations of the data only permitted a comparison between the continuous mining machine and the cutting machine. In each case, the sampling instruments were located reasonably close to the operators. The comparison of the dust concentrations between these two mining machines is illustrated in table 2, which shows the average dust concentrations for each of these machines. In every case, the mean respirable dust concentration found on the continuous miner was in excess of that found on the cutting machine, generally by a factor of 3.

Mine dust concentration by occupation  
(personal sampler)

Occupation	No. of mines	No. of samples	Range mg/m <sup>3</sup>	Mean mg/m <sup>3</sup>	MRE mean mg/m <sup>3</sup>
Continuous miner operator.....	21	178	0.02-21.44	4.08	7.7
Continuous miner helper.....	19	131	0.44-18.90	3.47	6.5
Cutting machine operator.....	15	98	0.71-15.42	3.69	6.9
Cutting machine helper.....	8	37	0.77-14.70	4.45	8.4
Coal drill operator.....	9	59	0.42-12.94	3.55	6.7
Loading machine operator.....	18	97	0.25-39.56	3.75	7.1
Loading machine helper.....	6	31	0.50-14.48	3.17	6.0
Roof bolter operator.....	25	296	0.09-38.50	2.46	4.6
Shotfirer.....	12	83	0.62-56.97	3.15	5.9
Section foreman.....	28	236	0.14-14.51	1.69	3.2

Comparison of dust concentrations in mines with  
cutting machines and continuous miners

(MRE, mg/m<sup>3</sup>)

Mine	Continuous miner		Cutting machine		Ratio of means
	Mean	Range	Mean	Range	
B-1	5.92	1.20-13.92	2.07	1.66- 2.48	2.86
B-6	11.80	3.98-22.16	11.68	4.09-23.47	1.01
B-7	16.30	1.79-36.71	5.17	4.18- 6.34	3.15
C-2	15.62	1.54-27.06	2.75	1.59- 4.12	5.68
C-3	10.68	6.28-15.08	3.27	1.62- 6.17	3.27
C-5	12.70	5.36-28.19	5.33	3.33- 7.33	2.38
C-6	13.47	8.93-18.90	4.72	4.10- 5.33	2.85

Another parameter of interest was the concentration of the total airborne dust. Data in table 3 demonstrates several interesting comparisons. First, the mean respirable dust concentration with the personal sampler was  $3.02 \text{ mg/m}^3$ ; with the MRE it was  $5.95 \text{ mg/m}^3$  or a ratio of  $\frac{5.95}{3.02}$  or 1.97. This compares very favorably with the theoretical ratio of 1.88. The same comparison made on the continuous mining machine yields a ratio of  $\frac{10.4}{5.25} = 1.98$ . Thus, the reliability of the two instruments, in terms of the translation of results, is well validated.

The total airborne dust at the cutting machine averaged  $63.1 \text{ mg/m}^3$ , and  $128 \text{ mg/m}^3$  for the continuous miner. It was evident that the continuous miner produces about twice as much dust as the cutting machine. This same 2 to 1 ratio was apparent for respirable dust when measured by either instrument.

Comparison of mean dust concentration between cutting machine  
and continuous miner

Personal Sampler

Sample site	No. of mines	Dust concentration, $\text{mg/m}^3$			Average respirable dust concentration	Average total dust	Ratio respirable/total
		<1.6	1.6-2.9	>2.9			
Cutting machine	15	4	4	7	3.02	63.1	20.9
Continuous miner	21	2	1	18	5.25	128.0	24.4

MRE

Sample site	No. of mines	Dust concentration, $\text{mg/m}^3$			Average respirable dust concentration	Average total dust	Ratio respirable/total
		3.0	3.1-5.5	5.5			
Cutting machine	15	3	8	4	5.95	63.1	10.6
Continuous miner	21	1	3	17	10.4	128.0	12.3

The standard for respirable dust as recommended by the Public Health Service was based on coal mine dust containing less than 5 percent quartz. Therefore, it was important in this investigation to know the concentration of quartz in the respirable dust. The data in table 4 compares the ash content of the coalbed with the ash content of both respirable and gross dust. There is a significant difference between the ash content of airborne dust and the ash content of coal. Doubtlessly, this is caused by the machine cutting into the rock strata and the noncombustible fraction of the dust contained in the incoming air. The quartz content of the respirable dust ranged from 0.4 percent to 3.1 percent with an average value of 1.5 percent quartz. It is obvious that the quartz content of the respirable dust was well below the recommendation of the Public Health Service.

Quartz and ash level in respirable and total dust - weight percent

No. of mines	Coalbed		Respirable and total dust			
	Volatile matter	Ash	Ash		Quartz (SiO <sub>2</sub> )	
			Respirable	Total	Respirable	Total
29	15-40.3	3.0-13.9	4.4-44.3	3.0-38.5	0.4-3.1	0.4-2.4

In all mines studied, the intake air was monitored for the concentration of respirable dust. Wide variations were found ranging from 0.06 mg/m<sup>3</sup> to 3.3 mg/m<sup>3</sup>. In one of the 29 mines measured, the mean concentration of the incoming respirable dust was greater than 3 mg/m<sup>3</sup> and in seven of the 29 mines, it was greater than 1.0 mg/m<sup>3</sup>. In 22 mines, however, the concentration of the incoming dust was less than 0.5 mg/m<sup>3</sup>. Thus, a concentrated effort must be made in many mines to clean up the incoming air.

This data is presented in complete detail in the expanded paper that follows this presentation. It should be emphasized, however, that it is not presumed or implied that the data is representative of the entire underground coal industry. The data is presented as being indicative of the relative dust concentrations and the dust control problems to be encountered in the industry.

The third criteria in the Bureau's plan was a determination of the engineering procedures that would control respirable dust in underground mines to a hygienically safe level, through one or more of the following engineering control methods:

1. The design of the coal mining machine to minimize dust production.
2. The effective use of ventilation to remove respirable dust from the work area.

3. Water infusion of the coal seam.
4. Liberal use of water on mining equipment and at dust generating points.
5. The use of wetting agents to allay dust.
6. The use of dust collecting equipment at points of dust generation.
7. The use of respirators or life support systems to provide personal protection for underground workers.

A detailed review was made of these methods in terms of their feasibility and available technology. Based on this review, it was evident that the two most promising methods of approach were ventilation and the use of water. In both cases, the technology was available and no significant delay would be encountered in its application. Studies by the Bureau coupled with the experience of other investigators indicated that water, both alone and in connection with wetting agents, had definite limitations. Although water sprays on mining machines have beneficial effects as a suppression measure for total airborne dust, current spray techniques have little effect on dust in the respirable ranges. Since ventilation appeared to offer the greatest degree of success, in August 1969, the Bureau undertook a concentrated study on the feasibility of improved ventilation techniques for reducing the respirable dust concentration to an acceptable level in the underground mining environment. These studies have proved the feasibility of this method of approach, and later in the Symposium, you will be informed of the results of this investigation.

Our research, coupled with that of the industry, is beginning to demonstrate the feasibility of substantially improving environmental dust condition in underground coal mines and the possibility of meeting hygienic standards which only a short time ago seemed virtually impossible. We are now of the opinion that adequate dust control can be attained in most mines, frequently at a minimal cost. If this can be accomplished within a reasonable time, there is little doubt that many lives will be saved, many cases of simple pneumoconiosis will be prevented from progressing into the more serious form of the disease, and great economic loss, to the companies, the workers, and the public will be averted.

QUESTION: I would like to ask Mr. Doyle if the 1.88 to 1 ratio between the MRE and AEC cyclones is now considered final by the Bureau of Mines?

MR. DOYLE: It is not considered as a final ratio by the Bureau of Mines. This ratio is based on a fixed sampling rate by the two instruments, in this case two liters per minute. If either sampling rate is changed, this ratio will also be changed.

So until a definite sampling rate has been established for the personal sampler, the 1.88 holds as the present sampling rate.

QUESTION: What density of sprays would you use for dust control?

MR. DOYLE: Sprays will be talked about in a later paper, so I would appreciate your holding that question.

All seven methods of control that were mentioned in my paper are control methods around which this whole program was prepared. So, there will be discussions on each of those points that I brought up.

QUESTION: In the sampling techniques used by the Bureau, do they differentiate between the rock dust and coal dust in your measurement?

MR. DOYLE: No. The amount of dust deposited in the filter is what is weighed. This could be, of course, rock dust, coal dust, or any other kind of dust that was taken into the filter.

We can make some kind of differentiation in the laboratory between the various dusts. This is done on many samples but not on all samples.

QUESTION: How would you sample and analyze the silica in the content of the coal dust?

MR. DOYLE: Questions of this kind will be covered after Mr. Jacobson's presentation.

QUESTION: I am very interested in why, of the eight methods you talked about, why you dismissed No. 8 so quickly?

MR. DOYLE: I think most of you would agree that respirators are not a basic method of engineering control. The use of respirators in the past, and I am sure even in the context of the present proposed legislation, would be to use them as an auxiliary control measure. This is the way it has been viewed in practically all industrial health situations.

QUESTION: I was speaking of pneumoconiosis -- not so much as a control but as a method of eliminating pneumoconiosis. Doesn't your respirator do this?

DR. DOYLE: A properly designed respirator, worn and taken care of properly, is designed to prevent the inhalation of pneumoconiosis-producing dust.

## PERSONAL RESPIRABLE DUST SAMPLER

by

M. Jacobson and J. A. Lamonica

---

### ABSTRACT

Equipment for evaluating the respirable dust exposure of individual underground coal miners was designed, constructed, and tested by the U.S. Bureau of Mines. As a result, the guidelines for sampling and evaluating respirable dust concentrations in the breathing zone of individual miners were finalized, and the equipment was made commercially available. The equipment and techniques, which are described in this report, are consistent with the provisions of pending coal mine health legislation governing respirable gravimetric dust concentrations.

### INTRODUCTION

Recent experimental findings indicate that all airborne dust inhaled does not enter the lungs; the dust of hygienic significance is that portion which reaches the terminal airways of the lungs. This portion, called the respirable fraction, contains no particles larger than 10 micrometers (10 microns) and about 50 percent of the 3.5-micrometer-size particles. (A micrometer is about 1/25,000 of an inch.) Since particles of this size range cannot be seen by the human eye, instruments used to evaluate the dust hazard should simulate the respiratory tract in its selectivity for the respirable fraction of dust particles. Since understanding of the physiological mechanics associated with dust retention in the lungs is limited, the criterion for selecting dust sizes of hygienic significance is the generally accepted deposition curve for dust in the terminal airways of the lungs. The weight of dust extracted from the lungs of miners examined in autopsy shows good correlation with severity of pneumoconiosis based on X-ray categorization prior to death. It is believed that the weight of the respirable fraction of airborne dust is the parameter of primary interest for the hygienic evaluation of dust exposure. A size criterion for the respirable fraction has been defined by work performed within the U.S. Atomic Energy Commission.<sup>1</sup> This is described by the sampling efficiency curve, shown on figure 1, which is dependent on the aerodynamic behavior of the particles.

As part of its continuing program of promoting health and safety in U.S. coal mines, the Bureau of Mines has been studying the concepts of respirable dust sampling since early in 1965. Sampling equipment and procedures were developed for evaluating the respirable dust exposure of individual miners and

---

<sup>1</sup> Lippmann, M., and W. B. Harris. Size-Selective Samplers for Estimating "Respirable" Dust Concentrations. Health Physics, v. 8, 1962, p. 157.

have been tested in surveys conducted in 46 underground coal mines; about 6,300 samples were collected.

### SAMPLING EQUIPMENT

The Bureau of Mines personal respirable dust sampler is a two-stage device. The first stage, a 10-millimeter nylon cyclone, performs as an elutriator or size-selector whose penetration conforms to a curve which is in close agreement with the criterion reported by the U.S. Atomic Energy Commission (this curve is obtained when the sampler is operated at 2.0 liters per minute). The second stage is a membrane filter that collects the respirable fraction of the dust. The dust collected is weighed to the nearest 0.1 milligram, and concentrations are expressed as milligrams of dust per cubic meter of air sampled.

The personal sampler continuously samples air from the worker's breathing zone during the full working shift. The atmosphere is drawn through the device at 2.0 liters per minute by a portable, battery-operated diaphragm pump.

The individual components of the personal sampler before assembly are shown on figure 2. A listing of equipment and associated components necessary for assembling personal dust samplers is as follows:

A. Approved battery-operated sampling pump.

It is essential that the pump be approved by the Bureau of Mines for use in underground coal mines. The pump must be capable of operating for a minimum of 8 hours at a flow rate of 2.0 liters per minute. The following equipment meets the above requirements; costs shown are approximate.

1. Casella Mark II Model B Pump without sampling head, \$200.  
Willson Products Division  
P.O. Box 622  
Reading, Pa. 19603
2. M-S-A Monitaire Sampler, Model G, \$200.  
Mine Safety Appliances Company  
201 North Braddock Ave.  
Pittsburgh, Pa. 15208
3. Unico Model C110 Pump, \$200.  
Unico Environmental Instruments, Inc.  
150 Cove St.  
Fall River, Mass. 02720

## B. Sampling head.

The sampling head consists of a 10-millimeter nylon cyclone and filter assembly mounted in a suitable holder for attaching to the worker. The following equipment meets these requirements:

1. M-S-A Gravimetric Dust Sampler, \$30.  
Mine Safety Appliances Company  
201 North Braddock Ave.  
Pittsburgh, Pa. 15208
2. Respirable Mass Lapel Sampler, \$30.  
Unico Environmental Instruments, Inc.  
150 Cove St.  
Fall River, Mass. 02720

## C. Filter assembly.

The filter assembly consists of a 37-millimeter vinyl membrane filter retained in a suitable filter holder. These parts are available from the suppliers of the sampling heads mentioned above and from other sources.

## D. Additional equipment.

1. Battery charger, \$35. The above-mentioned pumps have rechargeable batteries. The price of a battery charger supplied by the pump manufacturers may not be included in the pump price.
2. Volt-Ohm-Milliampere Meter, \$35. To be used for checking battery voltage and electrical trouble-shooting in the field. May be obtained from any electronic supply house.

## SAMPLING PROCEDURE

The recommended procedures for collecting and evaluating respirable dust samples are outlined as follows:

### A. Preparation of filter assembly and personal sampler.

1. Clean all parts thoroughly prior to assembly. It is suggested that filter holders be used only once. This will prevent possible leakage resulting from damaged rims occurring during filter removal.
2. Assemble the component parts shown in figure 2 into the completed sampling unit as illustrated in figure 3. Collecting surface of filter must face cyclone.
  - a. Make sure the filter has been preweighed.

b. The red and blue plastic plugs are used to seal the filter holders before and after sampling; use red for inlet, and blue for outlet.

3. Calibrate and adjust pumps to provide  $2.0 \pm 0.1$  liters per minute.

a. Pressure drop of sampling head must be considered during calibration.

b. Recheck pump calibration at least monthly, or as needed.

B. Placement of equipment for sampling.

1. Attach the pump to the subject's belt at the most suitable location. Position the pump so that it does not interfere with normal work operations.

2. Place the sampling head in the proximity of the subject's breathing zone, as shown in figure 4. The unit can be clipped or pinned to the subject's lapel or work garment in such a manner that the sampling head is maintained in a vertical or upright position during the sampling period.

C. Operation of equipment.

1. Turn on the pump and record the time.

2. On pumps having integral flowmeters, adjust airflow to 2.0 liters per minute.

a. Check the flowmeter reading after 1/2 hour of operation and at midshift to insure that equipment is operating properly. Adjust as needed.

b. Sampling is conducted during the full working shift.

3. Turn off the pump and record the time.

4. Disconnect sampling head and recharge battery. Do not invert sampling head during removal from pump.

5. Remove and clean cyclone.

D. Pertinent information: The following is an example of the information generally needed to properly evaluate the sample.

1. Sample No. and date sample collected.

2. Pump No.

3. Time on.

4. Time off.
5. Total sampling time, minutes.
6. Rate of sampling, liters per minute.
7. Volume of air sampled, (lpm) × (min).
8. Occupation sampled.
9. Subject's name.
10. Social Security No.
11. Section location.
12. Type of mining machine (Model No.).
13. Type of ventilation used (blowing, exhausting, auxiliary).
14. Type of mining operation (development, retreat, longwall).
15. Mine No.
16. Prewrite, mg.
17. Final weight, mg.
18. Weight of dust, mg.

E. Determination of Concentration.

1. Remove filter from filter holder. Care should be taken not to lose any of the sample or tear the filter.
2. Weigh the filter to the nearest 0.1 mg and record the weight on the information sheet.
3. Determine the respirable dust concentration using the following formula:

$$\text{Dust concentration (Mg/m}^3\text{)} = \frac{1,000 (W_2 - W_1)}{T \times R}$$

where  $W_1$  = initial filter weight, mg.

$W_2$  = final filter weight, mg.

T = sampling time, minutes.

R = rate of sampling, liters per minute.

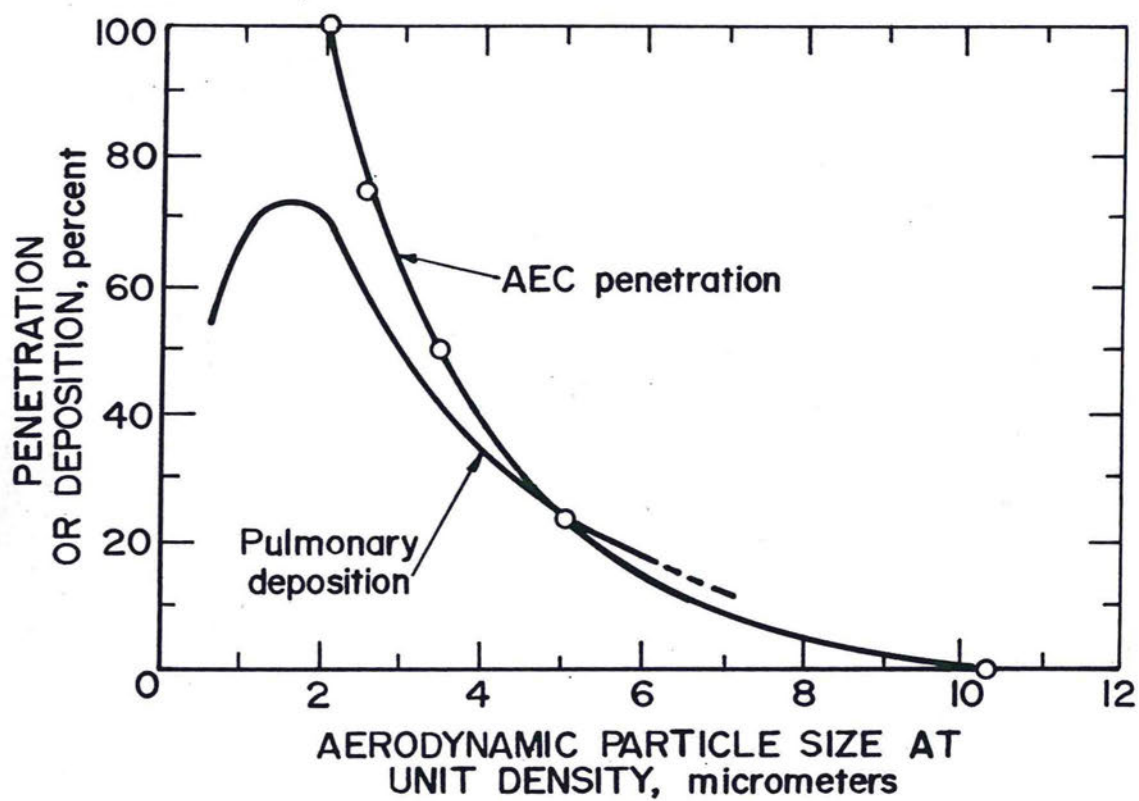


Figure 1.—Respirable mass deposition curve.

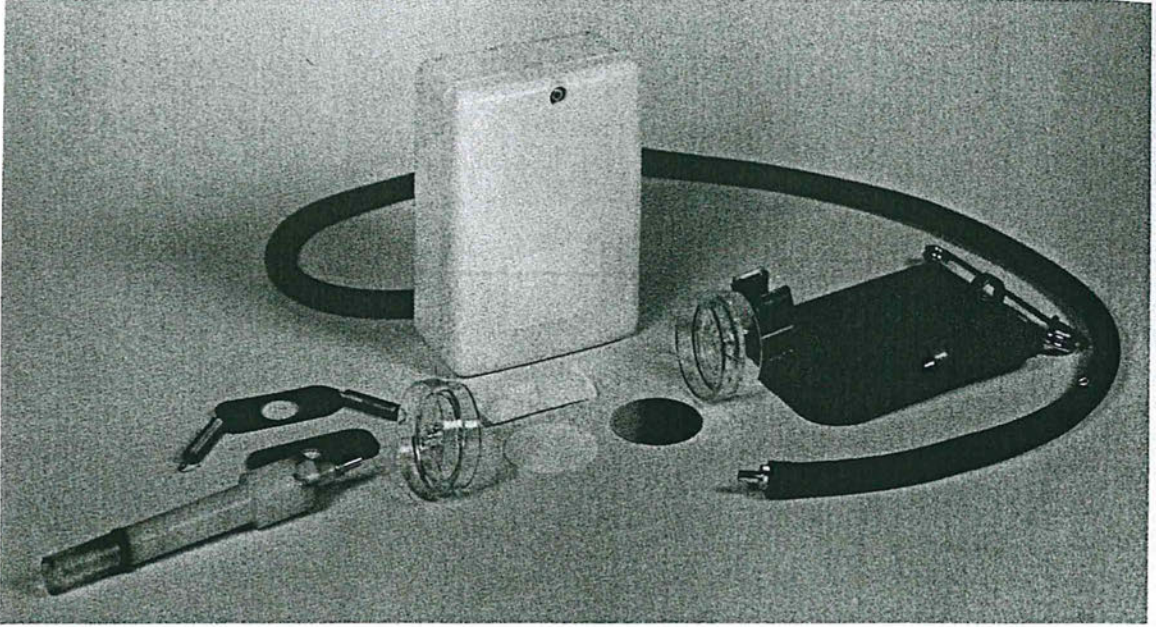


Figure 2.—Personal sampler unassembled.

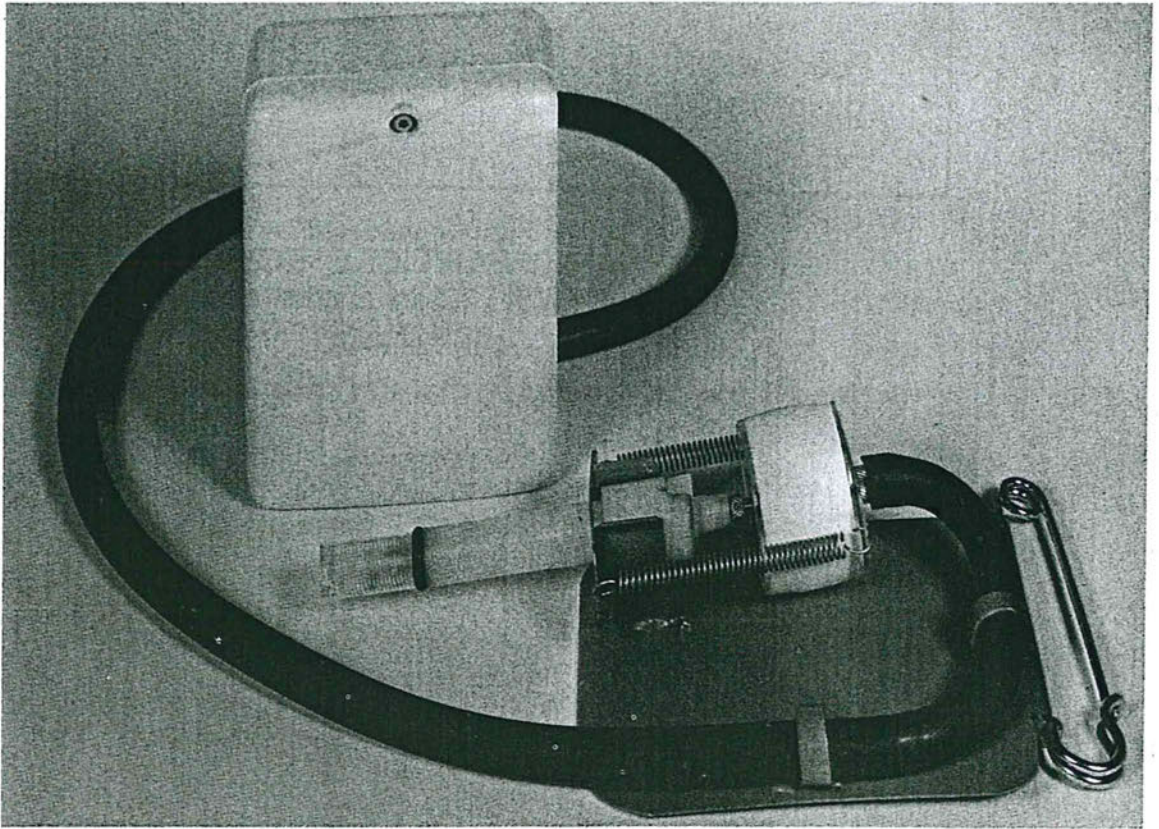


Figure 3.—Personal sampler assembled.



Figure 4.-Personal sampler ready for use.

MR. RIGG: Our next speaker, on "Assessing of Respirable Dust in United States Coal Mines", is Murray Jacobson, Acting Chief of the Pittsburgh Field Health Group of the Bureau of Mines.

## ASSESSING RESPIRABLE DUST IN UNITED STATES COAL MINES

by

Murray Jacobson

---

---

### INTRODUCTION

The inhalation of almost any dust should be regarded as potentially dangerous to health. Of primary importance is the quantity and composition of the dust inhaled and retained in the lungs for extended periods.

During the past 10 years, changes have occurred in the philosophy of assessing the health hazards of pneumoconiosis-producing dusts. Therefore, new dust sampling techniques and analytical procedures have been developed to provide the necessary data for evaluating underground working environments.

Recent experimental findings indicate all the airborne dust inhaled is not deposited in the lungs; the dust of hygienic significance is that portion which reaches the terminal airways of the lungs. This fraction is generally referred to as respirable dust. Therefore, instruments used to evaluate the health hazard in dusty atmospheres should simulate the respiratory tract in selecting the respirable fraction of the dust particles.

Since understanding of the physiological mechanism associated with dust retention in the lungs is limited, the criterion for selecting dust sizes of hygienic significance is the generally accepted deposition curve for dust in the terminal airways of the lungs. The mass of dust extracted from the lungs of miners examined in autopsy shows good correlation with severity of pneumoconiosis based on X-ray categorization prior to death.<sup>(1)</sup> Therefore, it is believed that the mass of dust in the respirable fraction is the parameter of primary interest for hygienic evaluation of dust exposure.

At present, there are two criteria for the respirable fraction. The first, resulting from work performed within the U.S. Atomic Energy Commission, <sup>(2)</sup> is defined by a sampling efficiency curve that passes through the following points: effectively 100 percent efficiency at 2 microns and smaller, 50 percent efficiency at 3.5 microns, and zero efficiency for particles 10 microns and larger.

The other criterion for the respirable fraction of dust, recommended and adopted by the Johannesburg Pneumoconiosis Conference, <sup>(3)</sup> is defined by a sampling efficiency curve that passes through the following points: effective;

100 percent efficiency at 1 micron and smaller, 50 percent efficiency at 5 microns, and zero efficiency for particles of 7 microns and larger. Particle sizes refer to equivalent diameter, which is defined as the diameter of a spherical particle of unit density having the same falling velocity as the particle in question.

Comparison of the two recommended respirable size criteria with the pulmonary deposition curve is shown in figure 1. The purpose of both criteria is to approximate dust deposition in the nonciliated portions of the lung.

### INSTRUMENTS

To effectively assess respirable dust concentrations encountered in the coal mine environment, two-stage sampling instruments have been developed. Currently, there are two types of respirable gravimetric sampling instruments being used in coal mines.

The personal respirable dust sampler (4) (fig. 2) is one of these instruments. The first stage, a 10-millimeter nylon cyclone, performs as an elutriator whose collecting efficiency closely approximates the criterion reported by the U.S. Atomic Energy Commission. (This efficiency is obtained with the sampler operating at a flowrate of 2 liters per minute.) The second stage is a membrane filter that collects the respirable fraction of dust that passes through the cyclone. The dust collected is weighed to the nearest 0.1 milligram, and the concentrations are expressed as milligrams of dust per cubic meter of air sampled. Each miner can be equipped with a personal sampler (fig. 3) to determine his dust exposure during the work shift.

Another device (fig. 4) is the Isleworth Gravimetric Dust Sampler, or MRE, (5) which was developed at the Mining Research Establishment of the National Coal Board at Isleworth. The first stage of the MRE, a four-plate horizontal elutriator, has a collecting efficiency that closely approximates the criterion recommended and adopted by the Johannesburg Pneumoconiosis Conference. This efficiency is obtained with the sampler operating at a flowrate of 2.5 liters per minute. The membrane filter used as the second, or collecting stage, is treated in the same manner as the filters from the personal sampler, and concentrations are expressed as milligrams of dust per cubic meter of air sampled.

These size-selective, two-stage gravimetric sampling devices are being used for evaluating the work environment and the worker's exposure in coal mines. Each instrument has its advantages and disadvantages, some of which are as follows:

#### Personal Sampler

##### Advantages:

1. Light weight.
2. Relatively inexpensive.

3. Can be attached to miner to measure his dust exposure during the work shift.
4. Prewighed filter cassettes or assemblies can be utilized for efficient handling in high speed, automatic weighing system.
5. Cyclone can be readily disassembled to remove the coarse fraction for analysis.
6. Calibration of instrument readily determined in field.
7. Normal positioning of sampler does not affect its operation.

**Disadvantages:**

1. Collection characteristics of cyclone cannot be precalculated.
2. Airflow through the cyclone materially affects the collection efficiency. (Some disagreement exists as to the correct airflow that is required for achieving the desired collection characteristics.)
3. Particle penetration through the cyclone is reported to decrease with concentration.
4. Agglomeration and disaggregation can occur within the cyclone, causing the characteristics of the sampler to change.

MRE

**Advantages:**

1. Nonrespirable fraction separated by sedimentation; therefore, aerodynamics behavior of particles is readily determined.
2. Collection characteristics of elutriators can be precalculated.
3. Recommended dust standards in the United States and in the United Kingdom are based on MRE results.

**Disadvantages:**

1. Bulky and heavy (9-1/2 lb.).
2. Relatively expensive.
3. Cannot be attached to miner to measure his dust exposure during work shift.

4. Filters are difficult to handle and cannot be easily handled in high-speed, automatic weighing system.
5. Instrument is relatively sensitive to horizontal positioning.

Vinyl membrane filters, or equivalent, are used in all the gravimetric sampling instruments. This material was selected because there is a negligible change in weight when sampling is done in the high-humidity atmosphere encountered in coal mine face areas.

Membrane filters were selected instead of "in-depth" filters for two basic reasons: First, the resistance to airflow is low and does not change materially with the quantities of dust collected; secondly, the dust can readily be removed from the filters for chemical and physical analysis.

The instruments and procedures described have been tested during studies conducted in operating underground mines. The instruments have all proven to be rugged enough for use underground at the working face, and have given reliable results that can be employed in assessing environmental dust exposures of coal miners.

To correlate results obtained with the various types of sampling devices, instrument sampling packages, each containing four samplers (personal, MRE, total airborne dust, and long running midget impinger) are positioned in the selected working section. Figure 5 shows such a sampling package. One package is positioned adjacent to the operator on or near the coal-cutting equipment; the second package is placed in the immediate vicinity of workers who are indirectly involved with the coal-getting operation (primarily, the roof bolters); and the third is placed in the intake airway to the section. All samplers operate the entire time the working crew is in the section.

Figure 6 shows the linear relationships between the personal gravimetric sampling data and the data collected with the MRE and the midget impinger at continuous mining and cutting machine operations in 29 mines, during the environmental dust survey. The correlation coefficient, 0.9, was calculated for the regression lines; the average ratio of individual MRE to personal gravimetric sampling data is approximately 2.

The importance of the relationship between data collected by personal and MRE respirable dust samplers must be emphasized. The proposed interim dust standards are specified in terms of  $\text{mg}/\text{m}^3$  as sampled by the MRE; therefore, this empirical relationship permits data obtained using the personal sampler to be reported in terms of equivalent MRE values.

The precision of the measurement of respirable dust concentrations depends on (1) the accuracy of the pump calibration, (2) the maintenance of constant flowrate, and (3) the accuracy of the weighing of the filters, before and after sampling. The sampling instruments are designed to operate within  $\pm 5$  percent of the specified flowrate; maximum deviation in weighing is about  $\pm 0.05$  milligram, before and after sampling. These factors can result in a statistical variation in dust concentration ranging up to  $\pm 0.4 \text{ mg}/\text{m}^3$ .

## BIBLIOGRAPHY

1. Nagelschmidt, G. The Study of Lung Dust in Pneumoconiosis. Am. Indus. Hyg. Assoc. J., v. 26, January-February 1965, p. 1.
2. Lippman, M., and W. B. Harris. Size-Selective Samplers for Estimating "Respirable" Dust Concentrations. Health Physics, v. 8, 1962, p. 157.
3. Orenstein, A. J., ed. Proceedings of the Pneumoconiosis Conference, Johannesburg, Republic of South Africa, 1959. Little, Brown & Co., Boston, 1960.
4. Jacobson, M., and J. A. Lamonica. Personal Respirable Dust Sampler. BuMines Tech. Prog. Rept. 17, September 1969, 8 pp.
5. Dunmore, J. H., and coworkers. An Instrument for the Sampling of Respirable Dust for Subsequent Gravimetric Assessment. J. Sci. Instr., v. 41, 1964, pp. 669-672.
6. Jacobson, M., S. L. Terry, and D. A. Ambrosia. Evaluation of Some Parameters Affecting the Collection and Analysis of Midget Impinger Samples. Presented at AIHA Conference, May 14, 1969, Denver, Colo.

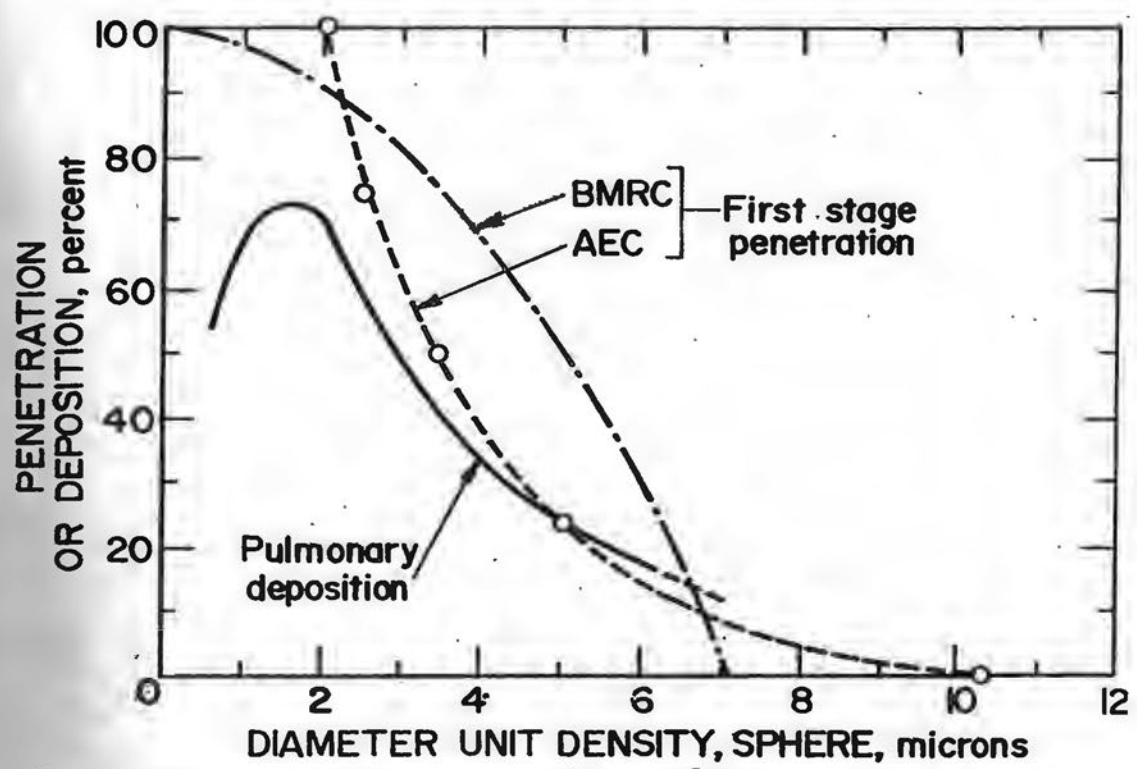


Figure 1.—Comparison of Recommended Respirable Size Criteria With Pulmonary Deposition Curve.

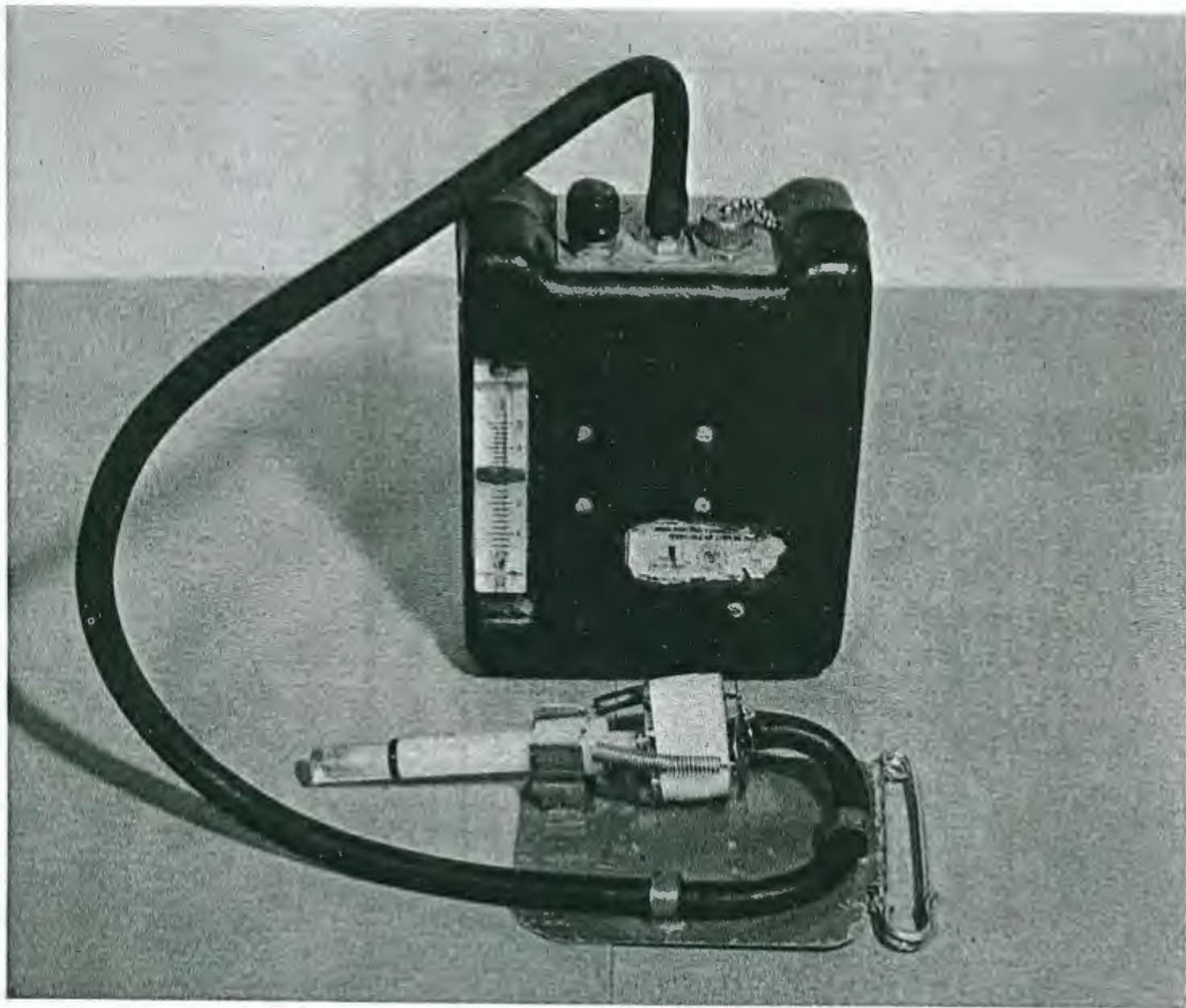


Figure 2.—Personal Sampler

Figure 2.—Personal Sampler



Figure 3.—Personal Gravimetric Sampler Ready for Use

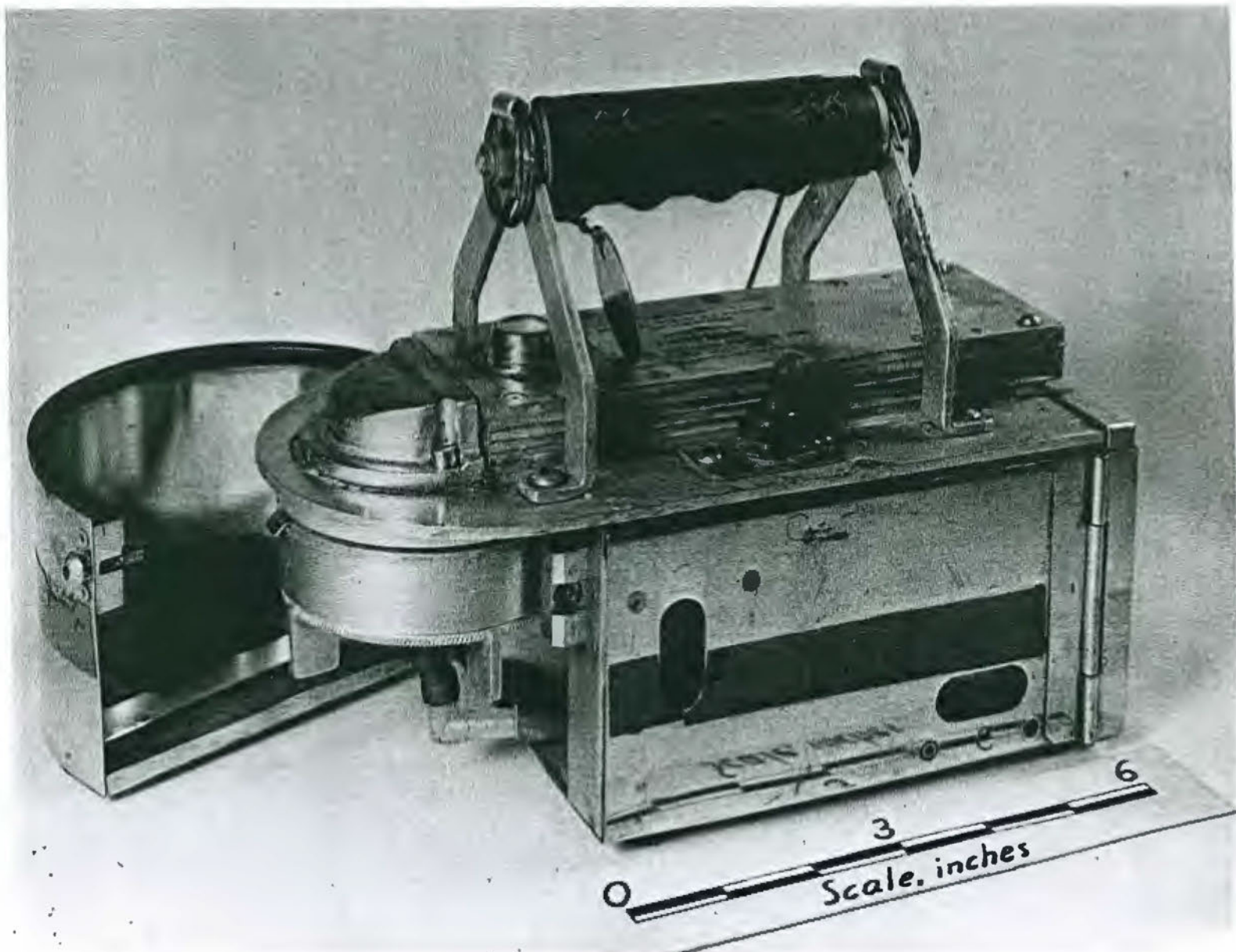


Figure 4.—MRE Sampler

Figure 4.—MRE Sampler



Figure 5.—Instrument Sampling Package

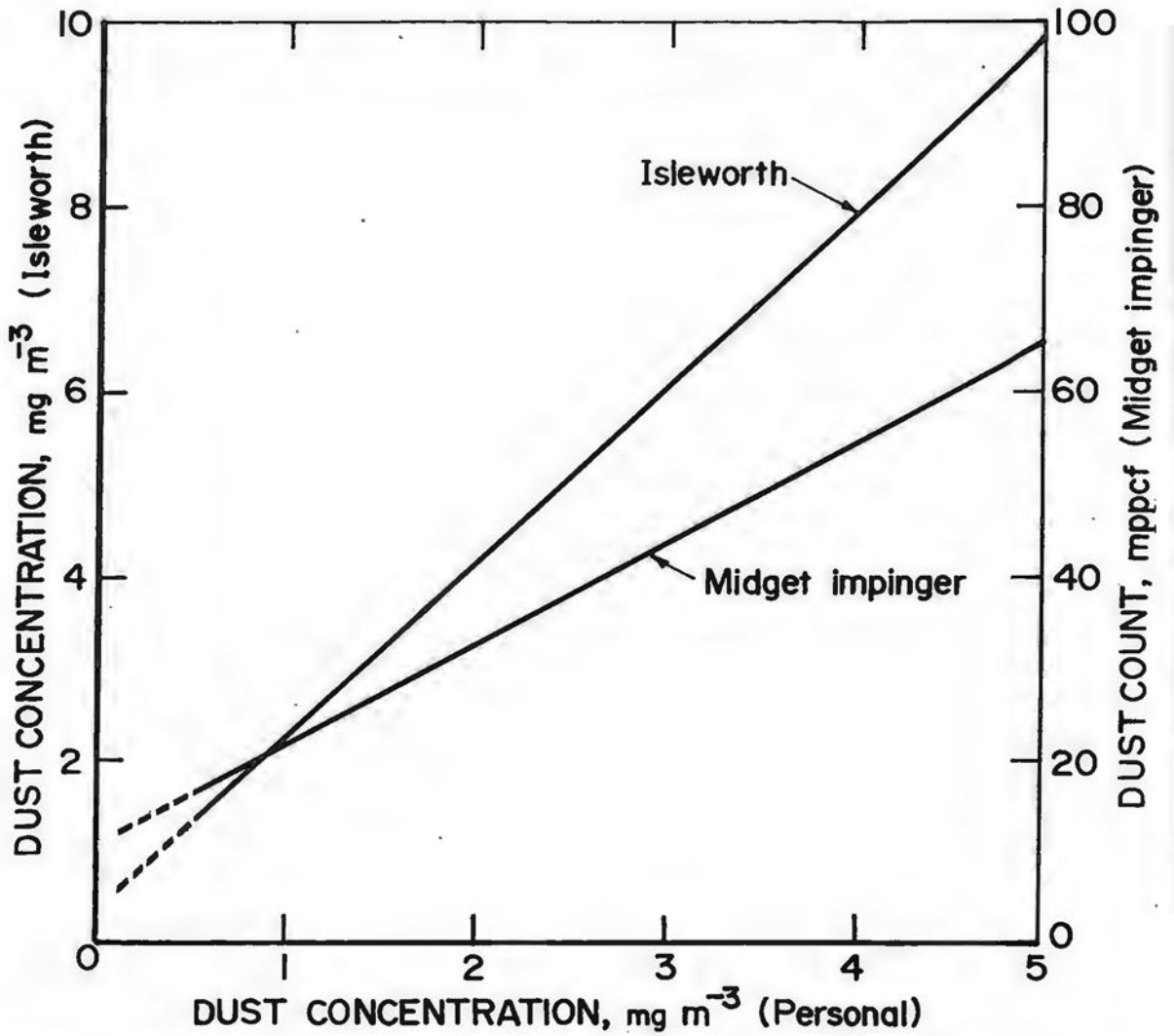


Figure 6.—Relationships between data collected with the personal sampler and that collected with the MRE and midget impinger.

QUESTION: In regard to the system described by Mr. Walton --

MR. JACOBSON: The system that Henry Walton described is the same one we use, primarily because of the smallness of our samples.

We initially started with X-ray diffraction, trying to squeeze down to a small enough quantity, and we were running into a lack of precision problem. So we went over to the infrared system, using the ash of the coal mine dust and picked off the silica peaks. This is correlated with the X-ray and also calibrated against free crystalline silica standards.

QUESTION: You mentioned you had some data on moisture on your filters. Did it vary during the high humidity and low humidity seasons?

MR. JACOBSON: What we did was to determine the change in weight on the filter at 90 to 95 percent relative humidity to see whether there was an effect. I think our increase in weight was about 2/100th of a milligram immediately, and as you let it set for a half hour, the change in weight decreased until it was within the weighing precision of the balance we are using. So this is why we neglected the slight change in weight that you would get during the sampling time, because this essentially disappears on standing.

QUESTION: What is the effect of the cleanliness of the worker's clothes on the sample? After a week, the worker's clothes get pretty dirty. If he shakes dust off, he can contaminate the sample.

MR. JACOBSON: We have collected about 2,000 individual personal samples in addition to our instrument package samples, and there is some effect. But, during any short period of time, we are only sampling 2 liters per minute out of a total of 960 liters on an eight-hour day. He would have to beat for one devil of a time to get enough to really materially affect the sample. I mean, it would have to be an outright intentional bias that he is trying to produce which can be introduced in many other ways, much quicker and much more simpler.

QUESTION: Do you have a procedure for eliminating any individual bias?

MR. JACOBSON: I can say, by way of experience, that when sampling in a normal run on a ten-shift survey, you may find one extremely high. When this sample is examined and you look at the particle size distribution on the filter, you will find that there are some large particles, indicating that this sampling head has been turned over. So, you automatically throw out that sample.

We have had some cases in which we did have extreme highs but did not find these large particles. Therefore, we must retain high ones just as well as low ones, if you are sure that there is no intentional upset as part of the turning it over.

QUESTION: What are the current standards to be based on?

MR. JACOBSON: In my last reading of both the Senate and the House versions of the bill, it says concentration of "X" number milligrams per cubic meter as measured by the MRE, or its equivalent, as specified by the Secretary.

QUESTION: What are the mechanics for removing the dust from the filters?

MR. JACOBSON: The vinyl filters that we have been using cannot be ashed very well. They do not give you an analytical ashing. We developed a different technique.

We remove the dust from the membrane filter, using an ultrasonic washing technique which was developed in our laboratory, and within two minutes, we remove better than 99.9 percent by weight of the dust from our filters. There is still some of the extreme fine left in the pores, but it's a very, very small fraction of the weight of the material.

MR. RIGG: Our next speaker, with a paper entitled, "Practical Problems in Implementing a Dust Control Program in Coal Mines," is William Kegel, who is Assistant General Manager of Raw Materials of Jones & Laughlin Steel Company.

## PRACTICAL PROBLEMS IN IMPLEMENTING A DUST CONTROL PROGRAM IN COAL MINES

by

W. G. Kegel

---

Congress and the administration in Washington have just presented the American mining industry with serious and complex new operating problems.

This paper is concerned with one of those problems, the program for controlling and monitoring the fine dust now known to be a possible cause of miner's pneumoconiosis. We are faced with a rigid new standard, and must prepare for regular and frequent dust surveys.

First, let us review some facts. We may be required to hold dust levels to a maximum of 4.5 milligrams per cubic meter and even less in a year or two. Respirable dust is that which is 5 microns or less in size.

A micron is one-millionth of a meter, or .000039 of an inch. By comparison, a human hair is about 50 microns in diameter. There are 453,000 milligrams in a pound, so that 4.5 milligrams is equal to one, one hundred thousandth of a pound. This is the weight of respirable dust that will be permitted in a volume of air equal to a cube 39 inches on each side.

This standard is attainable under many conditions. It is ambitious under others, and impossible to attain in some situations in some of our mines.

Many question whether, within the present state of our knowledge, these arbitrary limits are realistic. I think we can all agree that a recent statement by John E. Swearingen, Chairman of the Board of Standard Oil of Indiana, applies to coal mine dust as it applies to the problem of pollution generally. He said, "No one can argue that wherever pollution can be scientifically demonstrated to be a genuine hazard to human health, it should be eliminated."

I would add that in order to get the maximum value out of the dollars spent on control programs, those who formulate policy and administer the programs should set realistic standards that will accomplish the goal without imposing unnecessary burdens upon those paying the bill.

Our problem is to bring our mines into compliance with the new regulations and still maintain the coal industry as a pillar of the national economy. The productivity of our deep mines, 14 tons per man-day, has not been duplicated anywhere else in the world. This productivity has been of great benefit to our country and its economy. It is responsible, for example, for the low cost of electricity that we all enjoy.

American ingenuity, coupled with the American sense of cooperation and understanding, -- cooperation and understanding between labor, management and government -- exercised in an atmosphere of reason and the knowledge of the high stakes involved, can and will solve our problem.

Much will depend on sampling -- how and where samples are taken, and how the samples are interpreted. To appreciate this problem, we must first have a broad understanding of United States mining practice.

The most prominent mining system is the room and pillar, which can create multiple dust-producing areas when worked conventionally or with continuous mining machines, whether in the development or retreat phase of mining.

Presently, there are two systems for face ventilation: One uses an auxiliary fan and tubing; the other uses line brattice cloth to establish a parallel passageway for oppositely coursed air. There are three types of continuous miners, and when considering dust make, each of these presents different problems as to the dust produced, the ability to wet the face, and the ability to route the dust via the air stream. The development and retreat phases each present different ventilation problems. Since many companies, and sometimes individual mines, find a need for all three types of miners, and also do retreat mining, the multiple situation problem is common. The following examples illustrate the situations likely to produce dust in our system of mining:

The latest of the modern continuous miners is the milling type. It has found acceptance throughout the industry due to its ready adaptability to the room and pillar system. Like its predecessors, it is the product of much research for safe and efficient operation under a variety of mining conditions. When working under a weak roof, it will generally alternate working places with a roof drill. Each machine is a dust-producing source in its respective place, will require simultaneous ventilation, and quite probably, will become an acceptable monitoring point for the dust control program. This method of operation is presently the most desirable under the roof conditions mentioned.

Another type of continuous miner is the borer. In mines where the roof is good, the borer can drive up a series of entry advances, each 80 to 100 feet long, then turn a crosscut, which permits straight ahead mining for 500 to 700 feet. Since the borer drives an entry only inches wider than the machine's width, tubing best serves the ventilating problem.

As the machine advances, the tubing must be lengthened, and to do so means momentarily opening it and thereby momentarily stopping the air current that removes the dust. While this is being done, a greater dust concentration might be expected in the area of the operator.

A common operating procedure for borers is to follow the machine with a drill conveyor and then with a pick-up loader. Each of these machines could be considered a dust-producing source and, because of their individual positions relative to the tubing end, could possibly become monitoring points. The speed of this operation and the high concentration of machinery in a small area make monitoring very difficult, unless personal samplers are used.

When doing retreat work, the large close-fitting borer is moved forward and backward frequently enough to make the job of maintaining an uninterrupted air flow more difficult. Again, momentary higher dust concentration could result.

The third type miner is the ripper, which may, on development work, utilize roof drills ahead of the operator. Three men are in positions where dust monitoring may be advisable.

For some years, U.S. mines have been using a dust collecting system on these roof drills. This system does a good job when no water is present in the roof. However, if water is present in the roof, the drill operator switches to a scrolled auger. This brings the slurry down the outside of the auger, and if the hole goes dry, the cuttings could produce a cloud of dust. The operator can avoid this momentary dust cloud and usually does; a positioned sampler would not.

The ripper-type miner can be ventilated well with either tube or brattice line, but if drills are being used and can be considered a dust source for the reason just mentioned, additional attention will have to be given the position of the tube or brattice line. The drill operator on the canvas or tube side will be in the dust stream unless the tubing or brattice end is kept in by the man.

This explanation should point up the importance of the sampling procedure, and the need for a system of averaging dust counts in an area for some period of time rather than a spot determination which could falsely condemn an operation. It is also necessary that we be able to maintain a flexible system for the placement of samplers.

Where conventional mining equipment is being used, three -- and sometimes four -- places can be dust-producing areas. These would be the cutting machine, the loader, the roof drill (where used), and the place being shot or blasted. In conventional work, ventilation to each of these places without momentary interruptions would be rather difficult to accomplish.

In many conventional sections, doors are used to separate intake and return airways. These doors are frequently opened by shuttle cars hauling coal or by men moving about the section. When this is done, momentary breaks in the air flow result. If air sampling for dust were being done on a spot check basis, very irregular results would be recorded.

While considering miners and cutting machines, one must also investigate their cutting elements and the spray water system to be used. It is not the intention of this paper to discuss that field, but its importance should not be forgotten. We must also remember that much has been done in the United States to allay coal dust with water and to inert coal dust with rock dust. I would like to talk about rock dust in some detail.

When a program of dust suppression for respiratory reasons becomes the chief objective, we certainly should try to minimize the use of rock dust where possible. Extensive tests here have proven that from 22 percent to 32 percent of our rock dust is in the minus 5-micron range. With 5 percent silica in this rock dust, there are some disturbing implications.

Consider a mine producing 8,000 tons per day and using 15 pounds of rock dust per ton of coal mined. This means that 60 tons of rock dust are distributed

throughout the mine each day. Assume that 25 percent is minus 5 microns, or respirable dust. Then 13,600,000,000 milligrams of respirable dust are being put into the mine atmosphere each day, 5 percent of which could by law be silica. True, not all the dust is dispensed in working areas; more than half is distributed in return airways where no one works, but still the implication is staggering. This is not the product we are mining, but one we must bring into the mine and use in addition to the dust produced by the cutting action in coal. The questions are as follows: Will these additional particles complicate the procedure? Will they be considered as detrimental as coal dust? And finally, should we discount them when taking into consideration a man's lungs?

It becomes obvious that the rock dust procedure will have to be given careful consideration as to its effect on the dust survey program and, more important, the men. We must not forget that the silica content of rock dust is very harmful. Couple this with the realization that limestone is being used for acid neutralization today at a rate never before equaled. Large amounts of silica-free rock dust may be very hard to get as time goes on, and increased output of this product can be had only with large capital outlays.

Considering all these complexities, we feel strongly that the U.S. Bureau of Mines should reconsider its attitude toward the use of water for dust control. There are some places where water can do an excellent job, with no harmful effects on the men.

The U.S. Bureau of Mines has not yet worked out all the details of the dust survey program, but we do know some of them. Sampling will be done on some scheduled basis by the operator. The sampling will last one full shift and preferably include one sample from each production section each day. This appears to be much more than adequate and should probably be relaxed before a final decision is made. The whole series of samples from a particular section would be averaged over some reasonable period for establishing the actual dust level. This, of course, is the proper system to use in view of the facts related earlier in this paper. It will, however, involve cooperation between men and management because, whether the sampler is carried by a man or mounted on a machine, some care will have to be exercised to see that it is properly used and cared for.

The procedure will involve a unit known as the personal respirable dust sampler. This unit was chosen because of its light weight, lower cost, and the fact that it can, if necessary, be carried on the individual's person. We must be concerned, however, for a program that requires additional equipment to be carried on a miner's belt. Certainly a machine mounting would be more desirable and would undoubtedly represent a less vulnerable position. Any miner, operator, or laborer is expected to perform and does perform tasks that seemingly would jeopardize the unit when carried by the individual. More important, it seems very unwise to impose upon the miner an additional piece of equipment that would jeopardize his comfort, his efficiency, and very possibly his safety.

Only time and experience will determine the best way to position the samplers. There are places where they can accomplish their purpose only if carried by an individual. On the other hand, some resistance to this is sure to result. Machine or stationary mounting will not always be truly representative,

since a man can protect himself by his mobility. The compromise is most likely to be a flexible combination of the two, agreed upon by the Bureau and the mine personnel.

This particular personal sampler requires a battery and charger setup that will increase to some degree the general maintenance being carried on in the lamp house. The sample is collected on a 37-millimeter, vinyl membrane filter. These are to be sent to the Bureau with a list of pertinent information. Hopefully, a method for computerization can be devised that will minimize the paper work. Also necessary is some careful handling of the sampling head during the removing process.

Some information regarding Britain's method for sampling is appropriate and will point up our problems by way of comparison. A document titled F.4000, issued by the National Coal Board in 1966, has been revised effective October 1969. The following pertinent facts were taken from that report:

Sampling frequencies for coal face production shifts will be on a monthly basis, along with coal and stone headings or entries. Loading and transfer points in return airways would be monitored once each quarter, and coal face preparation shifts once each year. A place requiring monthly samples will be considered approved if the mean of dust concentrations for the last three months (or first or second month, if the area is new) is less than the standard agreed upon. This is now known to be  $8 \text{ mg/m}^3$ . Places requiring quarterly or yearly samples will be considered approved if the initial sample is less than  $8 \text{ mg/m}^3$ , or if the mean of all samples taken in a calendar month is less than  $8 \text{ mg/m}^3$ .

Here we see the use of average readings, taken over a representative period of operation, that I mentioned earlier. This level of  $8 \text{ mg/m}^3$  can be construed to reflect a standard of  $5.7 \text{ mg/m}^3$  an average for all workers at the working face. However, as we understand the British program, there is an implication that  $8 \text{ mg}$  is the figure that will generally be applied in practice.

The British have a provision in F.4000 for the equivalent of our room and pillar work. It reads as follows:

Work in bord and pillar districts shall be sampled continuously over the working shift. The sampling instrument shall be set up at a position close to a workman so as to obtain a sample which is representative of dust conditions at the working place, from the time that the men arrive to the time that they leave. When the men move from one working place to another during the shift, the sampling instrument shall be moved with them and sampling shall continue during the travelling periods.

Their reporting procedure is as follows:

All sampling data including a description of the working place and operations in progress, etc., are recorded and processed by computer. Print-outs will provide management with information on dust conditions and summaries will be provided for quarterly and annual reports. The computer data bank will also provide information required for general statistical and research purposes as requested by the Board's Departments.

The dust sampler's report shall provide the information required to complete the computer input form, as follows:

1. Area, colliery, seam, working place, operation sampled.
2. Date of sampling.
3. Instrument serial number, sampling time, volume sampled.
4. Thickness of the seam and of the extracted section, presence of dirt bands and faults, cutting in dirt, operations in progress and machines in use other than those sampled.
5. Air quantity and air velocity.
6. Dust suppressive measures applied which may have bearing on dust conditions in the working place on the day of sampling.
7. Sketch of the working place sampled.
8. Any remarks relevant to the dust conditions on the day of sampling.

As stated before, the British standard will be 8 milligrams per cubic meter. The standard is not mandatory. This fact makes the difference in systems. Since the British standard is not mandatory, there is no great need for rapid reporting of the results. Also, in the great percentage of British mines, advance longwalling is being done. A single entry system for air movement exists; generally, there is no great change in dust-producing conditions from day to day. The section does not change rapidly.

In the United States, room and pillar sections where 50 to 70 tons per face man-day are being mined, section configuration, air currents, and mining conditions change almost hourly. With a mandatory dust level rule, it is most necessary that an average or mean method be used as a basis for determining compliance, and that careful consideration be given for monitoring locations. It would appear that a room and pillar section would easily require two to three times the samples needed for an advancing longwall system if each man's position were to be adequately considered.

An example of British experience might give an insight as to the size of our job. An area in Britain mining 10.5 million tons per year finds it necessary to take 200 samples per month. With 360 million deep mined tons annually and the room and pillar system as our major mining system, we could be looking at 5,000 samples per day, or 100,000 per month. The processing of the 200 samples in the British example required one woman-month of labor to handle and list. Unless we can do much better in the laboratory, the U.S. Bureau of Mines would need 500 additional people for this work alone.

In going into this program, it is certain that problems will beset us from the start. A personally carried monitor will be resisted by the men. Rough or improper handling of the samplers may produce false readings. It may be wise for

individual companies to start gaining experience immediately, and we hope that the Bureau of Mines will accept information which, because of special conditions, becomes pertinent to certain operations.

As operators, we must be concerned about a program that contemplates almost continuous monitoring. We have been served a tight standard. It will, in many mines, require changes that will result in cost increases and perhaps affect productive capacity. Hopefully, we can find ways to ease the impact. First of all, I would suggest that we look at the British standard, which is nonmandatory. At the very least, we should consider a more practical period between dust level surveys.

I must point out here that our mines are much cleaner today than they were 15 to 25 years ago. Most surveys prove that pneumoconiosis is more prevalent in older miners who worked during the days of hand loading and semi-mechanization, and before the advent of the superior ventilation systems in use today. Our problems arise from the fact that the concept of 5-micron dust control is new. The standard is very low. There is very little printed matter on the subject as it applies to U.S. mining, and because our methods are so different, we can't expect much help from the British.

United States mines have not been operated in a manner that neglects their working force. Dust control has always been a major concern of responsibly operated mines, for various reasons. It is an explosive; it creates discomfort and lack of visibility; and it is generally a nuisance from a maintenance viewpoint. Much research has gone into dust control by using water at the face. Fifteen years ago, a family of small gallonage (high-pressure) spray pumps was introduced to do this job. Cutting bit speed and shape have been continuously experimented with and, most important, better ventilation from surface to face has been developed and used by the United States coal industry.

The dust surveys carried out heretofore by State and Federal agencies have not been designed along the lines of a regular and frequent program. The new program will have to be blended into our present system of mining so as to get the best possible results. While we can, in some cases, change the system of mining, we must remember that the wide variety of situations, the ultimate use of the product, the geographical area, and many other factors dictate the realization value of coal in a privately owned industry. If broad or radical changes are indiscriminately or rapidly enforced, irreparable damage to a portion of the industry could result. Cooperation, based on a full understanding by the operator and the inspecting agency of all the problems involved, will be essential. We are facing a mandatory standard almost from the start. It will mean learning to conform while conforming. Certainly, the industry will require the patience and the indulgence of all concerned.

QUESTION (D. C. JONES): I observed a very fine exhaust fan with an exhaust tube on a rotary machine in your mine. Have you tried to check what the dust count was at the operator's station under those conditions?

MR. KEGEL: We are using auxiliary fans at three of our mines in conjunction with continuous miners. We have been concerned with dust levels and have been trying to evaluate the ability of these fans to cope with dust. At two of our mines, tests have been conducted by the inspection agencies. We performed parallel tests using our personnel. We find that in most cases a 4.5 mg./m<sup>3</sup> standard could be met, but everything must be right. It is impossible to maintain ideal conditions during a complete shift. The room and pillar system of mining necessitates the continuous movement of equipment and thereby sets up different problems all during the shift.

QUESTION (J. D. SHREVE): How do you determine the exhaust point for your fans?

MR. KEGEL: I would like to defer this question, since a paper covering this will be given later today.

QUESTION (J. D. SHREVE): How about the positioning of the exhaust fan in the return?

MR. KEGEL: I would prefer to pass this question. There will be a paper presented on the subject this afternoon.

QUESTION: I would like to know what your reasoning is on the situations you described wherein older methods of mining cause more silicosis.

MR. KEGEL: I would prefer to say that more chance of pneumoconiosis, rather than silicosis, existed with older mining methods.

I firmly believe that mining equipment and practices 15 to 20 years ago produced more dust primarily due to less efficient ventilation at the face. We have operations, which we have carefully reviewed, that bear out the theory. Some of our mines completely span the practices and equipment complement of the industry from then until now. Hand loading and the premechanization era certainly couldn't boast the ventilation we use today.

QUESTION: What size tubing do you use on auxiliary fans?

MR. KEGEL: We started with 16-inch tubing on 5 horsepower fans. We are now working with 24-inch tubing and 15 horsepower fans; 24-inch tubing will not be practical on boring machines, we will probably have to settle for 18-inch tubing on this type of machine.

QUESTION: What kind of cooperation do you get from your people on a company-sponsored sampling program?

MR. KEGEL: I'm afraid we haven't had enough experience with this to make a firm statement. I have heard of isolated resistance. I would say this is minimal. You must remember any program performed up to now has been looked at as an experiment more or less. When done on a regular basis, cooperation could wear thin.

MR. RIGG: The question to Mr. Doyle is, was the practical standard considered as practical application?

MR. DOYLE: The standard was established on the basis of a request to the Public Health Service. This request went from the Bureau of Mines to the Public Health Service last July 1968, and it further requested that such a standard be given to the Department of the Interior by December 1969. The recommendation of the Public Health Service was 3.0 milligrams per cubic meter of air.

Their recommendation was based largely on the experience in the British mines. Prior to making this recommendation, they had sent several of their experts to visit Great Britain. Although much of the information that you heard this morning from Mr. Walton was not available at that time, this estimate was made on the best information that was available at that particular time.

The standard was not considered in terms of the practicability of the mining industry to meet this standard. This is not what we asked the Public Health Service. We asked them for a health standard, and this is exactly what we received. In terms of practicality, if we look at the present-day situation in those mines where inadequate dust control procedures are in effect, this is going to be a difficult standard to meet.

We must decide on technology to meet the particular problem at hand. Based upon the experience of some of the mines with adequate control, using a combination of control methods, such as water, ventilation, and adequate machine design it was indicated that at the present time 3 milligrams is not an impractical operating standard in many mines.

QUESTION: In using auxiliary fans, do you have problems from the increased air velocity?

MR. KEGEL: This is a definite problem and will be taken up in one of the later papers.

I have definite ideas about increased velocity and what it may bring about. I certainly feel that the use of rock dust in shuttle car roadways, for instance, can create more disadvantages. It becomes airborne in the intake airways and adds to the problem at the operator's station, while creating false information during sampling procedure. In a borer type installation, such as I described in my paper, we would subject quite a few people to extra dust.

QUESTION: Has there been any attempt to sample the dust in the return airways which would somehow represent dust exposure of the individuals ahead of that sampling point? I am certain we could use that as a representative sample for the exposure. What I am talking about is sampling that exhaust point somewhere in the return airways.

MR. KEGEL: The question is whether or not we have taken readings on the return airways in the room and pillar system. Unfortunately, we have not, but the Bureau undoubtedly has in its surveys.

I am not personally familiar with any particular readings taken in the return airways of the room and pillar system. To some degree, we would probably minimize this, because our system doesn't necessarily involve as many men there. In our system we must concentrate on the miner operator and the drill operator, in particular.

QUESTION: What I am saying, is it possible to monitor the entire dust consumption and the dust generation in the return airways that would represent, say, the main standard?

MR. KEGEL: The British are sampling 70 yards back from the face line in the return airway on their longwall units. Theirs is an advancing longwall system and therefore is limited to two entries. They are permitting  $8 \text{ mg./m}^3$  in this area or, as you heard earlier, the equivalent of  $5.7 \text{ mg./m}^3$ . It certainly can't be considered an average location relative to anyone on the face. I think we could do our sampling job in the vicinity of the individual in question.

If, for instance, a driller were being checked, we could set up a personal sampler in a stand as indicated in my paper. The unit would occupy a position that best represented this man's prominent location. A driller is pretty well placed for the duration of his particular operation period.

Brattice men and general men will require other arrangements. We can't overlook them; in this instance, a personal sampler has to be used. I feel that a personal sampler is going to be resisted in many cases. It will create various problems.

I tried to show in one of my slides what a man would look like when he ultimately donned all of this equipment; he is so loaded down that his mobility would be jeopardized. Particularly in low coal, the addition of a battery and the section of tubing will create problems for the man.

I realize that there are places where a personal sampler will have to be used, but wherever a mounted unit can do the job, I think we should endeavor to use it and keep the added weight and responsibility from the man.

QUESTION (Jim Scott): It has been said that we need 500 inspectors just to read the dust count. We are in the process of trying to supply you technical talent and mining engineers in particular. We have these odds. Where, from a practical viewpoint, are we going to get all the people that are necessary to run this equipment to implement your program and the standard mining inspection program?

MR. KEGEL: I think this is a real problem. I would only ask that the people we get have the ability to do the job. I think it is mighty important, particularly in the coal mines.

As far as working inside the mines, you have touched on something that I think is most important. We had better get the right kind of people to do this, or we are going to create many, many more problems than we have today. Only those people who are totally aware of the problem can fully appreciate what I am saying.

MR. RIGG: Henry, would you like to say something?

MR. DOYLE: Bill's estimate of it taking 500 people to do this particular job is considerably in excess of the estimates that have been made by the Bureau of Mines.

Of course, how we do it depends upon the legislation. At this time we are not attempting to outguess either House of Congress on what the legislation is going to be. Certainly, if the standards were based on a single-shift measurement, we will have quite a different problem from that if the standards were based on a multi-shift average.

The manpower estimates we have made relate to a multi-shift average. Frankly, I have forgotten the number of people estimated for this job. But Bill's estimate of 500 is far in excess of what we calculated.

I might also point out that we are seeking the advice of the industry and the labor unions in this matter. We have called a meeting of selected individuals from both groups to advise us on this particular problem.

So, I think it is quite feasible for us to meet either method of interpretation with a reasonably smaller group of people. We have planned an automated laboratory which would do the weighing and record the results on an ADP system. It would take out a certain number of samples, which has yet to be determined, for chemical analysis of silica, including size distribution, the ratio between volatile and nonvolatile material, and other essential data that we need. Again, I assure you we are still in the planning stage.

We must have a great deal of flexibility built into any system. Again I assure you at this time that we have no fixed system for implementing our plans. We do have a number of alternatives, and it depends upon the law and how it is interpreted as to the alternative which we would suggest.

QUESTION: The Bureau of Mines recruits the better superintendents, foremen, and engineers from the mining companies to implement the laws we work under. How do they expect us to keep the mines in the condition they want them, when they come in and recruit and take our best people and take our tax dollars and pay them?

It seems to me that you set up a program between your own people and recruit people away from the companies. You ought to set up a program to train your people.

MR. DOYLE: We have plans for recruiting and training individuals to come into this program. I don't think that we in the health field will be in too much competition with you in the industry, because I don't think you have too many of these kinds of individuals in the industry.

With respect to implementation of the health staff we are going to have to recruit largely from outside the mining industry. These individuals will have to be trained to do their jobs.

I expect the shoe is going to be on the other foot before too long; you are going to be taking people away from us to get your job done. I hope so anyway.

QUESTION: The problem is we can't match your dollars, because you are taking our tax dollars and paying them, and we are trying to keep our salaries up to a point where we have got to require our people to work longer hours and do harder work than required of your inspectors.

MR. DOYLE: You are talking to someone who has no control over salaries. I am sorry Director O'Leary is not here because I am sure he would like very much to comment on this matter of training.

We have some very definite plans, and I would be very reluctant to discuss those plans. However, the Director will be here tomorrow afternoon at the time of the panel, and I would suggest at this time you bring up the question of training with him. I am sure he would be very pleased to elaborate on the Bureau's total training plan.

MR. KEGEL: I would like to remind you that in most cases, mining engineers are taken through the assistant mine foreman status inside the mine to give them the experience the industry feels is necessary for top management. I can't see many good mining engineers staying on as assistant mine foremen, but they certainly need that experience. This is the way we operate, and I feel most people do likewise.

A good man is not held back, and certainly you can't overlook the experience he gets at the face. You can also see the inter-relationship with everything that's been talked about here today. We need good foremen, and we need good communication throughout our system.

We have three or four college boys now in our program. They ultimately get the best experience at the face, and this is best accomplished by some months of face bossing.

#### LUNCHEON ADDRESS

MR. FREEMAN: When Harry Perry invited me to speak today, he gave me only a little bit of insight as to why I was invited. He said I was the only person in Government he could find that he was sure would be optimistic about the future. So, I appreciate Harry's optimism in me. I think there might be a few others.

## FUTURE OF COAL AS AN ENERGY SOURCE

by

David Freeman

---

### INTRODUCTION

If Rip Van Winkle were a coal expert and had gone to sleep in 1954, he would be a very surprised man if he woke up today. As a matter of fact, even if he had only been sleeping for the past 5 to 10 years he would still be surprised. He would have gone to sleep assuming that the coal industry was slowly but surely going to vanish from the American energy scene, only to awaken to news stories of a market demand so great that there is actually a shortage of coal. In the short span of time that I have been following these matters, coal has emerged from its status as a depressed industry to a growth industry sharing in the booming growth of the nation's demand for energy.

Actually some members of the coal industry in prior years may have contributed to the feeling of gloom and doom as to the industry's future. I can recall attending meetings of coal groups where more time was spent talking about atomic energy than coal. At least we are now talking about coal -- its problems as well as its opportunities. To my mind this reflects the more confident mood of coal industry leaders. As far as problems are concerned, there are enough to go around for everyone in all parts of the energy business.

### FOSSIL FUEL MARKETS

Before looking into the future, I think it might be instructive to spend a minute or two looking back because history is usually helpful in analyzing the future. We often forget the very recent origin of large-scale use of fossil fuels in this nation. As recently as 100 years ago wood still provided 75 percent of this nation's energy supply. It was the industrial revolution that triggered the large-scale use of energy and it was coal that was the primary source. By the turn of the century coal had pretty well displaced wood as our source of energy and accounted for about 70 percent of our energy supply.

Through 1920 coal was king, supplying nearly 75 percent of our energy in the first two decades of this century. After 1920 coal's share of the energy market deteriorated rather rapidly as first oil products, then natural gas, and more recently atomic energy have joined the energy family in competition with coal. The coal industry's share of the energy market fell from 76 percent in 1910 to a low point of about 22 percent in 1962. Since then it has been holding its own and perhaps gaining somewhat.

The share of the energy market is perhaps not as important as the actual production figures. The growth in energy demand is so great that a source of energy can lose percentwise and still increase in actual quantities. Bituminous coal production reached its peak output to date of 631 million tons in

1947. Its low point in recent history was 392 million tons in 1954. The road back has been bumpy but since 1961 coal has shown a steady upward trend.

As we break down the various markets for coal, we get a more incisive preview of coal's future. Since 1950 the market for bituminous coal in the electric power industry has more than tripled, while all the other markets combined are little more than half of what they were in 1950.

This general pattern and the reasons why it occurred are all too familiar to everyone in this audience. However, the sharpness of the growth pattern in electric utility use, as well as the downward plunge in other uses, tell us something. The message these facts seem to convey is that the future of coal is largely tied to the expanding use of electrical power in this nation. As we shall later discuss, the present market for oil and gas may also be part of coal's future. I guess some would say there would be some poetic justice in such a development since oil and gas have grown largely at coal's expense in the past 50 years.

#### FUTURE OPPORTUNITIES

The first step in exploring the future opportunities for coal, as well as the obstacles that must be overcome, is to take a look at the broad dimensions of the energy market of the future.

Last year the United States used the energy equivalent of 10.6 billion barrels of oil or 2.4 billion tons of coal. These numbers are so large as to be meaningless, but they do give some indication of the scope for growth available to coal if it could tap the present markets for oil and gas which account for 75 percent of the total. One rough way to visualize this amount of energy is to assume that each and every car, truck, and bus in the United States has hitched behind it a trailer carrying about 20 tons of coal. This coal would be roughly equal to our energy requirements for a year. The proliferation of motor vehicles provides a graphic picture of the widespread nature of energy use, so we get a rough idea of where the energy is used.

Some feeling for the rate of growth in energy use can be portrayed if we realize that in the next 20 years this nation will probably consume more energy than has been consumed in the previous 70 years of this century. If we look to the past, all of the energy that was consumed in this nation prior to this century would not equal next year's consumption.

The most striking fact about our energy resources is that while oil and gas dominate the energy market, they are the two energy sources for which there are the smallest known potential supplies. U.S. oil and gas reserves are only a small fraction of the energy content of coal reserves. On a Btu basis, the energy in coal reserves is at least 10 times as large as natural gas and oil.

In broad terms, U.S. energy resources of natural gas and oil are sufficient to meet growing needs for decades, but certainly not centuries. Natural

sources can be supplemented by shale oil and the tar sands in Canada. But looking to the future, as I have mentioned, we need not think of coal separately from oil and gas, for we are confident that it is technically possible to convert coal into liquid or gaseous form, although it is not yet economical to do so. After all, "coal oil" was used to run the first internal combustion engines, and we may well come full circle in the next decade.

#### OUTLOOK FOR COAL

We come then to the question of just what are the future growth prospects of coal. In my judgment, the short-term prospects are more promising than at any point in the industry's recent past. I make the statement in full recognition that nuclear power is likely to capture a rapidly increasing share of the electric power market in the future.

One of the reasons one can be optimistic about the short-term future of coal is that coal's major market -- electric power -- is the fastest growing segment of the energy market, at least for the next few years. Thus, even if nuclear power grows -- as it will -- coal will be sharing a bigger and bigger market. Another reason is that the coal industry has already suffered its losses to competing forms of fuel and is now largely confined to markets where it has the inherent ability to compete.

It is therefore quite clear that coal's near-term future growth must come from the electric utility market. This market accounts for 60 percent of coal's total and it is one in which coal has shown major growth. Coal consumption by the utilities increased at the rate of over 6 1/2 percent per year from 1960 through 1968. This is a very healthy rate of growth when one considers that the utilities were at the same time increasing the technical efficiency of power production and that coal's share of the market fell from about 66 to about 62 percent.

The orders by the electric utility industry which have already been placed would appear to assure the coal industry of a steady increase in the electric utilities' market through the early and middle 1970's. If the rate of growth is some 5 percent per year, which does not seem unreasonable to me, electric utilities could be consuming some 400 million tons by 1975. If other markets hold their own, bituminous coal production in the United States could exceed the 1947 peak and be on the order of 650 million tons.

When we look beyond the next 5 years, the future of the coal industry becomes a great deal hazier. In my view, the possibilities for growth, and I stress the word possibilities, are perhaps even more promising than the short-term prospects. However, I would be less than candid if I did not add that there are some very large obstacles which will block that progress unless the industry, its customers, and all levels of government roll up their sleeves and work together to solve them.

Let us talk about the opportunities first and then perhaps the problems will seem worth solving. First of all, in the electric utility market it seems

reasonable to expect that in the coming years, nuclear power plants will surmount the present difficulties of delays in their manufacture and construction and will be providing fossil fuel plants with even stiffer competition throughout the nation. I doubt that nuclear power will sweep the market to the extent that many people -- including some in the coal industry -- thought a couple of years ago. But it is reasonable to assume nuclear plants will capture a larger share of the utility market as the years go by.

Nuclear power's growth will not be entirely at the expense of coal, however. Natural gas now supplies about one fourth of the fuel for electric power. Natural gas supplies are short, as compared to demand and in the late 70's its share of the utility market will probably begin to drop as available natural gas is diverted to more lucrative markets. However, residual oil will also be an active competitor. While there are opportunities for growth in the electric power market, beyond the mid-seventies, coal is going to be faced with stiffer competition than it has experienced in the past.

Coal consumption is apt to continue to increase in the utility market through most of the decade of the 70's, but the extent of that growth is very much a question mark. The answer depends on whether the coal industry will continue its trend of increased productivity while meeting the new health and safety requirements, whether economical technology to remove the oxides of sulfur from stack gases can be perfected soon enough, and whether we develop more efficient methods of power generation such as MHD that will better enable coal to compete. That is a rather imposing series of IFs, but we must face up to all of them.

#### RESEARCH AND DEVELOPMENT

The key to success in all three areas -- miner health and safety, air pollution control, and more efficient coal generating methods -- is research and development, a subject which the industry has understandably neglected during the years it was struggling desperately for survival against new competitors. If the coal industry is to remain a vigorous competitor for new powerplants in the future, then it must mount a more extensive research and development effort. The Federal Government should be a paying partner in this research effort, but it cannot do the job alone. And federal funding is much more likely if the research efforts are also attracting funds from the industry most vitally concerned.

The Federal Government has neglected its responsibilities for research in the fossil fuels, but so has the coal industry. We must both turn the corner together if the nation is to derive the benefit of the enormous resources of coal which could play such a useful role in meeting the energy needs of the future.

As the coal industry looks to its future, the entire energy market, not just electric power production, is open territory for coal. I believe that penetrating the market for energy in liquid and gaseous form is essential to coal's long-term growth. This is true because no matter how hard coal tries,

somewhere down the road -- sooner or later -- there will undoubtedly be more and more nuclear powerplants that will be able to undersell it. But, even if the growth in the electric power market for coal were assured to continue, there is every reason for coal to make a play for part of the oil and gas market, which today is over three times as large as the market for coal.

As you, of course, know coal is potentially a source of both oil and gas. Of the two, it seems to me that gas is the market which coal has the greatest opportunity for tapping in the foreseeable future. The economical liquefaction of coal may come in time, but the recent crude oil discoveries in the Arctic, the abundant supplies of crude at low cost on the world market, and the potential of shale and the tar sands suggest that the commercial liquefaction of coal is at least a decade or more away. The research effort should be pursued, but the marketing opportunities just don't seem as immediate as the market for gas.

The supply and demand situation make coal and gas a perfect match. Gas now supplies over 30 percent of the energy market, but our existing proven reserves of gas represent less than 7 percent of our total fossil energy reserves. Many are predicting that reserves of natural gas in the contiguous 48 States cannot support industry growth for more than another decade. Coal, on the other hand, supplies some 20 percent of the market but represents about 85 percent of our known fossil energy reserves.

If coal could be converted into gas economically, the acute problem of gas supply which threatens the very life of that industry in the next couple of decades could be eliminated for many more decades to come. And the coal industry would have a new market, larger than all its present markets, for the late 70's and 80's. This new market could more than offset any tapering of its rate of growth that may occur when nuclear power really gets established.

In my judgment, developing the technology to convert coal to high-Btu gas at economical costs is by far the best bet on the horizon to assure the long-term viability of the gas industry. There are pilot plants now under construction to test new technology to gasify coal. We need to speed these research projects and push them through the development stage as fast as possible. We need to pursue other good ideas for coal gasification on an urgent basis. Feasibility studies suggest that the coal gasification processes under development could well be economical if they prove out technically.

The point I wish to stress is that the gas supply problem should not be considered as solely the gas industry's concern. From coal's perspective, it is a gas supply opportunity. The coal industry should mobilize its forces -- both technical and financial -- to speed the coal-gas gasification research effort along. The industry should be looking ahead to the siting problems for coal gasification plants and locating large blocks of economic coal reserves that could be made available at strategic locations close to consuming markets. Knowing that coal is available -- if indeed it is -- would itself excite greater interest in speeding coal gasification efforts along.

One of the most attractive features of coal gasification to the general public and to the coal industry as well is that this process would completely bypass most of the environmental problems which now face the coal industry. In converting coal to high-Btu gas, the sources of air pollution will, of course, be removed and the conversion process could take place at a rather high efficiency. It would be a clean fuel as attractive as natural gas for air pollution control.

Transportation will, of course, be completely underground in pipelines so that aesthetic concerns which EHV transmission lines face would not be present. The coal gasification plant should be designed as an integral part of the mining process so that costs and environmental concerns could here, too, be held to a minimum.

I would like to suggest that the coal industry appoint a special committee whose purpose would be to map out a concerted coal industry effort to speed the economical gasification of coal. One function it could serve is to work with the gas industry in earmarking sites for coal gasification plants. Another would be to raise money to fund the necessary research. By focusing on this enormous marketing opportunity, the coal industry could help itself and also help solve a major national problem of future gas supply.

Let me make clear that coal gasification is still some years away and by no means a certainty even then. However, the opportunity is there and could become a reality in the next 5 to 10 years. It is a potential market that could account for hundreds of millions of tons of coal annually in the 1980's and more in the years beyond. If coal were the source of 3 trillion cubic feet of gas in 1980, which would constitute about 10 percent of our projected gas requirements, it would mean an additional 200 billion tons of coal. Thus, it is obvious that a major penetration of the gas supply market by coal would move coal into a whole new ball game.

I have tried today briefly to sketch out what I believe are the broad dimensions of coal's future. The need for energy is large and it is growing fast. Our coal resources are large and the cost of coal in place is very small indeed. One need not spend large sums exploring for coal. We know that there are vast resources available even though we are not at all certain as to the quantities available at particular prices. If we devote the necessary research and development to new mining methods that will improve efficiency as well as meet health and safety requirements -- and they are not incompatible -- there is every reason to believe that our vast coal resources can be extracted from the earth in a safe and efficient manner.

There remains a major hurdle in converting coal into a convenient and clean form. Here, too, the job can be done if the necessary research and development is undertaken on an intensive enough basis.

In one sense, the future of coal lies with the scientists and engineers whose task it is to develop the hardware to mine and burn coal economically and with minimum damage to people and to the environment. The problem is to put more of our best scientists and engineers to work on the problems. I can assure you that our Office will be exerting every effort to see that the Federal Government increases its efforts toward these ends and carries out its fair share of the job. The question before the house is whether the coal industry will join this effort which holds the key to its future. For the sake of the industry, its customers, and the nation, I hope the answer is YES.

## AFTERNOON SESSION

DR. POTTER: We are faced with a law limiting dust, and it is the consensus of a great many operators who have been working on this problem that the best solution is the matter of ventilation. Of course, ventilation can be aided and assisted by wetting agents, water infusion, et cetera.

There will be no biographical sketches of the authors this afternoon, the reason being that I can assure you that each person who is speaking is an authority on his subject.

The first speaker this afternoon is Donald Kingery, Acting Director, Health and Safety Technical Support Center, United States Bureau of Mines, in Pittsburgh. His topic will be "Ventilation, Theory and Principle."

## VENTILATION: THEORY AND PRINCIPLE

by

Donald S. Kingery

---

### INTRODUCTION

The establishment of environmental dust control requirements necessitates a hard look at the adequacy of operating primary ventilation systems. Most present primary ventilating systems simply grew over a period of years or were designed with the principal criteria being the expected face-methane liberation and the proposed mining system. Air volumes at the last open breakthrough usually are greater than that required by law and, in gassy mines, special efforts are directed to face-methane dilution control. However, little thought has been given to respirable air contamination by coal dust. In nongassy or slightly gassy operations less attention has been given to insure that adequate air volumes are available to control face ventilation.

Control of respirable coal dust in conformance with proposed standards will necessitate new concepts in both primary and face ventilating applications. Many of these may be difficult to realize with the basic systems available. The fundamental requirements of ventilation are large air volumes at the faces, uncontaminated intake air, split systems of ventilation for major and secondary splits, and face ventilation changes and improvements.

## VENTILATION THEORY

Mine ventilation is not a new art, although a better understanding and application of the basic principles will probably be necessary to control coal dust. These principles are as follows:

1. Airflow in a mine is induced by pressure differences between intake and exhaust openings.
2. The pressure difference is caused by imposing some form of pressure at one point or a series of points in the ventilating system.
3. The pressure created must be great enough to overcome frictional resistance and shock losses.
4. Passageways, both intakes and returns, must be provided to conduct the airflow.
5. Air always flows from a point of higher to lower pressure.
6. Airflow follows a square-law relationship between volumes and pressures; that is, twice the volume requires 4 times the pressure.
7. Mine-ventilating pressures, with respect to atmospheric pressures, may be either positive (blowing) or negative (exhausting). The common method of measuring the ventilating pressures producing air circulation is either equivalent feet of air column or equivalent inches of water. In most calculations, pressures must be reduced to inches of water, where 1 inch of water equals a pressure of 5.2 psf.
8. The pressure drop for each split leaving from a common point and returning to a common point will be the same regardless of the air quantity flowing in each split.

Mine resistance constitutes the most important factor of the ventilating system. This resistance is established by the size, number, length, and condition of airways. Multiple airways, both intake and return, substantially reduce mine resistance, as does reduced length of air travel. These two factors are probably the greatest concern of engineers attempting to increase airflow in existing mines. New and expensive air shafts may be necessary to shorten air travel; additional airways and reduction of resistance in entries are expensive, and results are often disappointing. This problem is serious in many operating mines and will limit the air volumes available for face ventilation. The installation of larger fans or increasing fan speeds can, at best, be considered temporary expedients.

### AIR VOLUMES NEEDED

Dust control requires both sufficient air velocity and air quantity. For example, sufficient velocity must be available in face areas to confine, capture, and transport generated coal dust; sufficient quantity must be available to dilute contaminated air that may pass workers.

The delivered air volume may vary with the same velocities in different coalbeds; consequently, design criteria should be based upon reasonable air velocities. The Bureau of Mines has found that adequate confinement of respirable dust at the generated source and protection of the machine operator require entry velocities of approximately 100 fpm. This requires a delivered air quantity at the mining machine of 5,000 to 12,000 cfm. For adequate dilution, these air quantities should be double at the last open breakthrough.

Such air volumes are exceeded in many of the new mines. However, in older mines, particularly in low coal, volumes of this magnitude may necessitate major improvements to the ventilation system. This could require additional air shafts, more airways, and new fan installations.

### UNCONTAMINATED AIR

For respirable dust control the air delivered to the working face must be as free of contaminants as possible. Bureau of Mines' studies have shown dust counts in intake air ranging from one-half to more than 2 milligrams of dust per cubic meter of air.

Air contaminants of small, respirable size will remain a part of the air current until they are either collected or dissipated by some method. This means that any dust that is picked up at any point along intake air courses may be carried to the working face. Dust sources are usually open coal dumps, coal transfer points, uncovered coal trips, belt transportation systems, and haulage roads, particularly shuttle car roadways. Reduction in airborne contaminants will result from sprinkling roadways and from efforts to allay or confine dust at dumping, loading, and other coal transfer points. The fact that intake air may travel several thousand feet along such roadways before reaching the working face complicates the problem.

Belt entries, coal dumping stations, and coal transportation storage tracks should, wherever possible, be on separate air splits with air directed to returns. Intake velocities should be maintained as low as possible. A common practice has been to reduce the number of intake entries at overcasts, thereby greatly increasing intake air velocities at that point. Velocities of 1,500 fpm or more will scour dust from coal trips. Respirable dust then becomes an airborne contaminant.

## SPLIT VENTILATION SYSTEMS

The Bureau of Mines has always recommended split systems of ventilation as the safest and most efficient methods for methane control. Such splits basically provide each working section with an individual air current; where air volumes and face ventilation systems are adequate, excellent methane dilution for multiple working faces results.

The problem of dust control is substantially greater since, with conventional mining units, several concurrent activities -- cutting, loading, timbering, and other work -- are performed on the same air split. In continuous miner operations less men may be exposed to return air from the miner, yet a common practice has been to operate two miners on a single face air current.

To provide maximum protection and insure the minimum working places on a face air current, air should also be split at the working faces. This requires a multiple entry panel with two outside entries for face returns. Intake air should be brought up the middle entries and split at the last open breakthrough returning both right and left. Two rows of permanent stoppings and two regulators are necessary. With such a system, a six entry system will have only three working places per air current. Air control at the face is usually easier, and shuttle cars need not pass through check curtains. More air may be required with such a system, yet in dusty operations this may be necessary for proper control.

## FACE VENTILATION

Face ventilation will be covered in a subsequent paper. However, I want to touch on certain fundamentals that may influence decisions within the industry.

Blowing face-ventilation systems, either line brattice or auxiliary fans and tubing, provide the easiest methane dilution control. However, they are poor for dust control because dust is carried back over workers. Exhaust systems, while best for face coal-dust control, require special attention to insure adequate methane control. Such systems will handle both methane and coal dust provided air volumes are adequate and are maintained.

## SUMMARY

As previously discussed, ventilation for dust control may require extensive and expensive modifications of existing ventilating systems to assure that adequate air volumes are available at working faces. Each mine is a separate problem. The high ventilation requirements proposed can be reduced, but respirable dust control nevertheless improved, by good mining practices and the successful application of water or other dust-allaying media.

The ultimate in respirable dust reduction will probably develop from the application of a combination of factors. This combination of factors could be dust capture at its source by foam, improved dust allaying techniques, and, of course, other approaches. At present, however, adequate uncontaminated air volumes and air velocities, perhaps in combination with these developing aids, appear the most important factors for coal dust control.

QUESTION (J. D. Shreve): How do you decide on the requirements of 70 to 100 feet per minute velocity?

MR. KINGERY: You will hear more about this in subsequent talks. This was developed empirically from a large number of tests in which we checked both air velocities and air volumes and dust counts. This was what the answer seemed to be.

These tests were conducted in different operating coal beds, under various mining conditions, and using different types of mining machines. We are basing this recommended air velocity on the energy necessary to confine respirable coal dust in advance of the machine operator. If you study face-flow air patterns, there is backward airflow, and, as Bill Kegel said today, face ventilation is changing constantly.

DR. POTTER: But this is not for blowing type of face ventilation?

MR. KINGERY: Well, I didn't discuss blowing types of ventilation, because I consider this system impractical for dust control. I would say, from our observations, I don't see how anyone can meet the proposed dust standard by using blowing-type face ventilating systems.

DR. POTTER: The next paper, "Ventilation, State of the Art," will be given by Kenneth M. Morse, Director of Environmental Health, U.S. Steel Corporation, Pittsburgh, Pa.

## FACE VENTILATION PRACTICES IN BITUMINOUS COAL MINES FOR DUST CONTROL, THE STATE OF THE ART

by

K. M. Morse and R. R. Godard

---

### INTRODUCTION

Even though ventilation practice in some bituminous coal mines is largely empirical, the aerodynamic forces that govern general ventilation design apply equally to coal mine ventilation. There is need of greater understanding and application of these principles to achieve the degree of dust control we all desire. However, it should be recognized that a number of coal operators have long recognized that the initial objective of ventilation for gas control was not always satisfactory for dust control, and they have continually improved ventilation practices to achieve both good dust and gas control.

The objective of any bituminous coal mine ventilation system is twofold. First, the primary ventilation system must course air through the main airways to the last open crosscut outby the working faces, thus making air available for face ventilation, and then return the contaminated air through return-air courses to the surface. Second, the face ventilation system must be designed to effectively utilize the available air in the last crosscut to sweep the working face, to capture and remove the dust, and to dilute and carry away gas emitted during coal-cutting and auxiliary operations. The main ventilation system may be well designed, but if the available air brought to the last open crosscut is not properly utilized for ventilating the faces, the total system has failed. Conversely, if the main ventilation system does not provide sufficient air volume at the last crosscut, the system is equally inadequate.

The advent of the continuous mining machine resulted in exposing more coal per working face in a given period of time, which increased the possible gas emission. This has resulted in increased attention to the improvement of face ventilation. Adequate face ventilation requires control of both dust and gas, both of which are simultaneously generated at the coal face. It is the intent of this paper to discuss the present state of the art in face ventilation and to indicate possible areas of research to improve our knowledge and subsequently the effectiveness of mine ventilation systems.

### BASIC CONSIDERATIONS OF FACE VENTILATION DESIGN

Methods of dust suppression, such as water infusion and sprays on the machines and at the bits, while highly important, are complementary to basic ventilation needs and merely reduce the dust load that the ventilation system must handle. In other words, ventilation of the face is the most important

single measure for dust control, and no other dust suppression measure should cause relaxation in attention to the ventilation system.

The effective ventilation of a working face requires knowledge of both the aerodynamic principles involved and practical experience in their application. The problem cannot be treated in a casual manner by simply putting some air to the face. Air flows between two points because of a pressure differential. Energy is required to move air within a confined space, such as a tubing, behind a brattice, or through any airway. Certain pressures are developed, such as velocity and static pressures, and certain requirements for distribution of the air must be met. Effective ventilation design depends upon knowledge of the factors which determine these requirements and upon their correct determination and balance in the design of a ventilation system.

The pertinent considerations in the design of face ventilation systems are these:

First, air should be mechanically exhausted from zones of dust generation, if dust is to be effectively controlled. Contaminant control ventilation cannot be generally effective by inducing the flow of air into a room or entry with the hope that it will thoroughly mix with or dilute the contaminant. Therefore, air should be exhausted from the face by a line brattice or tubing located as close as practical to the zone of dust generation.

Second, the range of influence for a blowing system is considerably greater than it is for an exhaust system because in the former the air retains its directional effect over a longer distance, whereas at a short distance from an exhaust opening, the airflow becomes largely nondirectional. This is shown in figure 1.

This illustration shows that for a blowing and exhaust opening having the same face velocity, 10 percent of the face velocity is reached at a distance of 30 diameters from the blowing or discharge opening; whereas the same reduction is developed only one diameter away from the inlet of the exhaust duct.<sup>1</sup> This demonstrates why an exhaust opening must be close to the source of dust generation to be effective and why, for methane control, a blowing opening can be effective at a greater distance from the face.

Third, the movement of air into an opening, such as an exhaust tubing or behind a line brattice, requires a pressure difference to both accelerate the air from rest to a required velocity and to overcome certain turbulence loss at the opening. This loss, known as the entrance loss, is caused by the opening and varies with its shape. For example, in the case of a tubing in which a velocity of 3,500 fpm is to be provided, this loss is approximately 0.7 inch of water, based upon a hood-entry loss of 0.9 velocity pressure.

Fourth, the most important area for ventilation is the working face. Effective control of dust generated in this area will provide control of the

<sup>1</sup> Industrial Ventilation Manual. American Conference of Industrial Hygienists Committee on Industrial Ventilation, P.O. Box 453, Lansing, Mich.

major dust hazard. Roof bolting, drilling, and conveyor transfer points are other significant dust sources. However, the use of approved dust collectors and wet drilling readily control the former, and water sprays are effective for the latter. Dust exhaust systems with an efficient dust collector may also be applied to conveyor transfer points where the use of water sprays is not desired.

Fifth, in controlling respirable dust we need to concern ourselves only with dust particles having a diameter of  $1/5,000$  of an inch (5 microns) or less. Once these very small particles are airborne, they are mainly carried with the ventilating currents out of the mine through the returns. In gassy mines the ventilation rate must also be adequate to prevent methane accumulation and should be also adequate to move the dust toward the exhaust brattice or tubing, where it can be captured and transferred into the returns and out of the mine. However, many larger particles are also produced. These must also be moved away from the face for visibility and directed to areas where they can be made inert as a precaution against dust explosions or dust propagation of an ignition. Therefore, the ventilating current must also accomplish this objective. However, once these particles are in the returns, they settle out at various distances proportional to the air velocity and the mass of the particle. The basic ventilation requirement is to dilute methane to safe concentrations and to move respirable dust away from the face workers. The air volume and velocity that meet these objectives should provide the secondary need for visibility and prevention of explosive concentrations of dust.

Sixth, a blowing system carries dust over the worker and, for safety, a very large air volume is necessary to dilute the dust concentration. This method of ventilation may be adequate only in the case where dust generation is kept to a minimum by water flushing of the bits or where water infusion is effective. However, this practice is generally contrary to good environmental engineering. Finally, air returning from one continuous miner face operation should not be used as intake air to course over another face operation, but should be directed immediately to a return.

#### FACE VENTILATION SYSTEMS

We have emphasized the important relation of the primary or main ventilation system to the face ventilation system; a few pertinent comments on the main ventilation system are indicated. As previously stated, air flows from one point to another because of a pressure differential between the points. Air is supplied and distributed through the airways of the main system based upon pressures developed by, and resistance to, airflow in such airways. Relatively small, sudden changes in the pressures at one or more points can affect the distribution of air in the various splits and consequently in the last open crosscuts. Therefore, major attention should be directed to the resistances at various points in the return airways, particularly in older mines, because roof falls and falls from the rib can substantially reduce the size of airways and thus sharply increase resistance. This problem does not generally arise in intakes because they are used for transportation and are

maintained in good condition. Therefore, it would be prudent to conduct periodic ventilation surveys of main ventilation systems. The surveys should determine airway pressures and air volumes in intakes and returns. This is most important, for ventilation systems are undergoing constant change as mining operations progress.

Another point regarding the main ventilation system relates to leakage in brattice-type systems. In many of the older mines relatively narrow (12- to 14-ft) entries were driven. In order to maintain sufficiently wide roadways for the movement of equipment, a small distance, such as 2 ft, between rib and brattice was maintained. Maintaining a tight roof and bottom seal on such a brattice to prevent high leakage results in a high-resistance brattice system. Some people are of the view that too tight a brattice will alter the pressures between various sections and thus the air available for face ventilation. They prefer a brattice system with higher leakage, which is of lower resistance, provided that a high air volume is supplied to compensate for the air loss. This type of system can be effectively applied for good face ventilation. However, in view of the fact that equipment movement in narrow entries causes appreciable brattice maintenance, it is concluded that driving wider entries, where permitted by roof structure, to afford a greater rib-to-brattice distance (4 ft) will yield improvement in ventilation control, in addition to the normally anticipated benefits.

Finally, let me say a word about endeavors to increase the airflow at the face by high-capacity exhaust tubing and auxiliary fan systems. Increasing the air volume available at the last open crosscut by this means could unbalance the main ventilation system by altering the pressures between sections and consequently the section regulation. This practice may affect dust and gas control in another section. The available air in the last open crosscut is the maximum that can be made available to the working faces on a split, which must be continuously ventilated with intake air.

### Two-Split System

It has been stated that each continuous mining machine should operate in a separate split of air to prevent dust from that operation passing over workers in another face. Such a system was described by Connor in 1961.<sup>2</sup> In this system the air is coursed over the continuous miner and is returned behind a line brattice directly to the return airways. A minimum of 8,000 cfm is coursed down the entry and exhausted behind the brattice. A minimum of 50,000 cfm is provided to the developing sections. The mining sequence in this ventilation system allows one machine to work two or three places on cycle with two shuttle cars working with the machine and being loaded directly by it. This system applied to a development section is shown in figure 2. Entries are driven about 16 ft wide with 12-ft roadways, resulting in a 4-ft distance between rib and brattice. The advance of the continuous miner is limited by safety requirements to the last roof bolt, which results in a 16-ft advance. The continuous miner then moves out to the other face, and the roof bolters enter the room to support the roof over the newly developed entry making the

<sup>2</sup> Connor, C. W., Jr. Sequence Development and Ventilation With Continuous Miners. Mine Inspectors Institute of America, Pittsburgh, Pa., June 1961.

place safe for return of the miner. As shown, the roof bolters are also provided a separate clean intake. Figure 3 depicts the same ventilation method applied to a pillar extraction section. Figure 4 shows a closeup of the ventilation of a cutting face and a roof bolting entry in pillar extraction work, indicating the distribution and return of clean air in each working face. We believe that this type of two-split ventilation system, with each mining machine on a separate split of air, is most desirable for face ventilation purposes. This system provides uninterrupted face ventilation, reduces air leakage, and provides optimum control of the air delivered to the face.

### Types of Systems

Face ventilation systems may be generally categorized into two types, namely, line brattice systems and auxiliary fan and tubing systems. Either may be of the blowing or exhaust type. A blowing system is best for methane control because it will effectively provide a good air sweep of the face. It is not a desirable system for dust control because dust-laden air is blown over the workers at the face. However, in conventional mining systems employing cutting machines, a blowing ventilation system is considered necessary to prevent gas accumulation in the kerf. In this instance, dust generation may be controlled by the use of water jets along the cutter bar. The best system for dust control with continuous miners is an exhaust system, for it will remove the dust from the breathing zone of the face workers. However, this is not the best system for methane control. As previously mentioned, an exhaust opening has a limited effective zone of influence. In any exhaust system the face velocity at the intake drops off sharply with distance, approximately according to the formula  $V = \frac{Q}{X^2 + A}$ , in which  $V$  is the velocity in feet per minute, " $Q$ " is the air volume in cubic feet per minute,  $X$  is the distance from the opening in feet, and  $A$  is the area of the opening in square feet. For practical use the area of the opening in the formula can be dropped when it is small, as it will have little influence on the calculated velocity.

In view of the above limitations, the optimum face ventilation system for both dust and gas control may be one that combines the advantages of both the blowing and exhaust systems. This would be an exhaust tubing or a line brattice on exhaust system with a diffuser fan or intake curtain on the opposite side from the exhaust system and with the discharge as close to the face as practicable. The supply air will sweep the face diluting the methane and move the dust-laden air into the effective zone of the exhaust system. Such a "push-pull" system allows the entry into the tubing or brattice to be a little further outby the face than an exhaust system not complemented by a diffuser. With such systems positive precautions must be taken to insure against the possibility of recirculation. One such precaution is to insure that the exhaust opening is always inby the machine operator and the inlet of the diffuser fan. It is not implied that this system is the only effective face ventilation system. We have found, based upon airborne dust measurements, that either the exhaust tube or brattice method of face ventilation can be effective without a diffuser fan, provided a sufficient volume of air is made to course down the entry to the face and is removed by the exhaust system. The required air volume is greater than that in the exhaust system with a diffuser fan mounted on the machine.

In considering air volume, attention must also be given to the velocity. Too high a velocity may be self-defeating in that it may pick up dust already deposited. British coal mine ventilation authorities<sup>3</sup> indicate that such pick-up is minimal if the velocity does not exceed 500 fpm. Using this limiting air velocity in a 12- by 6-ft active entry, the air volume would be 36,000 cfm, a volume well above that necessary to provide good face ventilation. However, this fact limits the velocity of a blowing system discharge if the air is to achieve a maximum dilution of the face-generated dust.

### Line Brattice System

This type of face ventilation system is in wide use. The exhaust type is shown in figure 5. It may be the exhausting or blowing type. Exhausting types may be complemented by a machine-mounted auxiliary or diffuser fan. The line curtain should be of woven duck, plastic, or fabric-reinforced plastic to limit loss of air through the curtain. The location of the line curtain with respect to right or left rib is established by the location of the air intakes and returns. An exhaust brattice system generally requires a high ventilation rate to compensate for air leakage around the curtain. In addition to leakage, deformation of the curtain toward the rib can materially reduce the air flow into the brattice intake because of the increased resistance caused by the reduced area. Good dust and gas control require major attention to preventing excessive leakage and deformation of the curtain. This may result in more time required for brattice erection in order to frame it or to install telescopic posts by which it can be supported. However, with a continuous mining machine on a separate split of air and with an exhaust brattice with a 2-ft tight rib distance in a 12- to 16-ft entry, good dust control has been achieved with 8,000 to 10,000 cfm coursing down the active entry when leakage is kept within 30 percent. This can be accomplished without framing the brattice if posts are used to prevent excessive deformation.

A well-erected, minimal-leakage, exhaust brattice system will provide, in our opinion, better performance than an equal-capacity system of the exhaust tube type. This is due to the fact that the area of the exhaust opening is greater and, therefore, is effective over a larger cross-sectional area of the active entry. However, it generally requires more maintenance and installation time than the exhaust tube system. The effective application of the exhaust brattice system requires that the curtain intake be located as close as possible to the face. However, in practice it is difficult to maintain a distance closer than 10 ft, and performance may be improved, if necessary, by a greater ventilation rate through the active entry or by the use of a machine-mounted diffuser fan.

Recently Luxner<sup>4</sup> of the U.S. Bureau of Mines published interesting data on airflow and methane patterns achieved by an exhaust and blowing brattice,

<sup>3</sup> Lynn-Jones, H. Practical Aspects of Dust Prevention and Suppression. Presentation before Dent Committee, Subcommittee of House Labor Committee, London, England, May 12-15, 1969.

<sup>4</sup> Luxner, James V. Face Ventilation in Underground Bituminous Coal Mines: Air-flow and Methane Distribution Patterns in Immediate Face Area-Line Brattice. BuMines Rept. of Inv. 7223, 1969, 16 pp.

handling 5,000 and 10,000 cfm of air, for various brattice distances outby the face. The work was done in equipment-free entries with simulated methane emission rates of 10 to 30 cfm. This data is useful, but conclusions derived therefrom relating to actual operating faces must at best be limited. The study did not consider the effects of high-speed bits creating turbulence at the face, the entrainment of air by high-velocity water jets, the absorption of methane by spray water, and the reduced cross-sectional area of the entry caused by the presence of mining equipment. Despite these limitations, the data is a contribution to our knowledge of face ventilation and should be reviewed by those responsible for mine ventilation. Figure 6 shows the airflow patterns for a line brattice on exhaust. Under the conditions of the test, Luxner claimed that the areas inby the primary air stream are practically non-ventilated. However, he concluded that an exhaust brattice system can provide reasonably good methane dilution and excellent dust capture when it is installed within 5 ft of the face, provided the air velocity in the active entry approaches 100 fpm. Therefore, for an entry height of 6 ft, an air volume of 6,000 cfm entering the active entry would be necessary. This air volume is relatively in line with our experience. However, it should be emphasized that significant brattice deformation must be controlled and leakage kept minimal. It would be more practical to undertake this type of ventilation research under conditions more representative of a working face and to record the magnitude of the primary and secondary air velocities.

#### Auxiliary Fan and Tubing Systems

This type of face ventilation system has found favor among some operators for use in continuous-mining entries. In their view, face ventilation can be more adequately provided under the conditions existing in an entry. The size of continuous miners and the rate at which the machine advances in a 14- to 16-ft entry require continual extension and modification of the face ventilation system. The movement of shuttle cars and of the continuous miner in and out of an entry require increased attention to brattice systems of ventilation when the entry is relatively narrow.

In this type of face ventilation system, the exhaust tubing may be hung along the rib from spads driven directly into the coal. In some applications the tubing intake is mounted on the machine as shown in figure 7. In this installation a 16-ft section of 18-in-diam tubing was collapsed and slipped over a metal sleeve mounted on the machine. As the machine advances, the tubing extends to the full 16 ft, which is the maximum distance allowed for machine advance in this instance before moving out for roof support operations.

The use of the auxiliary fan and tubing system of ventilation does not eliminate the need for maintenance and extension and retraction of the system as mining progresses. In addition, a tubing system is a high pressure loss system and this effect can be materially increased by excessive kinking of the tube, excessive sagging, and the use of bends having centerline radii of less than 2-1/2 tube diameters. Furthermore, unless a large-diameter tubing is used, and entry conditions can limit this, such pressure losses in a system may require quite large motors to deliver the necessary system capacity. In

addition, care must be taken that the system does not interfere with the regulation of airflow between splits or sections. Precautions must be taken to locate the discharge of the fan at sufficient distance in the return to prevent recirculation when cutting through from one face to another and to make the discharged dust inert. However, properly installed and properly maintained, an exhaust tubing and auxiliary fan system can provide good face ventilation, particularly when complemented by a machine-mounted diffuser fan. Generally, the exhaust system should provide a minimum flow of 5,000 cfm into the inlet of the tube, the diffuser fan should have a capacity of 1,000 to 1,500 cfm, and the tube diameter should be 18 inches or greater. An example of such a system is shown in figure 8.

One of the problems associated with the design of a tubing and auxiliary fan system is the lack of data on tubing resistance and entry and bend loss. The data available from tubing manufacturers is meager. This information is inadequate because it does not allow for sagging, kinking, or bending of the tubing, conditions that cannot be totally prevented in an actual mine installation. Peluso<sup>5</sup> has developed information on the tubing friction loss, entry loss, and 90° bend losses for jig-supported tubing and on the friction loss for sling-supported tubing. This work was also conducted in a machine-free entry. Therefore, the data are more representative of ideal conditions than actual mine conditions, because they do not indicate the effect of misalignment, sagging, kinking, or the characteristic bending found in practice. Nevertheless the data materially add to our knowledge of the resistances in a flexible tubing face ventilation system and should be reviewed by anyone installing an auxiliary fan and tubing system. The importance of a fairly taut tube to friction loss is shown in this data. The loss in sling-supported, 18-in-diam tube handling 4,000 cfm was 1.7 inches of water per 100 ft; in jig-supported tube, the loss was 0.85 inches of water per 100 ft. This implies that resistance loss is increased 100 percent when sling-supported tubing is used. However, this loss is small compared with those resulting from kinking, sharp bends, and poor joints. Therefore, the maintenance of an exhaust tube is as important as the maintenance of a line brattice.

The airflow patterns for an exhaust tubing system measured in a machine-free entry reported by Luxner<sup>6</sup> are shown in figure 9. They appear to be approximately similar to those that his work indicated for an exhaust brattice. Both show the importance of maintaining the entry into the tubing or brattice as close as practical to the face to minimize secondary airflow, which may contaminate the primary airflow to the face. This work has resulted in a recommendation that the entry to the tubing should be maintained at distances outby the face no greater than 3 to 4 tube diameters, or approximately 5 feet. Dalzell<sup>7</sup> has stated that, when the exhaust tubing is maintained at this face

<sup>5</sup> Peluso, R. G. Face Ventilation in Underground Bituminous Coal Mines: Airflow Characteristics of Flexible Spiral-Reinforced Ventilation Tubing. BuMines Rept. of Inv. 7085, 1968, 13 pp.

<sup>6</sup> Work cited in footnote 4.

<sup>7</sup> Dalzell, R. W. Face Ventilation by Line Brattice and by Auxiliary Fans. Pres. at 57th National Safety Congress and Exposition, Chicago, Ill., Oct. 27-30, 1969. To be published in Transactions of the National Safety Congress (1969) by the National Safety Council.

distance and sufficient system capacity is available to maintain an air velocity through the active entry of 100 fpm, face-produced contaminants can be confined to the immediate face area and captured. This view appears to be based upon Luxner's previously mentioned work in determining airflow patterns in machine-free entries. As we indicated, such airflow patterns were obtained in a machine-free entry. We undertook some limited studies several years ago in an entry occupied by a milling-type continuous miner and an exhaust tubing and auxiliary fan face ventilation system. Velocity measurements were made between the machine and face with and without the cutter disks rotating and with the exhaust tubing 4 ft and 20 ft outby the face. The velocities that we determined are shown in figures 10 and 11. It is obvious that the location of an 18 in tubing, for the ventilation shown, at a distance of 20 ft from the face did not indicate good face ventilation, whereas the converse was the case for a 4-ft location of the tube. Adequate ventilation would probably be achieved with the tubing located at 6 to 8 ft from the face. However, we wish to emphasize that this work was a limited study, and while the bits were running, the effect of high-velocity water jets in entraining air to the face could not be evaluated. This could be done in future studies by mounting high-velocity air jets on the machine to simulate the action of water jets.

An exhaust tube and auxiliary fan system can provide adequate dust control and gas control only when methane emission is low. Therefore, it is better practice to complement this type of system with a machine-mounted blowing fan of 1,000-to-1,500-cfm capacity. The outlet of this fan should be extended as close to the face as possible. Not only does such a diffuser fan provide a better air sweep of the face for methane dilution, but it provides improved dust control and allows the entry end of the tubing to be from 10 to 15 ft outby the face. The capacity of the diffuser fan should not exceed about 25 percent of the capacity of the exhaust tube system. Several applications of this type of system have been made by the Bureau of Mines. Figure 7 shows one such system which may be the most practical. In such an arrangement, the discharge of the diffuser induces additional air to the face, by acting as an ejector, than would be the case if the discharge was closer to the face. The same type of system applied to ventilating the face during a box cut and slab cut is shown in figure 12.

In designing an exhaust tube and auxiliary fan system, it is important that the pressure losses be calculated to permit determination of the necessary power requirement of the system. These losses consist of the resistances to airflow developed in the system by tubing resistance, bend loss, joint loss, and entrance loss. The sum of these losses is the total system loss, which must be known to select the fan and motor.

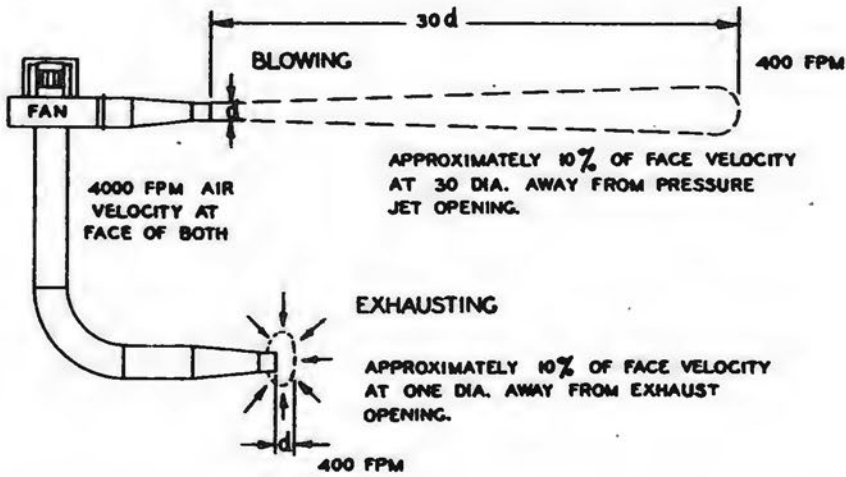


Figure 1.—Comparative Airflows in Blowing and Exhausting Face Ventilation Systems.

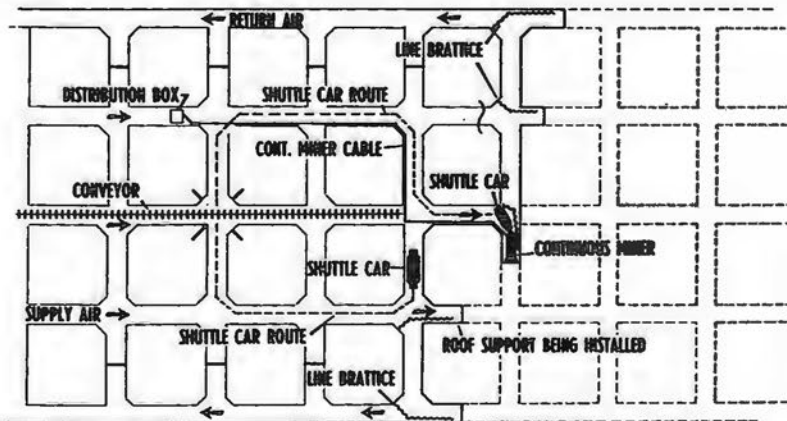


Figure 2.—Two-Split Ventilation System in Development Section of Mine.

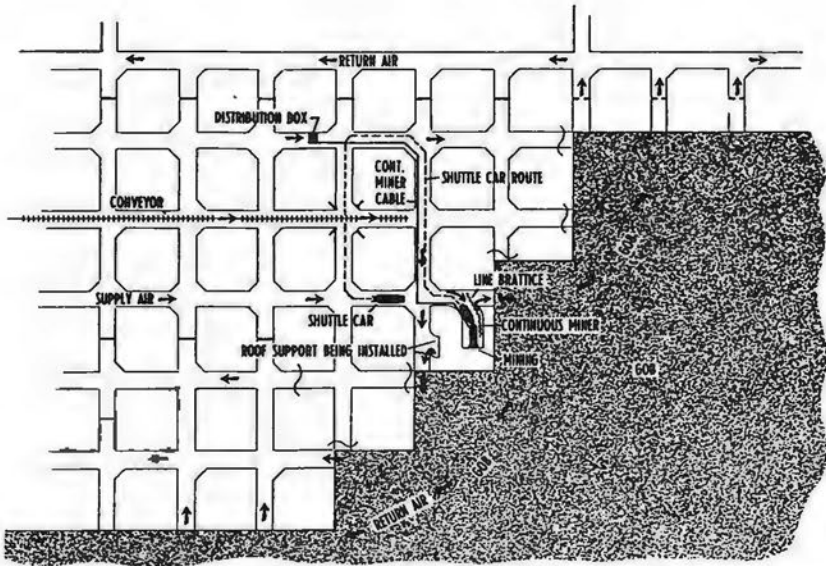


Figure 3.—Two-Split Ventilation System in Pillar Extraction Section of Mine.

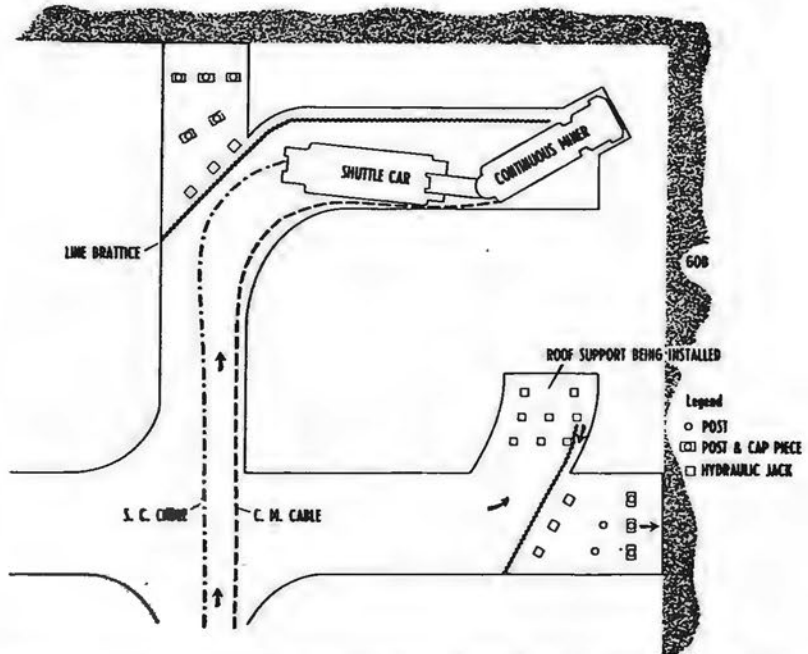


Figure 4.—Closeup of Two-Split Ventilation in Pillar Extraction Section of Mine.

37-114 O-70-7

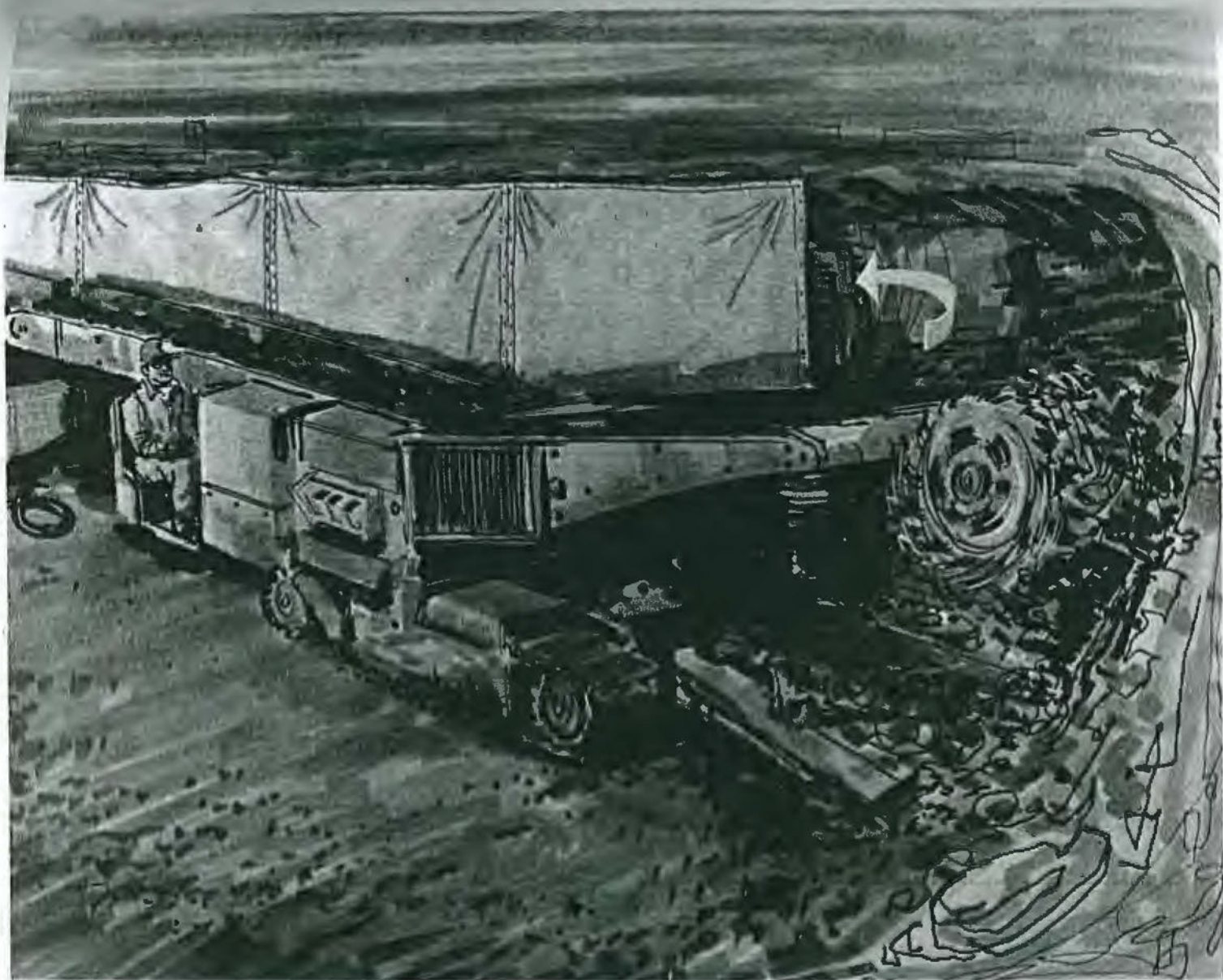
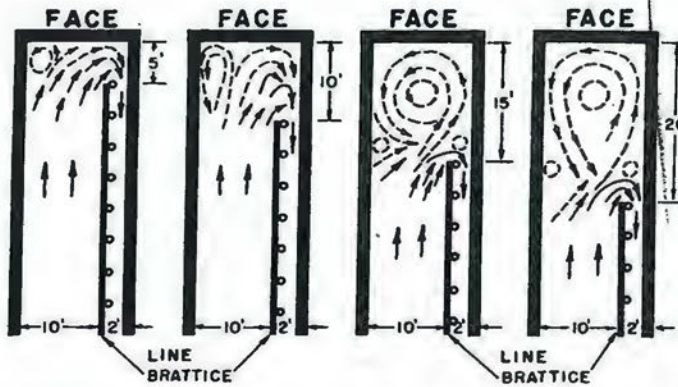


Figure 5.—Exhausting Line Brattice Ventilation System.

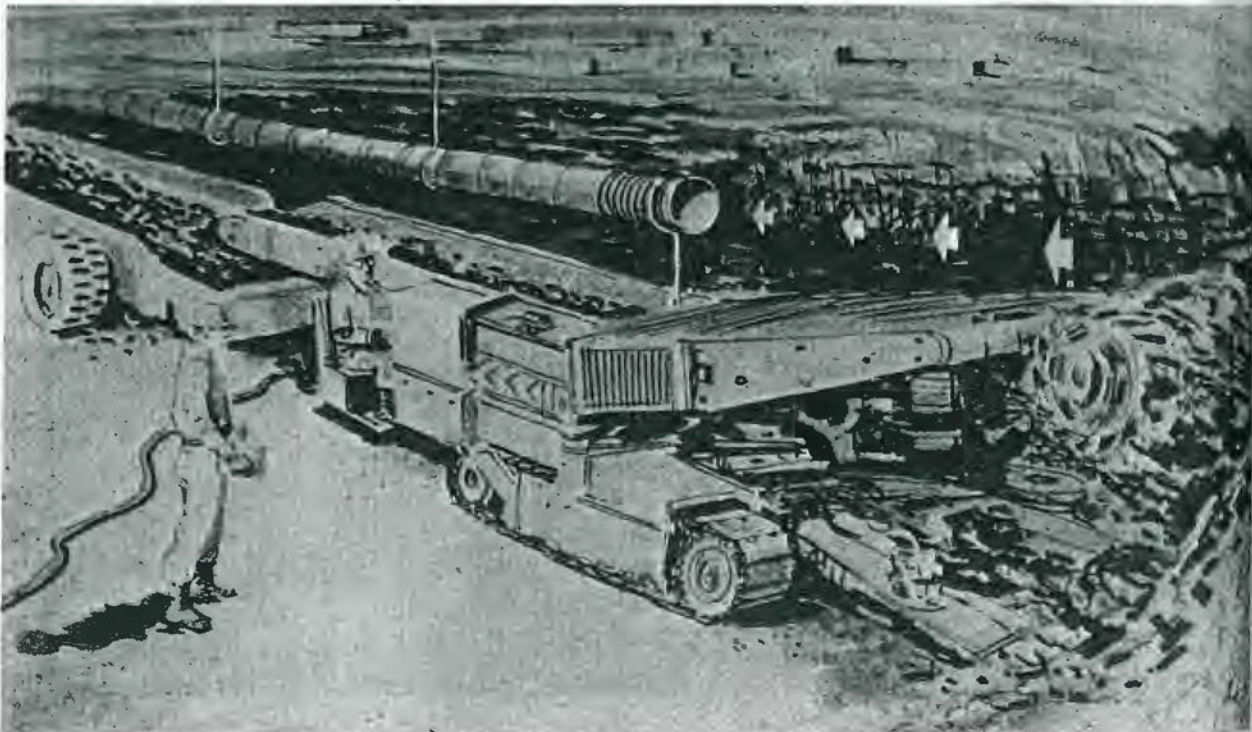
**AIRFLOW PATTERN FACE VENTILATION  
EXHAUST BRATTICE**



**LEGEND**

- TURBULENCE
- PRIMARY AIRFLOW
- - -> SECONDARY AIRFLOW

**Figure 6.—Airflow Patterns in Exhausting Line Brattice  
Face Ventilation.**



**Figure 7.—Exhaust Tubing Ventilation With Intake Tube Mounted on Mining Machine.**

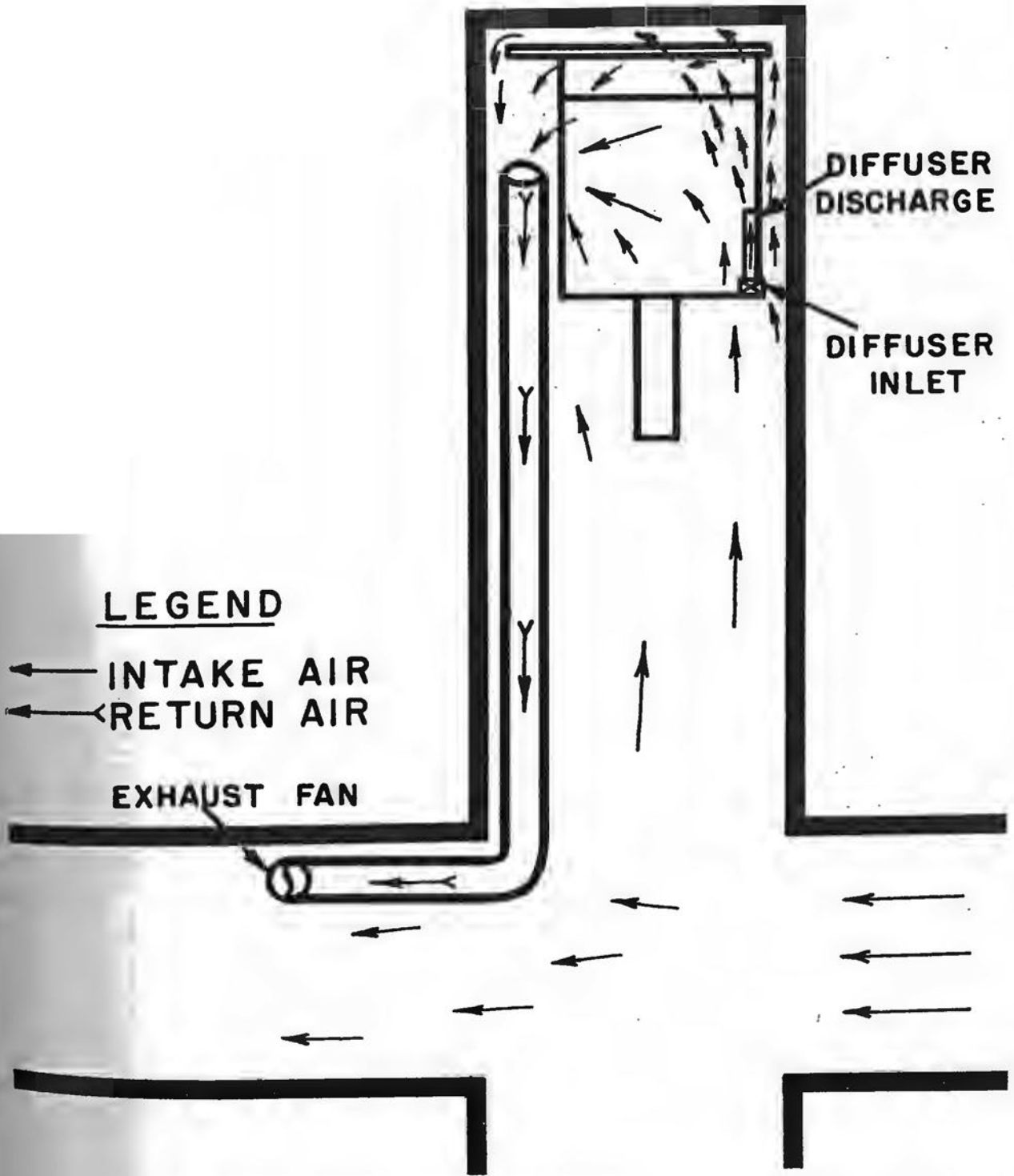
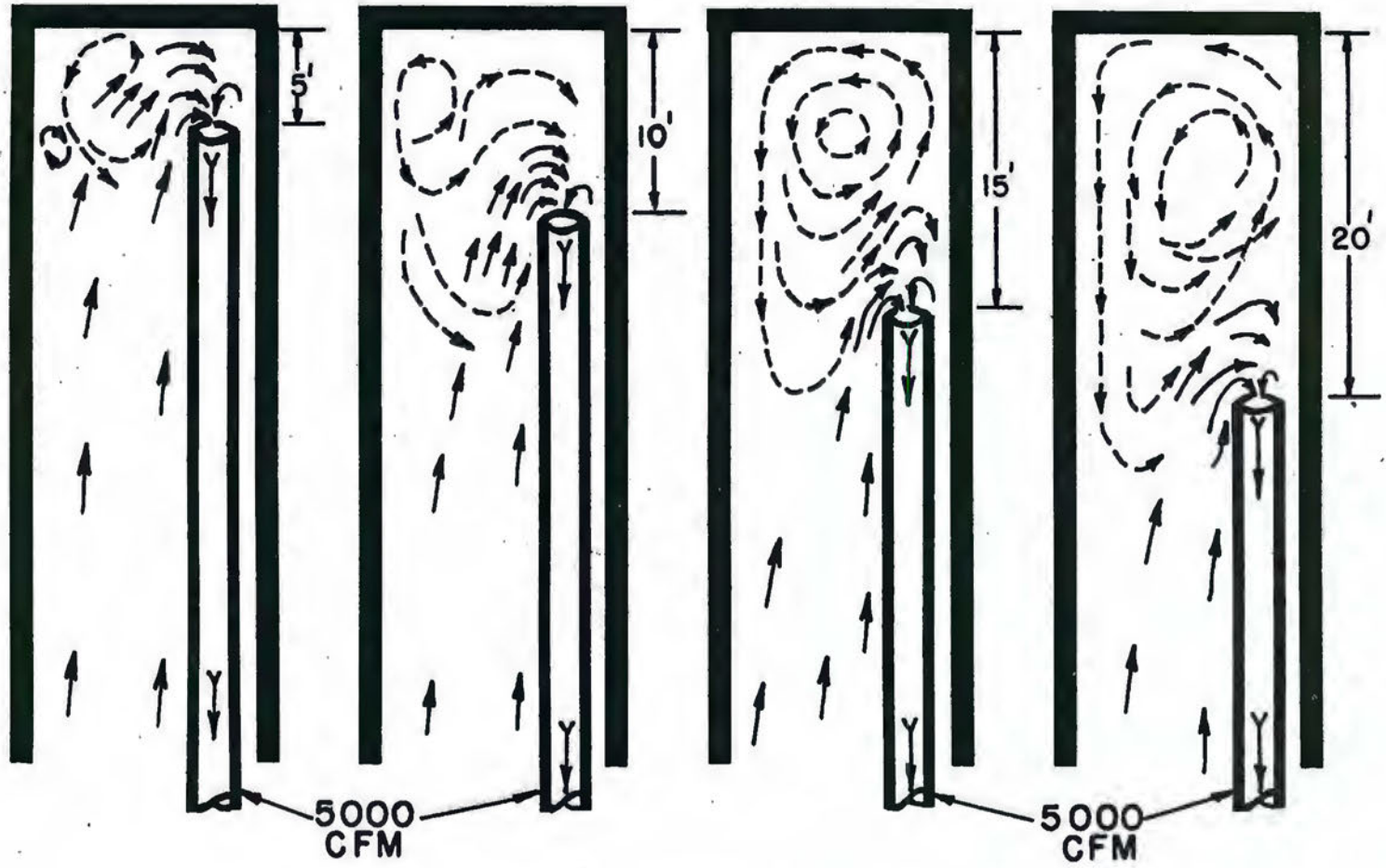


Figure 8.—Modified Auxiliary Face Ventilation System Designed for Methane and Dust Control.



**LEGEND**  
——> PRIMARY AIRFLOW  
- - -> SECONDARY AIRFLOW  
Y-> RETURN AIR

Figure 9.—Airflow Patterns for Exhaust Tubing System Measured in Machine-Free Entry. Entry 12 by 6 ft. Tubing, 18-in-diam, Installed Near Roof.

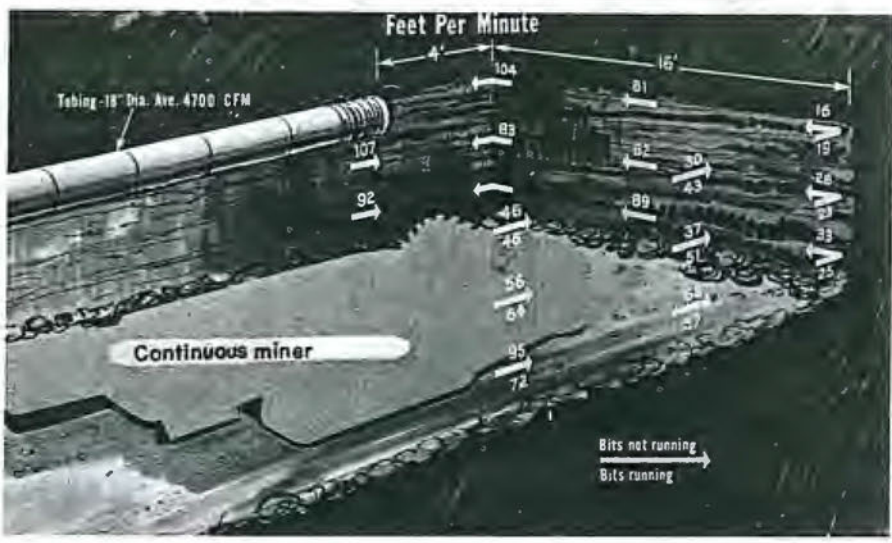


Figure 10.—Average Velocities at Face With Tubing 4 Feet From Face.

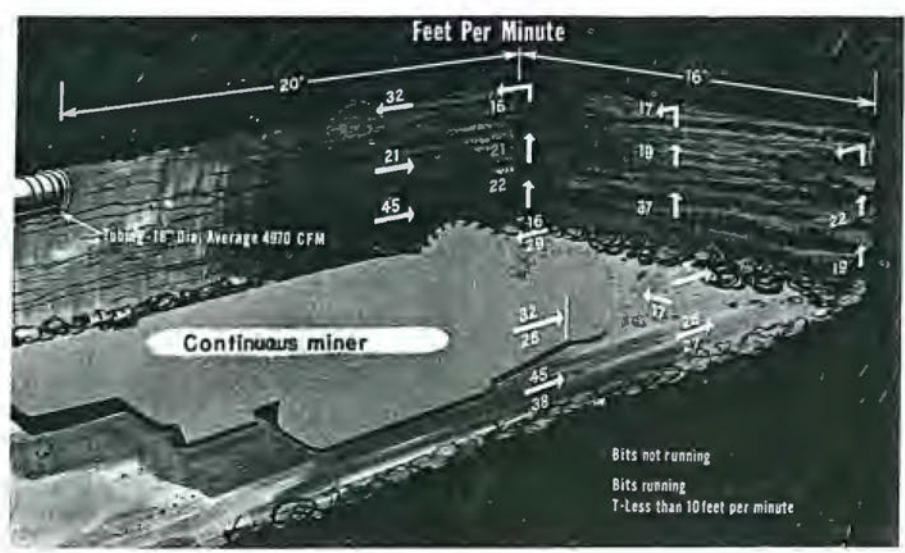
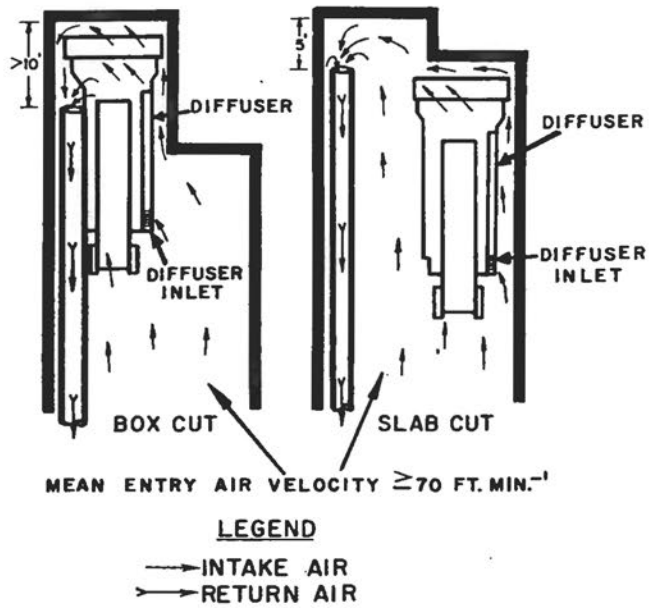


Figure 11.—Average Velocities at Face With Tubing 20 Feet From Face.



**Figure 12.—Auxiliary Face Ventilation System Designed for Methane and Dust Control.**

### CONCLUSION

We have endeavored to indicate that a face ventilation system is dependent upon the main ventilation system, since the design of the latter determines the available air in the last open crosscut. The factors that determine the effectiveness of brattice and auxiliary fan and tube systems of face ventilation have been discussed. These factors include the air volume handled by the system, the volume of air coursing to the face through the active entry, and the location of the entry of the system with respect to the distance from the face. Maintenance problems exist in both types of systems and must be controlled if the system is to be effective. An exhaust system is much more effective. An exhaust system is much more effective for dust control than a blowing system, but the latter type may be utilized in those instances where dust generation is appreciably controlled by water flushing of the machine bits or water infusion. The former is being practiced in some conventional mining operations with water applied to the cutting bar. Dust and gas control may be improved in continuous mining by using a single machine on a single split of air and by utilizing an exhaust-type face ventilation system with a machine-mounted diffuser fan directing air to the face. There is need for considerable research on face ventilation under conditions more nearly simulating actual mine conditions and for development of a dust collector of adequate efficiency that can be mounted on the machine.

DR. POTTER: We have a change in the program at the present time. Henry Doyle, Acting Assistant Director, Mineral Industry Health, Bureau of Mines, will present a paper on "Studies on the Control of Respirable Coal Mine Dust by Ventilation."

STUDIES ON THE CONTROL OF RESPIRABLE COAL MINE DUST BY VENTILATION<sup>1</sup>

by

D. S. Kingery, H. N. Doyle, E. J. Harris, M. Jacobson,  
R. G. Peluso, J. B. Shutack, and D. P. Schlick

---

## ABSTRACT

Experiments initiated by the Bureau of Mines on August 26, 1969, and recent work of others, have demonstrated the effectiveness of ventilation for controlling concentrations of respirable coal mine dust. Substantial reductions in dust concentrations have been attained by increasing the volume and rate of air movement across the face and by controlling the airflow pattern.

Ventilation experiments conducted by the Bureau using high-pressure fans as auxiliary ventilation units showed that face-generated dust could be effectively controlled in five mines employing continuous mining machines. Additional data were obtained on industry installations in two mines using similar ventilation systems. By maintaining an airflow approaching 100 fpm across the entry, the experimental system reduced the concentration of respirable dust by factors as great as 6.4. In all mines where the system was used, the face-generated dust concentrations were reduced to below 3 mg/m<sup>3</sup>. Total respirable dust in two cases was above the 3 mg/m<sup>3</sup> value because of the dust content of the intake air. In some mines, depending upon the type of coal being mined and other dust control factors in use, it was possible to obtain concentrations of less than 2 mg/m<sup>3</sup>.

Although the technology for the application of the dust control system investigated is readily available, it is evident that additional engineering studies should be made in each mine where the system is to be applied. Conditions in some mines may require a modification of the system. On the basis of the Bureau's experience to date, further studies will be made so that the various engineering parameters encountered in underground coal mining can be evaluated.

## CONCLUSIONS

The following conclusions can be made from this investigation:

1. Controlled face ventilation employing a high-pressure auxiliary fan together with other components of the system will substantially reduce the

---

<sup>1</sup> H. N. Doyle gave a short version of this paper at the symposium. The full report, previously published by the Bureau of Mines (Tech. Prog. Rept. 19, 1969), is reprinted here.

concentration of respirable coal dust at the working face of underground coal mines. By maintaining an airflow from 70 to 100 fpm across the entry, results showed in all instances that the average respirable dust concentration at the continuous miner was reduced to less than  $3 \text{ mg/m}^3$ . Total respirable dust in two cases was above the  $3 \text{ mg/m}^3$  value because of the dust content of the intake air. In some instances, however, respirable dust concentrations were reduced to less than  $2 \text{ mg/m}^3$ .

2. Through proper engineering design of the auxiliary and main ventilating system of the mine, the hazard due to methane will also be reduced.

3. Because of the effects of concentrations of respirable dust in the incoming air the system investigated, by itself, is not a complete solution to the respirable dust problem. For the system to be totally effective, dust controls must be applied at dust generating points in the incoming air passageways.

### INTRODUCTION

Pneumoconiosis, a respiratory disease which is caused by inhaling fine particles of coal mine dust, is recognized as a major occupational health problem in underground bituminous-coal mines. Consequently, the Bureau of Mines has launched a major effort to find ways for controlling respirable coal mine dust. Studies by the Bureau and other mining research agencies have indicated that the efficient use of water and ventilation represent the fundamental approaches to effective dust control. Although water sprays on mining machines have beneficial effect as a suppression measure for total airborne dust, current spray techniques have little effect on dust in the respirable range.

Calculations based on the theory of small particle behavior and air motion indicated to Bureau investigators that an airflow of between 70 and 100 fpm across the entry should result in significantly lower dust concentrations.

After analyzing engineering studies by the Bureau of Mines and the industry, it became apparent that a method for achieving the desired entry velocity was by using a high-pressure auxiliary fan and by maintaining the end of the exhaust tubing about 5 feet from the face. This assertion was supported by the following concepts:

1. Adequate airflow at the face confines coal mine dust generated ahead of the operator and captures dust particles. Dust can then be transported by the system and discharged into the return entry, where it can be treated or collected.
2. Previous studies conducted by the Bureau demonstrated the effectiveness of ventilation for the control of methane released at the working face. Similar techniques could be effective for dust control.

## METHOD OF INVESTIGATION

The Bureau's investigation was centered upon the use of an auxiliary high-pressure axial-flow direct-driven fan with variable pitch blades. The original estimated power requirements were from 20 to 40 hp. An approved fan with such requirements was not available and could not be quickly supplied by a manufacturer. Therefore, two fans, operating in parallel, each with horsepower sufficient to produce 5,000 cfm, and a fan with a 10-hp motor capable of producing 9,900 cfm, were used in the first experiment. This series was conducted in a mine where coal was being extracted by a continuous miner from the Pittsburgh coalbed averaging about 6 feet in height.

Although favorable results were obtained in this initial study, the fans used could not produce the desired entry velocities originally specified by Bureau engineers. A second study was conducted using a 60-hp auxiliary fan from the Bureau's experimental mine in order to obtain higher entry velocities. Because of the fan's size and power requirement, it could only be used in mines capable of accommodating it. In the second mine studied, coal was extracted with a continuous miner from the Sewickley coalbed averaging 50 to 54 inches in height. Subsequent studies were conducted in mines in the Pocahontas No. 3 and No. 4 and Illinois No. 6 coalbeds.

Dust measurements were made according to standard Bureau procedures. For the purpose of this report, samples collected with an MRE instrument contained in the instrument package mounted on the continuous miner were used as a basis for comparison. It would have been desirable to use a personal sampler on the machine operator as the reference point. However, in some mines studied, the machine operators performed multiple tasks, requiring several different operators for each machine on a given shift. Therefore, the operator's exposure could not be used for obtaining representative data. Baseline studies of respirable dust concentrations were made wherever possible in the Bureau's studies to establish the effectiveness of the ventilation system being tested.

Figure 1 illustrates the system used throughout this investigation.

VENTILATION THEORY<sup>2 3</sup>

Following the introduction of continuous mining equipment to the bituminous coalfields, increased production rates and rapid face advance led to increased frequency of methane ignitions from improper or poor face ventilation. As a part of a program to reduce this hazard, the Bureau of Mines

<sup>2</sup> Luxner, James V. Face Ventilation in Underground Bituminous Coal Mines: Airflow and Methane Distribution Patterns in Immediate Face Area-Line Brattice. BuMines Rept. of Inv. 7223, 1969, 16 pp.

<sup>3</sup> Dalzell, R. W. Face Ventilation by Line Brattice and by Auxiliary Fans. Pres. at 57th National Safety Congress and Exposition, Chicago, Ill., Oct. 27-30, 1969. To be published in Transactions of the National Safety Congress (1969) by the National Safety Council.

obtained information relative to airflow patterns developed in the immediate face area by various combinations of ventilation methods and devices. Following these studies, basic systems of air control were devised for dilution and removal of methane face emissions without accumulations of high concentrations in the occupied face region. Methane control and dilution was in all cases achieved by planned air circulation.

Although continuing progress has been made in face ventilation techniques, dust loading in the face atmosphere clearly indicates that ventilation systems now used are often inadequate to maintain respirable dust concentrations within acceptable limits.

Settling rates of airborne particulates less than 10 microns in diameter show that dust in the respirable size range may be transported for great distances by air currents. Because respirable dust generated at the face is transported by the air stream, ventilation techniques originally designed to control distribution and accumulation of methane face emissions can be used to confine, capture, and remove airborne dust produced at the face.

The theory for the control of coal mine dust is that dust particles smaller in size than 10 microns tend to behave in the same manner as a gaseous contaminant such as methane. Thus, the control of respirable dust is a function of the volume and velocity of air moving across the coal face. Another requirement is to maintain the zone of contaminated air as close to the face as possible to minimize the exposure of face workers.

Bureau studies on methane control methods have revealed definitive airflow patterns. These patterns are shown in figures 2 and 3. At the start of the investigation, information given on figure 2 was used to determine that exhausting air from the face in sufficient volume to assure a sustained velocity approaching 100 fpm across the entry, would result in minimizing the concentration of respirable dust. Diagrams shown on figure 3 established the need for maintaining the tubing within 5 feet of the coal face.

Experiments performed at the Bureau's experimental coal mine related horsepower requirements to air velocity and air volume under a variety of operating conditions as shown in figure 4.

From the data incorporated in figure 4 it was estimated that for entries having a 56 sq ft area, a 15-hp, high-pressure, auxiliary fan, used in conjunction with a 20-inch diameter tubing, would be required to minimize the concentration of respirable coal mine dust; for entries of 96 sq ft, a 30-hp fan used with 24-inch tubing would be required to achieve the same result. In both cases noncollapsible tubing is specified, due to the effects of high exhaust pressures generated by the system.

Based upon this investigation and past Bureau experience, where conditions of extreme methane liberations override respirable dust control requirements, both dust and gas control objectives can be met by using a machine-mounted diffuser blower and an auxiliary fan system, as illustrated in figure 5.

For the ventilation system investigated in this study to be effective, these criteria must be met:

1. Intake to the exhaust system must be maintained within 5 feet of the face, and the volume of air induced by the system must be adequate in providing a minimum velocity of 70 fpm across the entry.
2. Recirculation of methane and respirable dust must be prevented by insuring that the volume of air being delivered to the crosscut is in excess of the demand of the exhaust system.
3. Coal should not be permitted to accumulate at the tail of a continuous mining machine, thereby restricting airflow, nor should other obstructions be permitted to restrict the airflow.
4. Incoming air should be relatively free of respirable dust.

#### DUST SAMPLING

Dust sampling instrument packages were placed in strategic areas -- one on the continuous mining machine, and another in the intake airway. To obtain comprehensive data on dust concentrations, these packages contained a variety of sampling equipment, including long-running midjet impingers, personal samplers, total airborne dust samplers, and MRE instruments. In addition, personal samplers were placed on the machine operator.

All gravimetric samplers were operated continuously and provided integrated values for the full face shift. To determine interim or cyclic values, long-running midjet impingers collected periodic samples. Thus, by relating midjet impinger to respirable gravimetric samples, it will be possible to discern mining practices which result in unusually high dust concentrations.

#### SUMMARY OF FIELD CONDITIONS

Studies were conducted in developing sections of five mines using continuous mining machines in five coalbeds of three different States. Coalbed height varied from 52 to 78 inches in the Bureau's tests. These tests were conducted in the Pittsburgh, Sewickley, Pocahontas No. 3 and No. 4, and Illinois No. 6 coalbeds. Water applied by sprays at rates varying from 5 to 15 gallons per minute was monitored by Bureau engineers using meters installed in the supply line.

In the tests fan pressure and air quantity ranged from 3.75 inches of water at 5,000 cfm to 15 inches of water at 15,000 cfm. In one instance, fans were employed in parallel systems. The exhaust systems tested produced air face velocities from 35 to more than 100 fpm. At each mine the maximum practical size tubing ranging from 18 to 24 inches was used in order to obtain maximum airflow volumes.

## DISCUSSION OF TEST RESULTS

These experiments demonstrate that in the mines studied it is possible to attain a substantial reduction in concentrations of respirable coal mine dust; the respirable-dust-concentration-reduction factors range from 1.7 to 6.4. The mines studied represented, in our opinion, difficult dust problems, either due to the type of coal being mined or for other reasons. In all mines studied production rates did not deviate significantly from normal during the survey period as indicated in table 1. The study was limited to mines employing continuous mining machines. The technology of the ventilation system described here should be applicable to all types of underground coal mining.

TABLE 1.--Basic data on mines studied

Mine	Coalbed	Bed height (inches)	Production (raw tons)				Shifts surveyed	
			Normal ventilation		Improved ventilation		Number of shifts	
			Average	Range	Average	Range	Normal ventilation	Improved ventilation
A	Pittsburgh.....	78	536	384-600	540	490-660	4	7
B	Sewickley.....	54	210	150-225	178	165-204	3	3
C	Pocahontas No. 4.	78	190	108-228	160	128-204	6	6
D	Pocahontas No. 3.	52	332	144-480	330	252-404	9	5
E	Illinois No. 6...	72	370	342-396	460	387-648	2	5

Figure 6 presents Bureau results obtained by measuring the respirable dust concentration on the continuous mining machine at a point near the operator. Mines A through E are studies conducted entirely by the Bureau. In these mines dust studies were made before and after the ventilation system was in operation. Mines F and G are mining industry installations using in general the techniques described in this report with the notable exception that the fans used in the industry installations had less capacity than the one used by the Bureau of Mines. Also, baseline dust data were not available for these two mines.

In all mines studied, the incoming air was contaminated with respirable dust. Based on the assumption that it is possible to minimize this contamination by dust control or suppression at the appropriate dust generation points, the data shown in figure 7 was derived by subtracting the dust load of incoming air from the concentration of the respirable dust measured on the continuous mining machine. By using the adjusted concentrations for respirable dust, all average concentrations -- with one exception in which the velocity of incoming air was only 35 fpm because of the small-size fans -- were below  $2 \mu\text{g}/\text{m}^3$ .

Uncontaminated intake air is necessary for respirable dust control. Actual measurements have shown dust concentrations in intake air ranging from one-half to over 2 milligrams of dust per cubic meter of air. Respirable dust particles will remain a part of the air current until either collected or dissipated by some method. Such coal dust contaminant sources are usually from open coal dumping stations, coal transfer points, uncovered coal trips, belt transportation systems, and roadways. These contaminant sources should be placed on separate air splits if possible or the air velocities passing over such points reduced.

Adequate air volumes at the face for coal dust control may require extensive and expensive modification and improvements in the primary ventilating system. These may be new air shafts and new fan installations, increasing the number of air courses, both intake and return, and other methods to reduce the mine resistance.

Figure 8 is a scatter diagram of all face-generated dust concentrations in comparison to the entry velocity expressed in feet per minute. The indicated upper limit curve shows the entry air velocity necessary to assure that at least 97 percent of the dust samples will be below the indicated value. For example, an entry velocity of 85 fpm would maintain the face-generated respirable dust concentration below  $3 \text{ mg/m}^3$ ; 110 fpm would result in concentrations below  $2 \text{ mg/m}^3$ ; and 130 fpm would result in concentrations below  $1 \text{ mg/m}^3$ . Based on the dust characteristics of the coalbed, the design of the mining machine, the amount and efficiency of water utilization, and other engineering parameters, it may be possible to reduce these entry velocities.

Because this report presents only the timely first results of the Bureau's investigations, engineering tables showing all gravimetric and midget impinger concentrations, production rates, water control data, and a detailed description of mine conditions have not been included. A Bureau of Mines information publication containing comprehensive data is being prepared.

DR. POTTER: I think it has been clearly demonstrated that ventilation is going to play by far the greatest part in handling respirable dust in the United States.

DR. POTTER: The first part of the program dealt with ventilation as a means of controlling respirable dust. The next portion of this session will be on water as a control method.

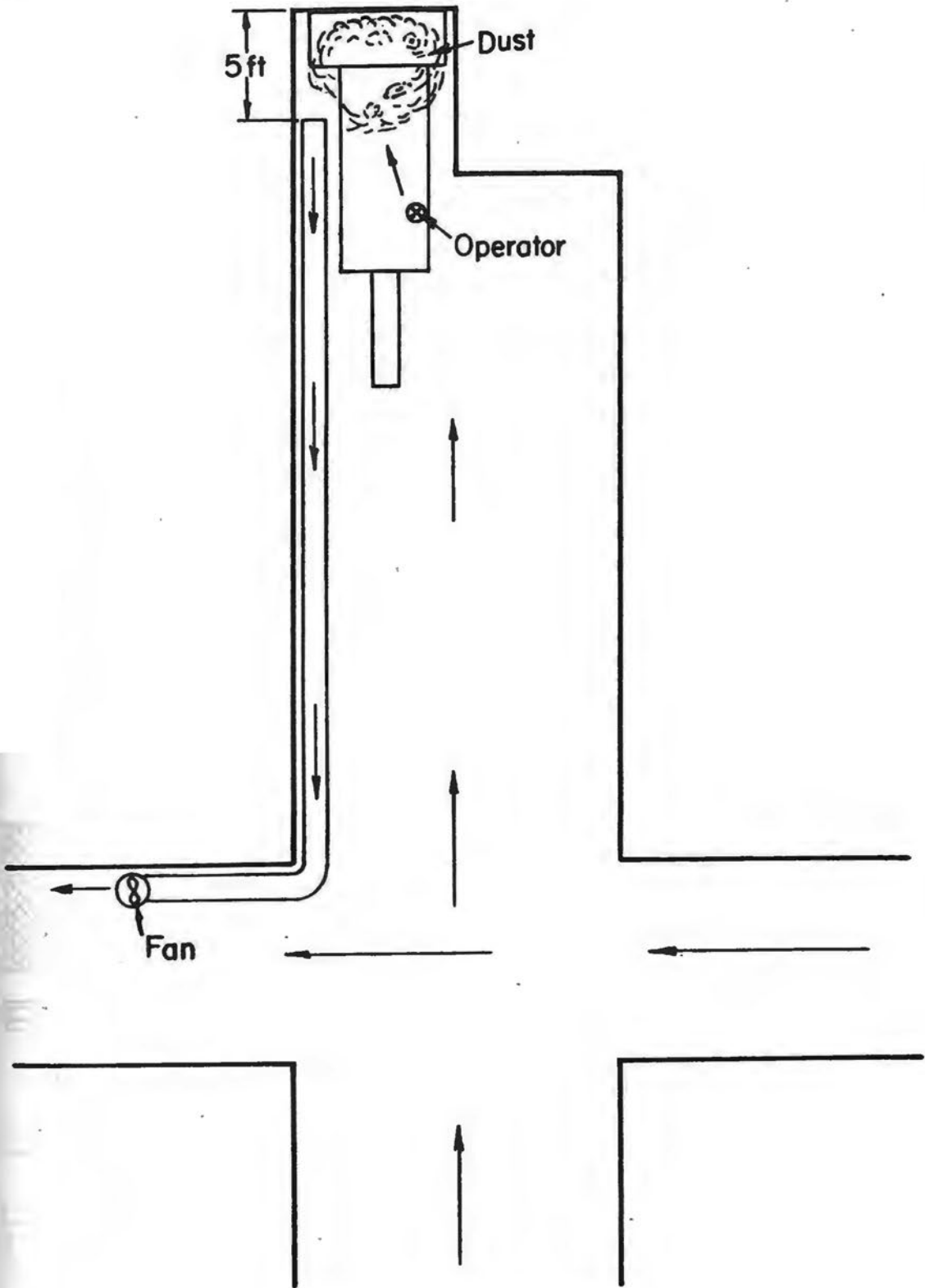


Figure 1.—Auxiliary Ventilation System.

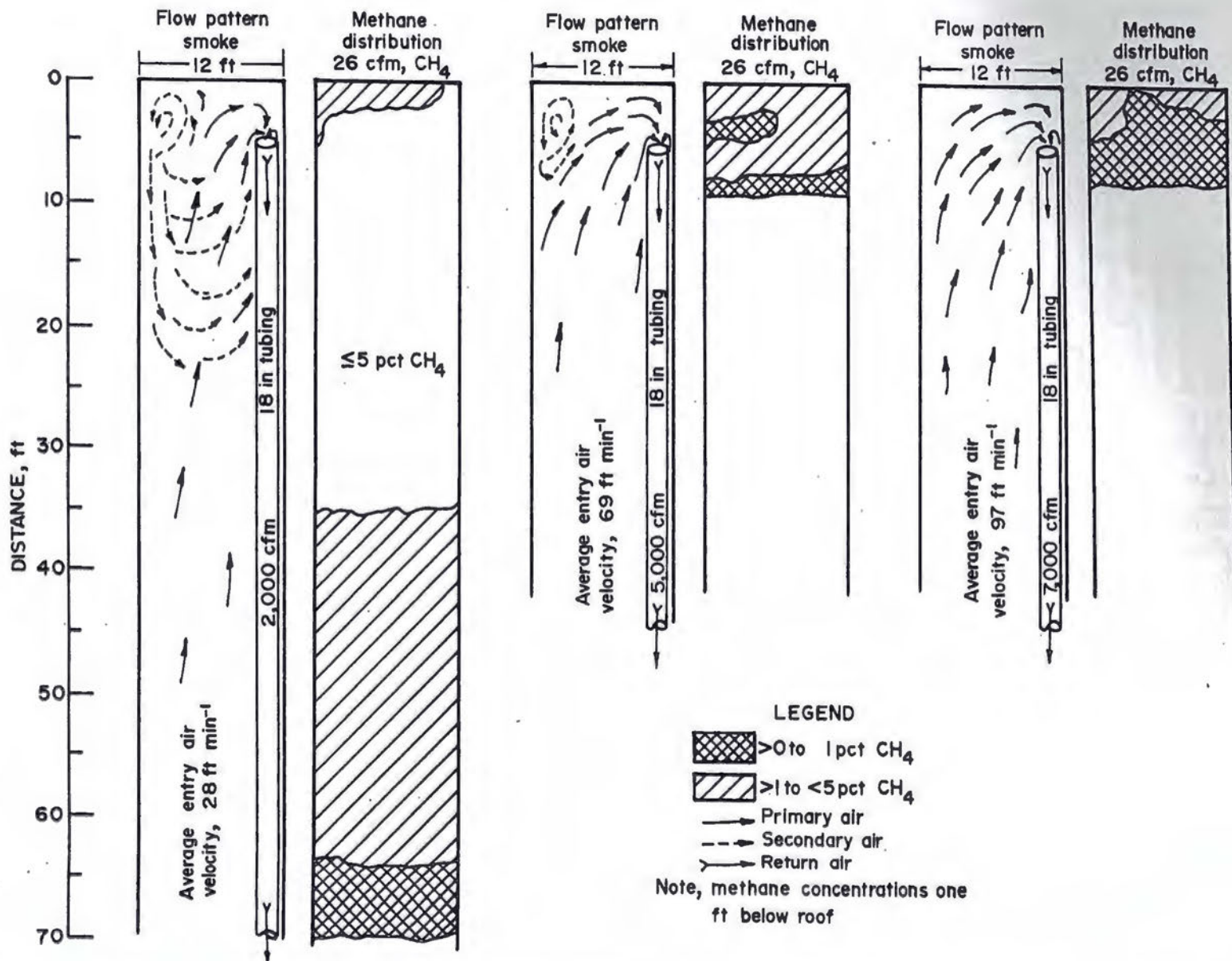


Figure 2.—Face Airflow Patterns of Methane Distribution.

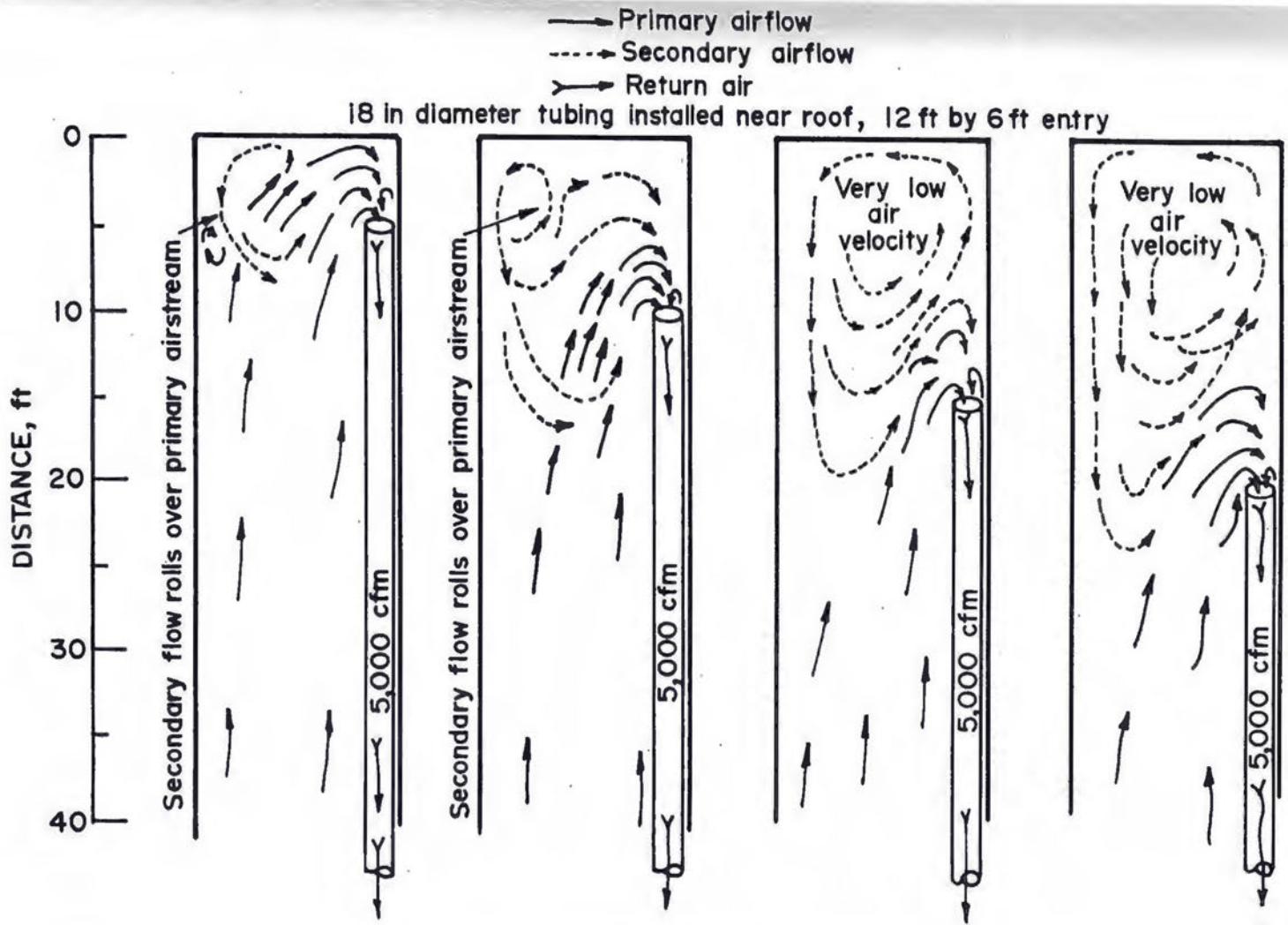


Figure 3.—Face Airflow Patterns With Exhaust Tubing.

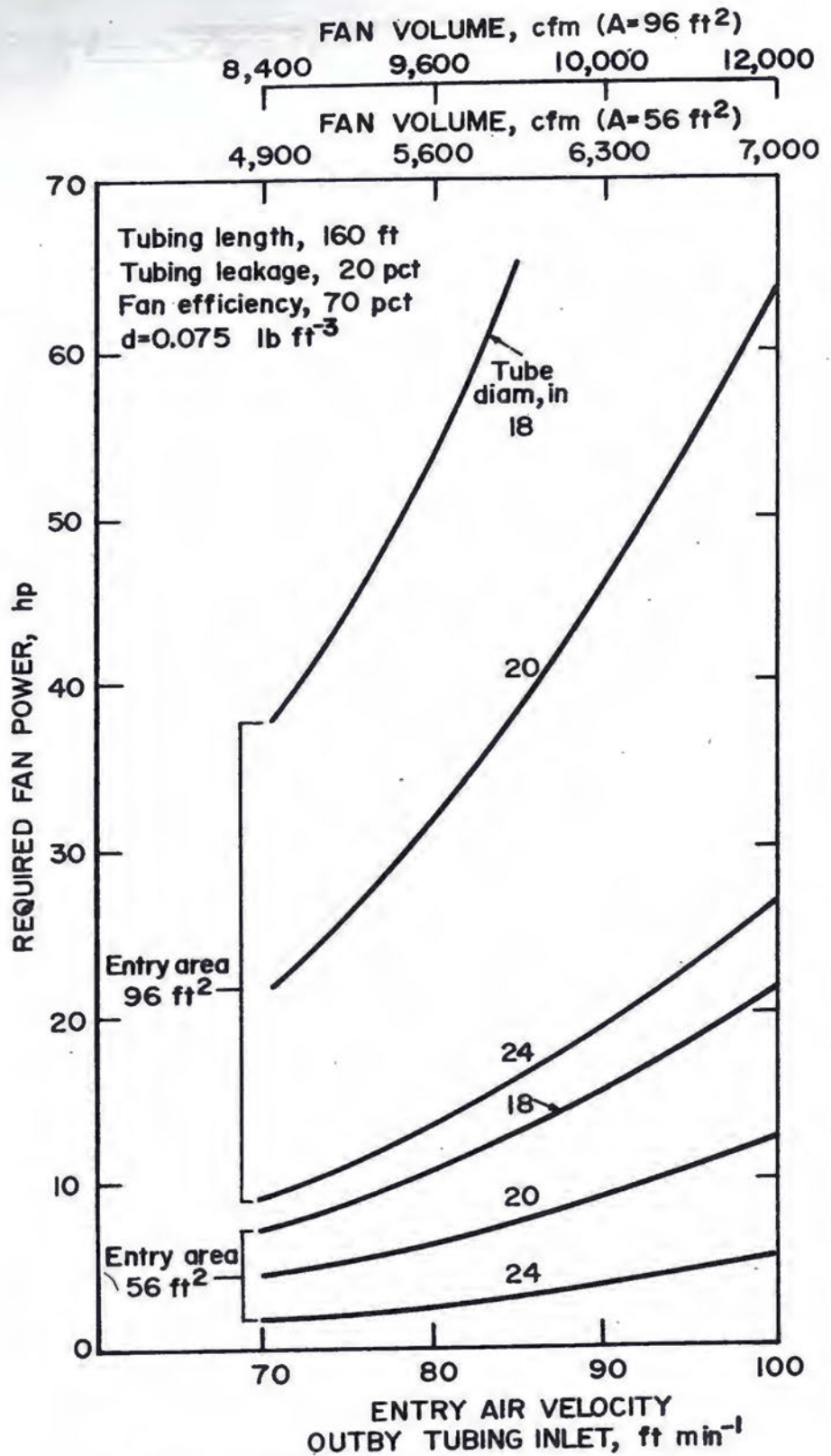


Figure 4.—Required Fan Horsepower Versus Entry Air Velocity for Various Tubing Diameters.

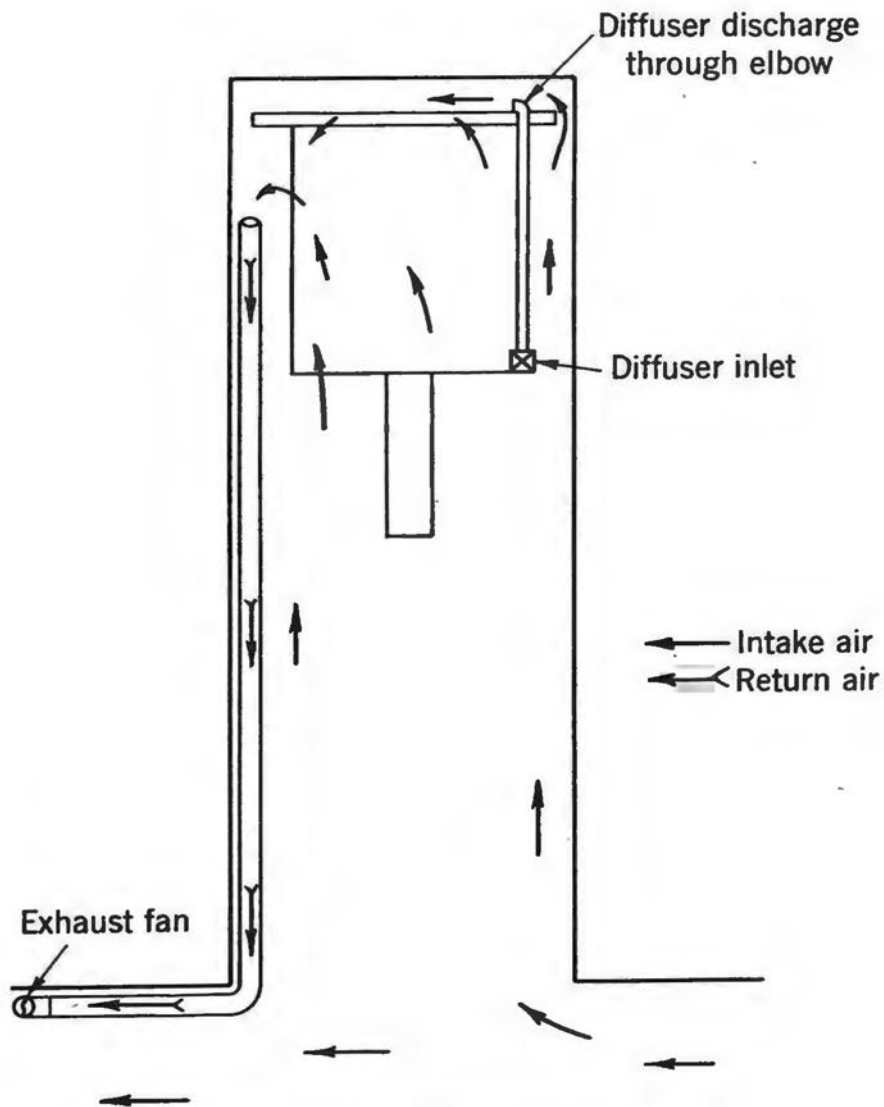


Figure 5.—Diffuser-Assisted Exhaust System.

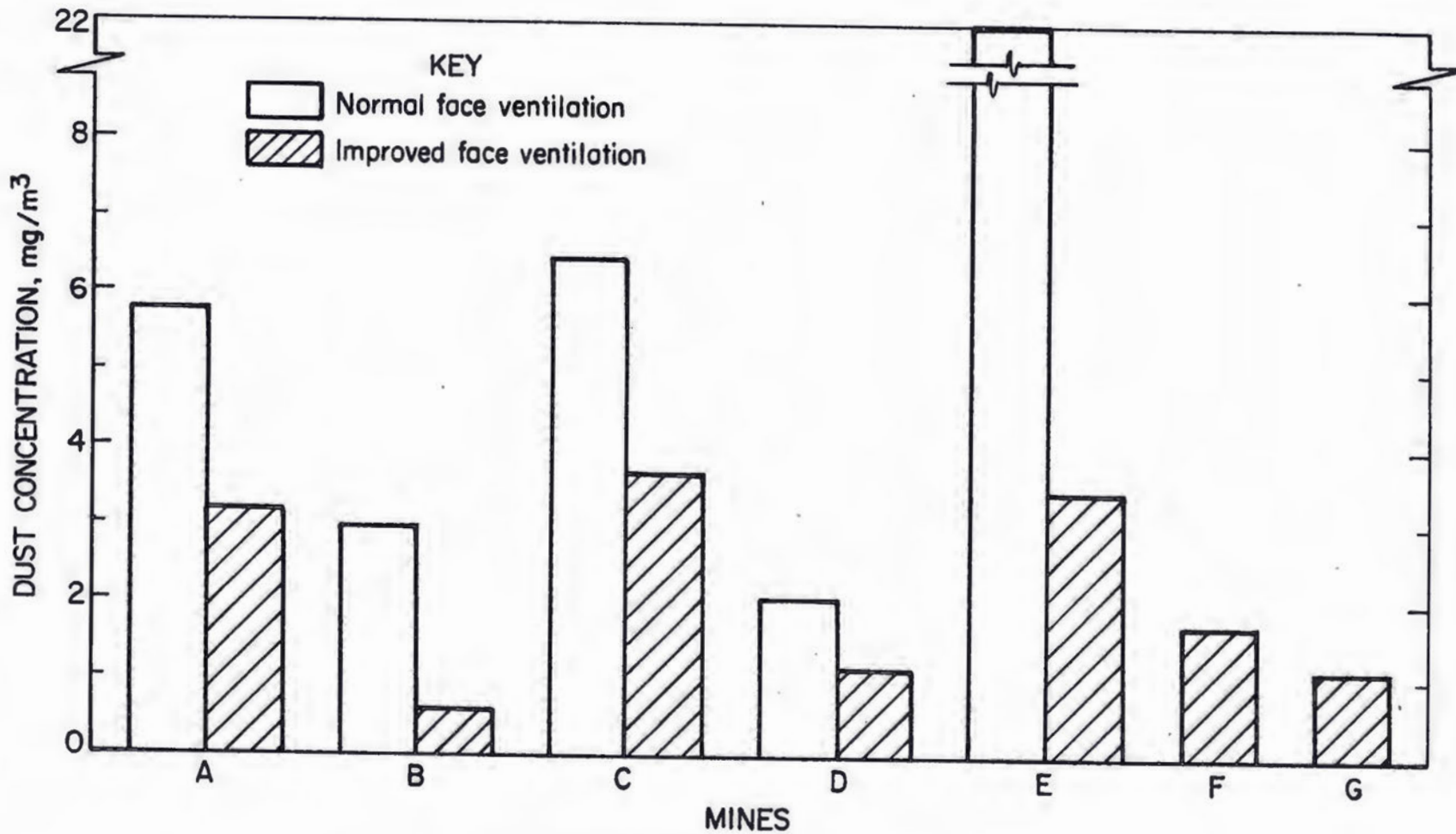


Figure 6.—Total Respirable Dust Concentration at Continuous Mining Machine.

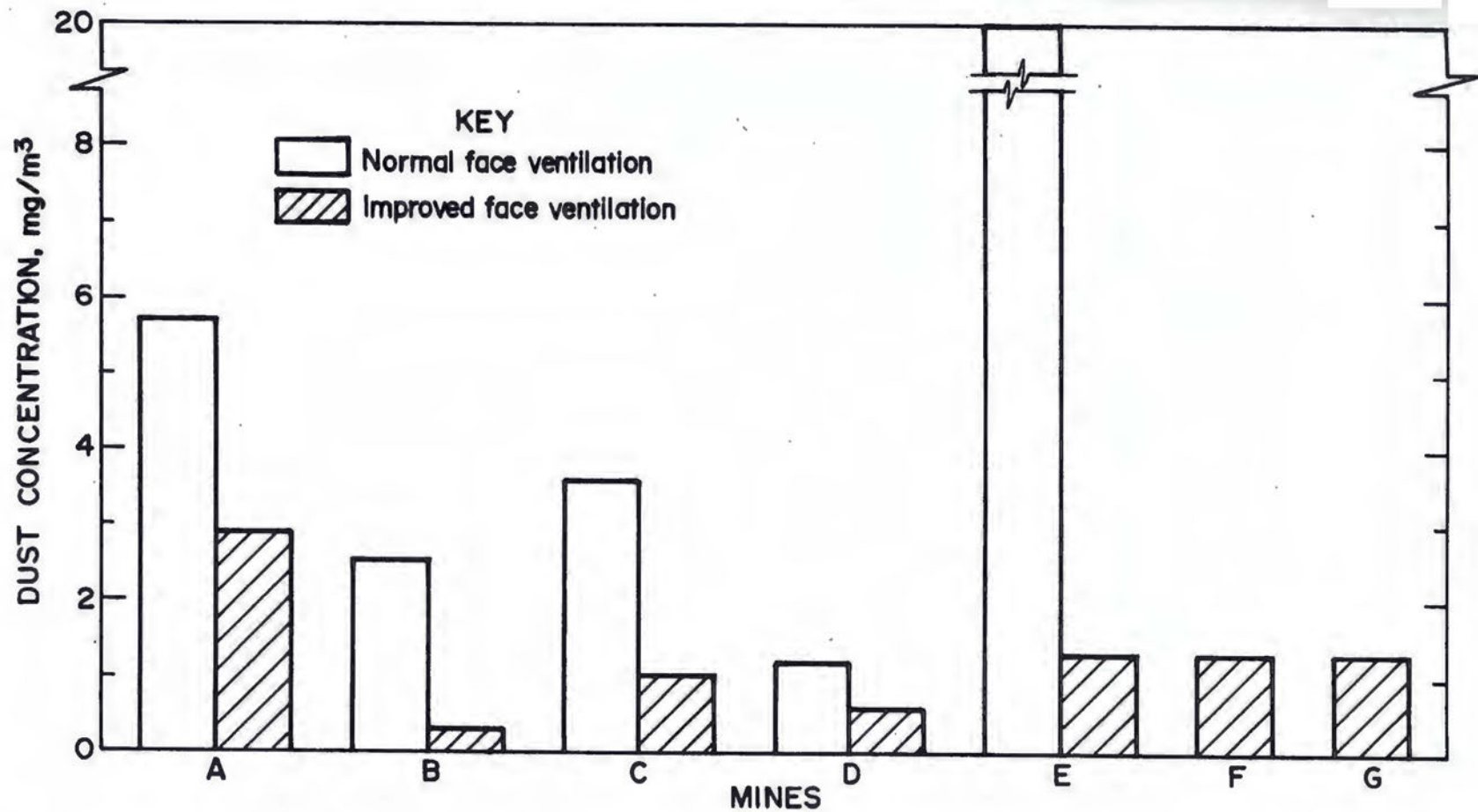


Figure 7.—Face-Generated Respirable Dust Concentration at Continuous Mining Machine.

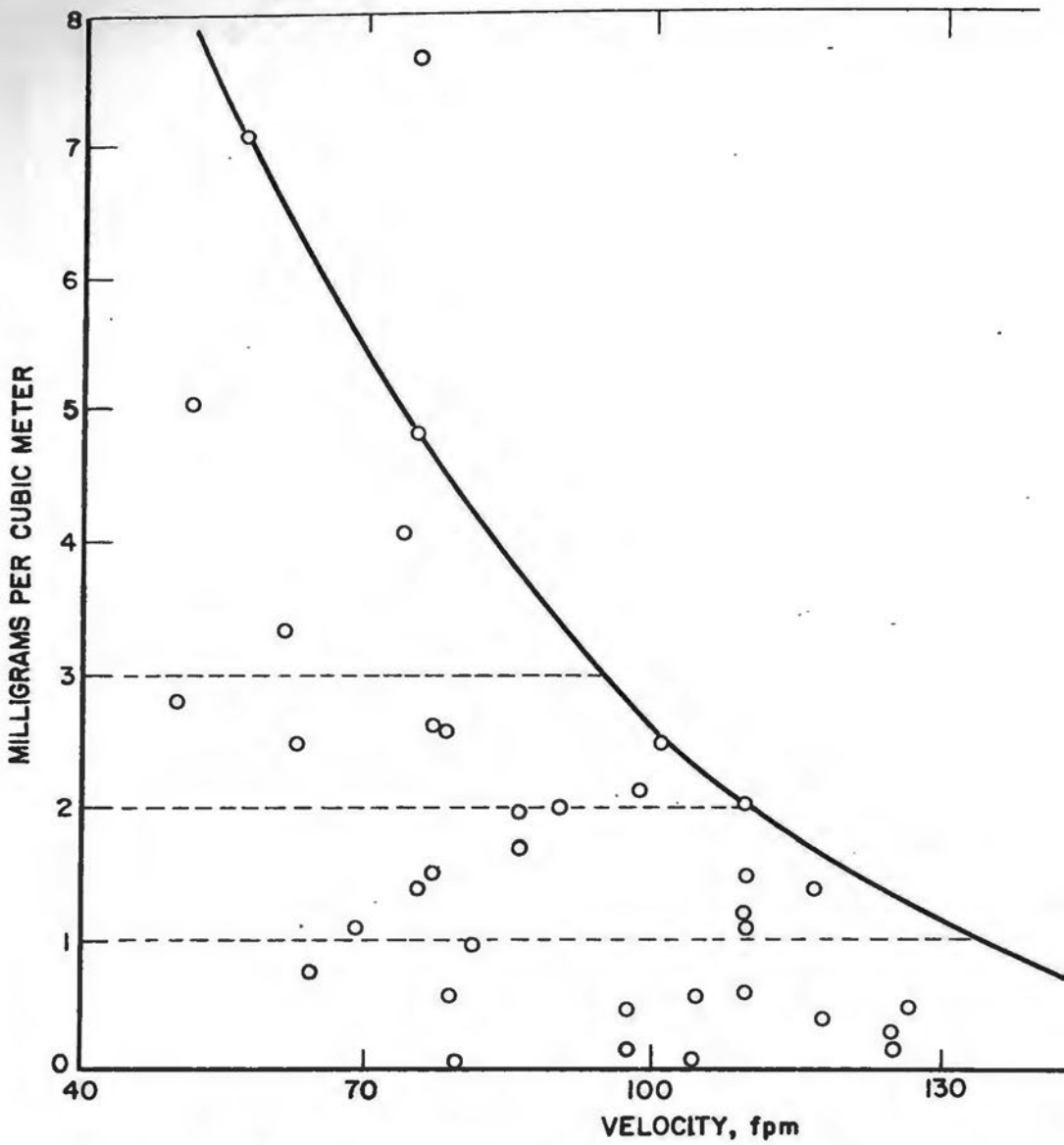


Figure 8.—Upper Limit Curve for Entry Velocity Vs. Face Dust Concentration.

The next speaker will be Dr. Hans Breuer, the Chief of Central Office for Dust and Silicosis Control, Steinkohlenbergbauverein, Essen, Federal Republic of Germany.

## WATER AS A CONTROL METHOD: THEORY & FOREIGN EXPERIENCE

by Dr.-Ing. H. Breuer

---

---

### INTRODUCTION

For many years, water has been used in mining to wet the coal and to bond sedimented dust in order to avoid the development and whirling up of respirable dust. This has been done, for example, by water infusion through short boreholes and by spraying water onto the coal during transport and onto the sedimented dust.

The increased concentration of workings (in Germany, longwall faces) during the past 10 years, aimed at daily outputs of and exceeding 3,000 tons, the increase of the daily advance to 8 m and more, and the use of novel machines for coal winning and road driving have enhanced the dust problem. Additional and improved methods of dust suppression are needed. This is true especially in the use of water, which can be easily taken to the dust sources. The question is how this water can be applied efficiently but in low quantities. The given methods of coal production, the sequence of operations, the water content in the coal to be conveyed and loaded, and the working conditions at the face must be considered. The intake air volume supplied to the faces has been increased significantly during recent years. This must also be considered because the higher air speed may lead to an increased whirling up of dust, which can, however, be prevented by a sufficient wetting of the coal.

This short description of the function of water in dust abatement shows the complexity and interrelationship of the detailed questions involved. The other methods of dust suppression and the assessment and sampling of airborne dust are equally complex subjects. These problems can be solved only by cooperation among the mines, the manufacturers of equipment, the mines inspectors, and the miners unions. About 10 years ago, the High Authority of the European Community for Coal and Steel drew up extensive research programs for dust measurement and dust abatement. Representatives of the British coal mining industry, too, took part in these programs. I am convinced that this Symposium on Respirable Coal Mine Dust will greatly intensify the contacts and the exchange of information with our colleagues in the United States.

### THEORY

Before I describe our investigations and the application of water for dust suppression, the following brief theoretical considerations will throw some light on the planning and implementation of tests and the assessment of their

results. In order to reduce the whirling up of dust from the coal under transport, the low adhesive forces of nearly dry dust particles must be increased substantially. The best effect can be expected when the voids between the individual particles are just about filled with water. The higher capillary forces then developed hold the particles firmly together. These forces, however, disappear when water content is too high. The surface tension of the water then present no longer suffices to bind the particles firmly. The consequence is a process of desegregation. Slurry is formed and, possibly, under high air velocity, as with pneumatic stowing, the dust-laden water can be atomized with the result that airborne dusts develop again. The water volume necessary to reach the optimum effect depends on the size distribution and type of dust, but also on the properties of the water. The effect of water application can be improved by means of wetting agents, in which the increase of the wetting speed plays an important part. Salt solutions ( $\text{NaCl}$ ,  $\text{CaCl}_2$ ,  $\text{MgCl}_2$ ) prevent too quick an evaporation of the water and increase, at the same time, the coagulation of the dust particles.

The capture efficiency of water droplets for the sedimentation of dust particles in the air current is essentially a function of the relative velocity between the water droplets and the dust particles and the relation of the diameter of the dust and water particles, as well as the attainable distance of the water droplets in the air current. For dust particles between 1 and 5 microns the droplet size should be about 0.05 to 0.3 mm. The capture efficiency, however, diminishes rapidly with the decreasing size of the dust particles and droplets. Fine water droplets in the size range of mists have hardly any effect on the sedimentation of dust. The coagulation of small particles hardly contributes to an increase of efficiency because the number of dust particles and water droplets is often too low and the time available is too short.

Because of the usually low relative speed between water droplets and dust particles and, consequently, the low degree of efficiency, the range of application of sprayers for this purpose is limited. Dust clouds with high concentration consisting mostly of fine rock dust must be sucked off and be collected in dust extractors. Energy must then be applied to --

1. Increase the relative speed between water droplets and dust particles (such as in a Venturi tube or in a compressed air jet with annular slot and water injection).
2. Increase the falling speed of the particles as done in centrifugal separators (for instance in the cyclonette, where the water collects the dust particles along the cylinder wall).
3. Increase the turbulence forces in a porous plastic filter material sprayed with water, where the water is used above all to clean the filter.

In all ranges of water application for dust suppression, the study of the flow behavior and the pressure loss of water in pipelines, hoses and machines with the frequent changes in diameter and flowing direction up to the sprayers

is a necessity in practice. The same is true also for the discharge of the mixture of dust and water in the dust extractor. According to experience, the data required, therefore, can usually not be taken from technical tables. The necessary data must be found by detailed tests carried out at the machines themselves.

## EXPERIENCE

### Face Infusion

The reduction of dust development by face infusion increases with more intensive and homogeneous distribution of the water in the coal. It has not been possible so far to find, beyond doubt, values of the porosity and permeability of the coal, specifically the moisture content of the coal, the quantity of water, and the development of pressure. Neither is the quantitative determination of the distribution of water in the coal quite secure yet.

Studies of coal samples in tablet form showed maximum water absorption from 1 to 15 percent (by weight). These water contents were attained, without additional pressure, after more than 20 minutes. For some samples, the water absorption had not been terminated even after 50 minutes. In most of these cases, the addition of wetting agents did not lead to any worthwhile improvement. Other studies of coal samples showed that the maximum water content of 5 to 6 percent (by weight) was reached only with pressures of more than 150 g/cm<sup>2</sup>. The capacity of coal to absorb water is by no means uniform; it is influenced by the manner in which the seams were formed and how they were subjected to later rock movements. In longwall faces, the zone -- influenced by working pressure -- of increased permeability exists parallel to the coal face. This zone, situated near to the face, is highly capable of absorbing water and contains a lot of dust because of the strong and different movements of the seam sections. Farther from the face, there is another zone with high additional pressure much above the normal load of the seam and, usually, with lower capability of absorbing water.

Face infusion (fig. 1), taking these conditions in the coal into account, is made from the gateroads, from the coal face, or from other working points outside the seam. For the water infusion from the gateroads, a small water volume is continuously infused into the coal at a low pressure. The permeability, in a certain direction, of seams in the face vicinity favors the infusion and continuous moistening of the working panel. This method of water infusion has many advantages. It is applied now in the majority of retreating faces, which are particularly suited for this process.

If this method of water infusion is not feasible for operational reasons, discontinuous infusion from the coal face must be adapted to the weekly advance. This second method, which is applied in advancing faces, is carried out when coal winning is not taking place. A high volume of water is pressed into the coal within a short time in order to wet it thoroughly, causing high infusion pressures and often breaking up the coal, which makes mining easier.

The method of water infusion through a borehole, for example, from a gateroad above the seam, is also fully developed. It can seldom be applied, however, because it requires undisturbed and homogeneous deposits. Such conditions are rarely found in the German coal mining industry today.

### Wetting of the Coal and Rock Dust

By water infusion, the water content of the coal is increased about 1 to 3 percent (by weight), while the dust concentration is reduced by 30 to 60 percent. In some cases, however, water infusion does not achieve the admissible dust concentration. This is true especially for coal winning by shearer loaders, where the cut coal is additionally dampened by sprayers arranged at the shearer loader. With these sprayers, part of the airborne dust is settled before entering the air current. In faces worked by coal plows and with a coal not susceptible to water infusion, a section of the coal face, depending on the position of the coal plow, is sprayed by hand or by automatic switching. The coal face and the coal worked down are sprayed and some of the airborne dust is sedimented. There are still the many simple water sprays as the coal is transported to the shaft that could be mentioned. These, however, are usually not really necessary if the coal is sufficiently right from the beginning.

The spraying of water to the cave goaf, formerly applied to a large extent, is scarcely employed today because the dust settled on the floor is usually wet enough due to the application of water during coal winning.

Much emphasis was laid during our studies on dust suppression during pneumatic stowing, and testing plant was put up for this purpose. The tests showed the predominant influence of compressed air consumption and the size distribution of the stowing material on the development of fine dust. Also in this case, the water content of the material, with a high percentage of fine rock dust, played an important part (fig. 2). The increase of the water content from 2 to 5 percent (by weight) in the size range  $< 10$  mm of the stowing material caused a considerable reduction of the fine dust concentration,  $k$ , in the air used for stowing. A further increase of the water content did not reduce the fine dust concentration much more. But slurries often formed, causing operating defects. In some tests, the dust concentration increased again because the air with high velocity atomized the dust-laden water in the pneumatic stowing pipe. The water content required for dust bonding depends on the type and size distribution of the material. The optimum value can neither be determined for individual types of material nor be followed up by measurements. Thus, we recommended the following simple rule: If dust is whirled up by several good blows on a hand sample of stowing material, water must be added. If no dust becomes airborne and if the hand remains nearly dry, the stowing material contains enough water. If the hand becomes wet, the water content is too high.

This rule should be applied also to assess the water content of coal under transport. We studied statistically the influence of the water content in coal from faces worked by coal plows or shearer loaders by means of the fine

concentration,  $c$ , measured by the BAT I<sup>1</sup> at the face ends. The curves in figure 2 for these types of coal winning show the same tendency as the one for pneumatic stowing. In the coal plow faces, the fine dust concentration,  $c$ , decreased sharply up to a water content of about 5 percent (by weight) of the coal <10 mm. In shearer-loader faces, the corresponding value is around 4 percent (by weight). The majority of the coal plow faces showed water content of the coal between 2.5 and 4 percent (by weight) and the shearer loader faces between 4.5 and 6.5 percent (by weight), a consequence of the additional water-spraying from the machine. More than 6 percent (by weight) may possibly cause trouble in the separating plants, especially when the dust is separated from the coal by air. Therefore, the aim should be to use as low a water quantity as possible. One means is to adjust water spraying to the respective separating process. Another is to shut down the water sprayers that are not necessary for further wetting of the coal on its way to the shaft.

In this connection, the question of improving the efficiency of water spraying and spraying by means of wetting agents or salt solutions is of interest. The relevant tests showed good results in several workings just recently, but there were also quite a number of unsuccessful trials. The reasons are still being studied.

#### Influence of Air Speed

When suppressing dust, attention must be paid, apart from the water content of the coal to the ventilation speed. Our investigation of dust development during pneumatic stowing showed that, even with the very high flow speeds in the stowing pipe, there was hardly any whirling up of dust, provided the coal was sufficiently wet at any given time. We tried to determine the influence of ventilation speed on the concentration of dust by several statistical studies of a large number of data collected from 1956 to 1968 under different operating conditions (fig. 3). The mean ventilation speed in the faces was calculated from the measured return air volume, assuming a free cross-section of the coal face of  $F = 5 \text{ m}^2$ . Because these measurements had been carried out with different sampling devices, the results of the individual series a to d had to be converted to a reference value with the relative dust concentration = 100. This was done for the air volume range between 100 and 600  $\text{m}^3/\text{min}$ . In the faces of the steep (a) and of the flat measures the fine dust concentration decreased sharply in 1956 with increasing air volume from 100 to 400  $\text{m}^3/\text{min}$ . At that time, dust suppression by water was applied only to a limited extent. The drop in concentration curves a and b is mostly due to the dilution of the dust cloud by a higher air volume. Because the ventilation speed was below the critical value of about 2 to 3  $\text{m}/\text{sec}$ , as determined in the laboratory with dry coal, the effect of the whirling up of dust was not yet noticeable. The more recent statistical studies in 1967 in coal faces worked by plows and shearer loaders (c) did not show the expected increase in dust concentration up to an air volume of 1.200  $\text{m}^3/\text{min}$ , corresponding to a ventilation speed of about 4  $\text{m}/\text{sec}$ . This is presumably due

---

ratio MRE to BAT I = 5.5 to 1; scatter of about 50 values, 4.0-7.0 to 1.

to the higher water content of the coal because of water infusion and water spraying. In one trial face operated by a shearer (d), where only the influence of the design and the mode of operation of the machine on dust development had been studied, the dust concentration increased markedly with higher air speeds, because the coal was almost dry. Such an increase has to be reconciled with the results of the previously mentioned laboratory tests. We intent to study soon, in a larger ventilation model, the influence of the ventilation speed on the whirling up of dust as a function of the water content of the coal and of other operating conditions.

#### Sedimentation of Dust Particles by Water Droplets

Today, water sprayers are less used to sediment the dust out of the air current. The sprayed water often has ill effects on the rock properties and working conditions. Besides, the water sprayers have been replaced by other and equivalent methods, such as dust-binding stemming for shotfiring by vials with water contents of at least 250 cm<sup>3</sup> per borehole. The efficiency of the water sprayers (manufactured by Messrs. Lechler, Stuttgart) with a diameter of 1 to 4 mm were studied in a tunnel with 7.5 m<sup>2</sup> cross section, for their effect at a water pressure of 10 to 40 kg/cm<sup>2</sup> on fine rock dust. The droplets filled completely this cross section. Of course, these optimum conditions can hardly ever be reached in practice. Figure 4 shows the most important factors on the efficiency of the sprayers: The specific water consumption in litres/m<sup>3</sup> air and the water pressure in kg/cm<sup>2</sup>. Under the optimum conditions in the tunnel, sedimentation of the fine dust, measured by a Tyndalloscope, of 50 percent could be reached with a water consumption of about 0.5 l/m<sup>3</sup> air and a water pressure of 10 kg/cm<sup>2</sup>, or with a water consumption of 0.35 l/m<sup>3</sup> air and a pressure of 20 kg/cm<sup>2</sup>. At a pressure of less than 10 kg/cm<sup>2</sup>, which is often found underground, the efficiency drops quickly. Accordingly, about 250 l of water per minute at a pressure of 10 kg/cm<sup>2</sup> would have to be sprayed in order to reduce the dust concentration by 50 percent in an air current of 500 m<sup>3</sup>/min. Thus, sprayers should be employed only selectively at points underground with a low air volume and a rather low dust concentration.

There was a special case in past years for the shearer loader and other coal cutters. With outside sprayers additionally fitted to these machines for water supply to the picks and with a water consumption of 20 to 40 l/min and a water pressure of at least 20 kg/cm<sup>2</sup>, fine dust concentration could be further reduced. Figure 5 shows how the efficiency of the sprayers depends on the size of the dust particles. All the dust particles > 10 microns were sedimented, but the capture efficiency of the water droplets decreased sharply for particles < 5 microns.

#### Wet-Type Dust Collector

According to our experience, ordinary water-spraying methods do not suffice in high dust concentrations, especially if these contain a lot of fine rock dust. In such cases, the dust must be sucked off in a collector. Wet-type dust collectors can be designed within the required small dimensions. They are

especially suitable for narrow conditions required for coal winning and heading machines. We tested several methods and found them to be more efficient compared with ordinary water sprayers (fig. 5).

According to their mode of operation, the wet-type dust collectors can be divided into three groups, each of which will now be described by a typical example. One of the wet-type dust collectors, called "Roto-Vent" and manufactured by Messrs. Hölter of Gladbeck, uses the very high speed of a compressed air jet enriched with water droplets for dust separation (fig. 6). The compressed air flows out of an annular ejector and then mixes in a tube with the sucked-up, dust-laden air. The high relative speed between water droplets and dust particles effects the dust separation. The depression produced by the jet is high enough to suck the dusty air and to collect the dust-laden water droplets in a centrifugal separator. The relation of compressed air to sucked air quantity is between 1 to 5 and 1 to 7, that is, 15 to 20 m<sup>3</sup> compressed air/min at a pressure of 4 kg/cm<sup>2</sup> are necessary to suck up 100 m<sup>3</sup>/min. The water consumption is 0.3 l/m<sup>3</sup> of air. Under these conditions an efficiency of up to 99 percent has been reached for rock dust 1 to 5 microns in size. Below 1 micron, however, the separation efficiency drops quickly, as with other wet dust collectors. This device can be built within small dimensions. However, it can be employed in the described way only where sufficient quantities of compressed air are available. If this is not the case, some of the air required for sucking or even the entire compressed air can be replaced by a fan with high-energy consumption. The device then works like a Venturi separator. The contaminated water can be cleaned in an additional aggregator. Subsequently, it can be supplied again to the dust collector or can be used to moisten the material to be conveyed. Discharge of the dust-water mixture into the main drainage system of the mine is not advisable.

Fig. 7 shows another type of wet dust collector, the so-called "cyclonette," manufactured by the Büttner-Werke AG in Krefeld-Uerdingen, with an air throughput of 150 m<sup>3</sup>/min. This device has all the components and structural parts necessary for dust collection under mining conditions. It can be disassembled into easily transportable pieces. The device is 1.1 m high, 0.9 m wide and, including the fan, 6.65 m long. The sucked air is separated on a plate with about 2,000 cyclonettes. Each cyclonette has a diameter of 10 mm and is 40 mm high. The air inlet speed is 50 m/sec, which corresponds to a pressure loss of 360 mm of water. Water is continuously sprayed on the cyclonette plate at a rate of 0.3 l/m<sup>3</sup> air. The water droplets are separated with the dust along the wall of the cyclonettes. The resulting muddy mixture drops into a collecting basin. Very fine droplets are caught in a drop separator. The separation efficiency is 100 percent for rock particles >2 microns; below the particle size of 1 micron, the efficiency diminishes rapidly. The water for dust extraction is circulated. Between 10 and 30 l/min are continuously taken from the collecting basin, and the same quantity of fresh water is always fed into the circuit. The dirty water can be utilized for spraying the coal or the debris from headings.

Another type of wet dust collector containing a Viledon-filter mat (type P 15/500, manufactured by Messrs. Freudenberg of Weinheim/Bergstrasse) is at present being developed to separate dust from a large air volume with a low or

coarse dust content. This mat is made of firmly bonded multidirectional fibrous fleeces. It is already used, however, in a dry condition or with water spraying, to clean the air in front of fans, heating installations etc. In the type developed for underground use, the filter mat is continuously sprayed with water on the air inlet side (fig. 8). The water binds the dust separated on the mat and cleans it at the same time. At certain intervals, the mat must also be washed from the rear side. The degree of efficiency for rock dust in the size range 1 to 5 microns is about 95 percent (fig. 5) at an air speed of about 1.5 m/sec and a pressure loss at the mat of 40 to 80 mm of water. This dust collector is still in the trial stage, in which especially the manner of cleaning the mat for different types and quantities of dust will be studied.

The dust collectors just described and shown in Figures 6 to 8 have different applications because of their difference in energy demand, degree of efficiency, and size for a given air volume. They must be designed as small and easily transportable as possible and should be adjusted to the different dust and operating conditions of coal winning and heading machines.

Section II

CONTROL TECHNOLOGY

Figures 1-8 to WATER AS A CONTROL METHOD: THEORY & FOREIGN EXPERIENCE

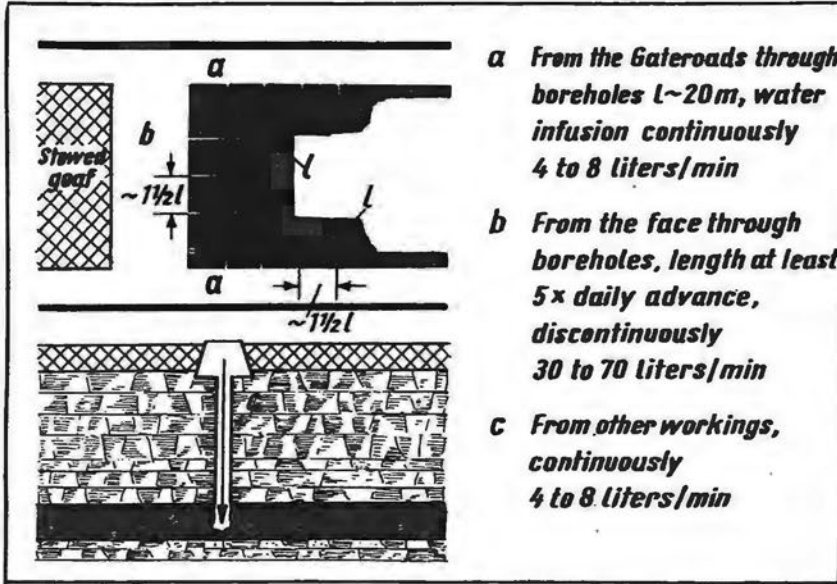


Figure 1.—New Methods of Face Infusion.

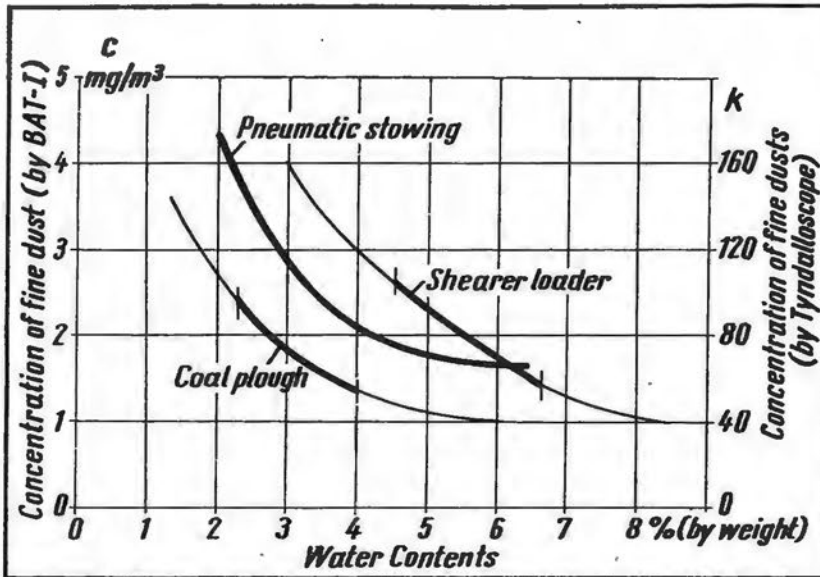


Figure 2.—Influence of Water Contents on the Concentration of Fine Dusts.

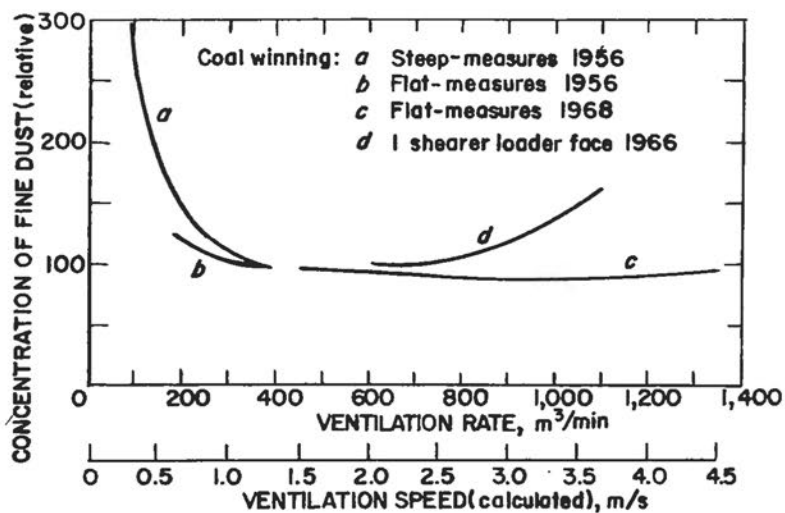


Figure 3.—Concentration of Fine Dust as a Function of Rate and Speed of Ventilation

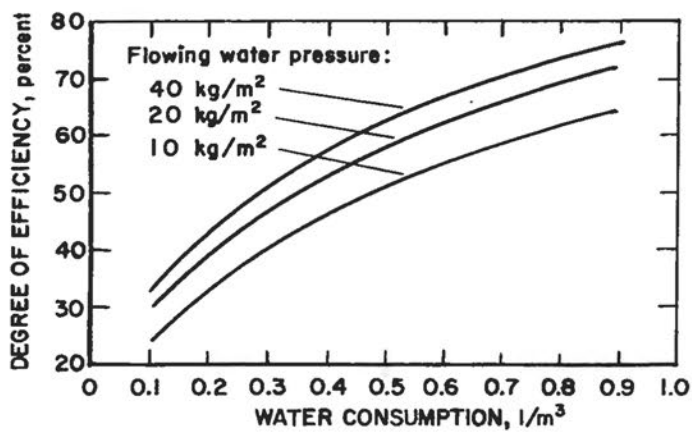


Figure 4.—Sedimentation of Fine Dust by Droplets.

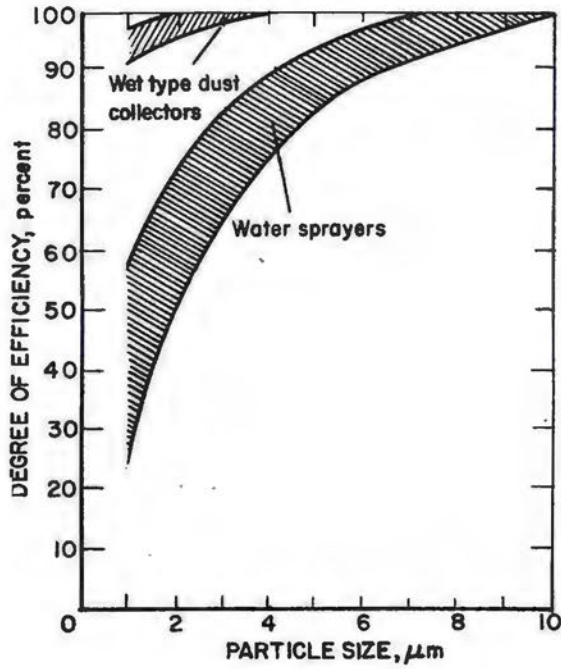


Figure 5.—Sedimentation of Dust by Wet-Type Collectors and Water Sprayers.

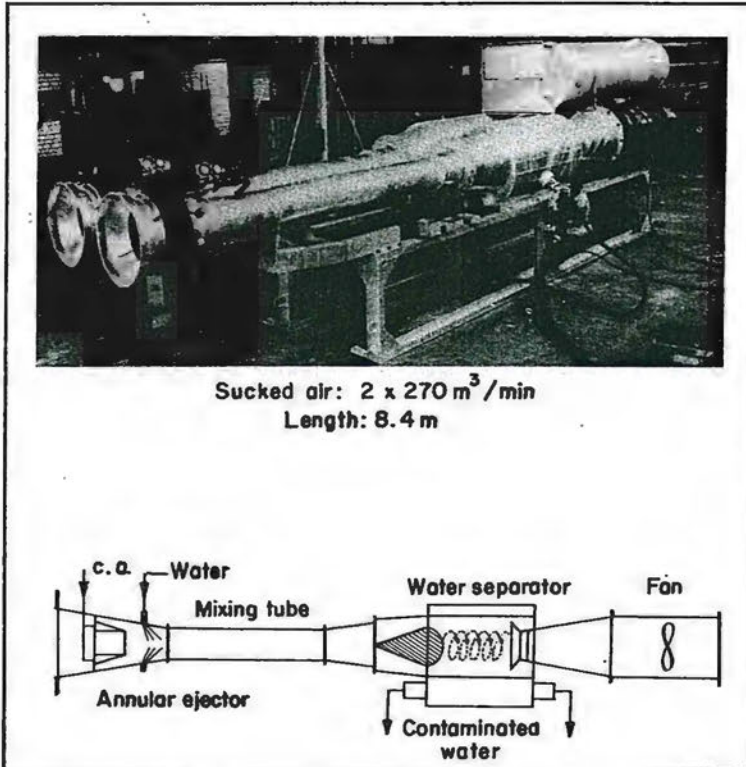
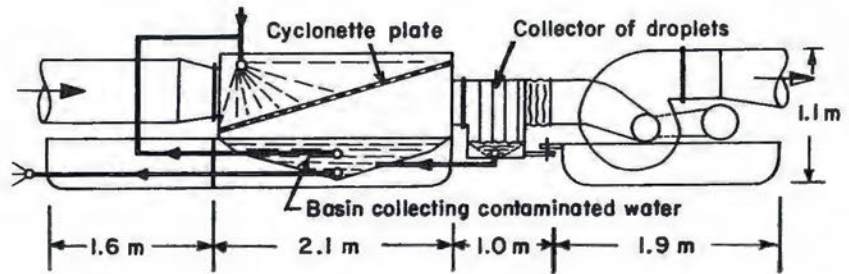
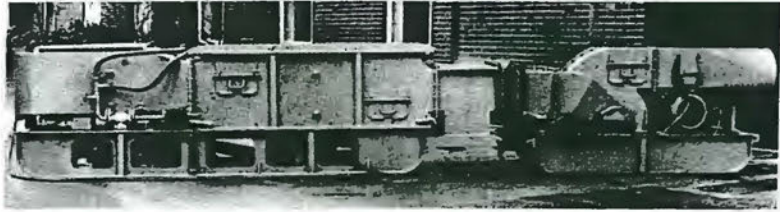
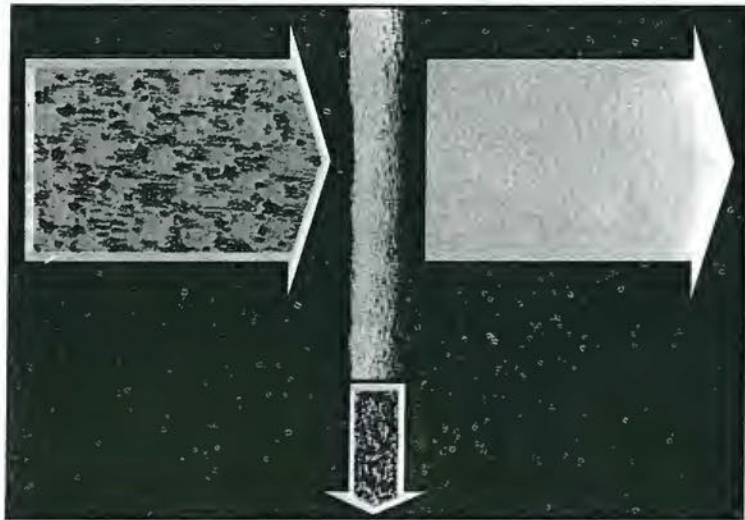


Figure 6.—Wet-type Dust Extraction by Annular Ejector.



**Figure 7.—Wet-Type Dust Collector, Type Cyclonette.**



**Figure 8.—Wet-Type Dust Collecting by Viledon-Filter Mat.**

DR. POTTER: Continuing on water as a control agent, Thomas Kobrick, Director of Safety and Environmental Health, Bethlehem Steel Company, will speak in respect to "State of the Art--Sprays and Wetting Agents".

## WATER AS A CONTROL METHOD STATE OF THE ART SPRAYS AND WETTING AGENTS

by  
Tom Kobrick

---

### INTRODUCTION

The use of water as a control method for suppressing airborne dust has long been recognized and used throughout the coal mining industry. Water, combined with face ventilation, is today the most common means employed for the control of airborne dust concentrations.

A study by the Bureau of Mines in 1939 (1)<sup>1</sup> reported dust reduction of up to 80 percent for wet cutting methods in conventional mining versus dry cutting. For more than 30 years the coal industry has been supplying water for dust control underground. Today in mines employing 15 or more employees 79 percent of the total production is mined with water piped to the equipment, over 98 percent of all continuous miners in operation employ water sprays, and the installation of sprays has become standard practice, built in by the manufacturers of continuous and conventional mining equipment. While the number and placement of sprays may vary, continuous miners will usually have 12 to 24 sprays, and generally use 10 to 20 gallons of water per minute. The use of built-in pumps has permitted operating pressures of 200 to 300 psi.

Nozzle configuration, volume, pressure, and placement variations have been studied to determine the most effective systems. However, even with larger volumes, higher pressure, and increased quantities of sprays, water by itself has not proven to be completely effective in reducing airborne respirable dust. The application of a spray system does indicate a very noticeable difference in a dust cloud, due primarily to its ability to "knock down" larger sized particles. Respirable dust, however, in the range of 1 to 10 microns tends to behave more like a gas than a dust and therefore is very difficult to capture. Most nozzles commonly in use produce a fine mist with a particle-size diameter of approximately 100 microns or larger. Increased pressures and atomization with compressed air can reduce this size, but water spray particle size of less than 20 microns is very difficult to attain. It necessitates small orifices which easily plug, and the distance which such a fine mist can be projected is limited, resulting in poor contact with the dust particles at their source of origin.

---

Underlined numbers in parenthesis refer to items in the list of references at the end of this report.

## USE OF WATER SPRAYS ON CONTINUOUS MINERS

Recent studies conducted by one operator (2) indicated that spray-nozzle water pressure in the range of 200 to 250 psi was most effective in allaying airborne dust and minimizing plugging of spray nozzles. It was found that by combination of spray-nozzle geometry and 250 psi water pressure a 59-percent reduction from baseline measurements in respirable airborne dust in the breathing zone of a continuous-miner operator was noted. These tests were made on a boring-type continuous miner.

Bureau of Mines (3) have indicated a need for use of a minimum of 2 to 3 gallons of water per ton of coal mined. Although some operators use more water than the 2 to 3 gallons per ton, the increased quantities appear to have little effect.

One of the problems associated with the use of large quantities of water is that too much water will make the bottom of the entries wet, thereby causing difficulties in tramping and maneuverability of equipment.

Tests were conducted at the Ellsworth Division of Bethlehem Mines Corp. to determine the effectiveness of additional sprays, pressures, and quantities in reducing airborne respirable dust. The Ellsworth Division is located 15 miles from Washington, Pa., operating in the Pittsburgh seam. The seam height is approximately 60 inches, with an additional 14 inches of draw slate removed for roof control. The room-and-pillar system is employed, using oscillating ripper-type continuous miners.

In an attempt to get the water sprays close to the origin of dust generation, three additional sprays were added to each of the two cutter casings as close to the cutters as possible. One spray was pointed toward each of four cutter wheels, and two sprays were pointed directly toward the face. Water pressure varied from 100 to 200 psi and the water flow rate ranged from 12 to 25 gpm. Dust measurements were made in the breathing zone of the continuous-miner operator using midget impingers and subsequently analyzed by standard light field microscopy dust-counting procedures. Additional tests were made to evaluate the use of flat sprays instead of full cone sprays. Test results indicated that the flat-type sprays proved to be no more effective than the full cone sprays normally used. In addition, increasing the quantity of water from 12 to 25 gpm had no apparent effect on airborne dust concentrations. Increasing the water flow rates of the rib, hopper, and conveyor sprays by an additional 5 gpm resulted in a wet bottom which hampered the tramping of the machine. Conversely, it was determined that it was possible to increase the water which was sprayed at the face up to 25 gpm without causing any tramping difficulties. The additional sprays mounted on the cutter casing proved to be no more effective in reducing the respirable-sized dust than the normal spray system. The results of this test work indicated that greater volume of water could be applied, as long as it was sprayed directly on the face, than had been previously experienced at this mine. Dust measurements indicated that the attempt was unsuccessful, in addition the cutter wheels could be observed cutting dry even though as much as 25 gpm were applied to the face.

## WATER APPLIED DIRECTLY ON CUTTER BITS

The water spray system normally used on mining equipment attempts to wet the dust particles after they have become airborne.

In attempts to prevent dust from becoming airborne, thereby reducing the need for making contact with the dust after it has already been placed into suspension, the Mining Research Establishment (MRE) of the National Coal Board Great Britain, has experimented with flushing the cutter picks of a shearer on a longwall miner. Results of this study (4) have been reported by representatives of MRE.

Initial experiments consisted of a 4 1/2-inch-diameter disk. For each of the 12 pick positions three water outlets were provided; just ahead of the pick, 1 inch ahead, and 2 inches ahead.

It was found that in all three positions there was some reduction in both respirable and gross airborne dust concentrations. When the jets were far from the picks, respirable dust was affected much less than the larger sized particles. When the water was directed from the jets to be in contact with the cutting faces of the picks, dust suppression greatly improved, including both the total suspended and respirable dust. Table 1 lists the results of tests with the experimental disk.

Table 1.--Experimental disk, dust suppression efficiency, percent

Water-jet position	Water, 2.5 gal/hr		Water, 5.0 gal/hr	
	Respirable dust	Gross airborne dust	Respirable dust	Gross airborne dust
1/2 inches ahead of picks.....	21	60	31	85
3/8 inch ahead of picks.....	24	60	42	85
Flushing on pick points.....	68	80	88	94
Flushing pick faces.....	81	86	88	94

The experimental work proved to be so promising that a full-sized disk with two picks was constructed with water flushing the picks. Results of this study proved it to be as effective as the small disk. Interestingly it was also learned that when a wetting agent was applied a somewhat improved efficiency was noted in respirable dust suppression, but only on the high-rank coal, which is reported to be similar in nature to the low-volatile coals in the United States. The results of the laboratory tests indicated that water flow to each pick ranging from 1/2 gpm for high-rank coal to 1/12 gpm for low-rank coal would be appropriate.

## RESULTS ON A FULL-SIZED SHEARER

Laboratory results of this project prompted the design of a full-scale shearer with water flushing the picks. A Mark II ripping machine with three rotating drums and 120 cutter picks was adapted so that each cutter pick had a water jet flushing it. Using 11 gpm of water, a 63-percent reduction of respirable dust was noted, as compared to dry cutting.

A second series of tests were conducted on an Anderton shearer drum. Here 15 gpm of water were applied through jets to 34 cutter picks. An average reduction of 64 percent in respirable dust was noted compared with dry cutting, whereas the conventional dust suppression sprays at the same water flow rate gave a reduction of 24 percent in respirable dust dispersion compared with dry cutting.

## FLUSHING CUTTER BITS IN THE UNITED STATES

Results of the MRE test program were promising enough to encourage adaptation of the bit-flushing approach in the United States on continuous miners. Experimental field tests (2) of a boring-type continuous miner equipped with water sprays between bit blocks on the boring arms to improve wetting the coal before cutting, revealed a reduction of 78 percent in the respirable dust from baseline measurements.

Efforts were also made to adapt this same principle to an oscillating ripper-type continuous miner. Lee Norse Co., in cooperation with several coal operators, began development of such a spray system and incorporated the design as standard equipment on at least one of its models, which consisted of four cutter wheels, each with 12 cutter bits. This design incorporated 48 sprays mounted in the cutter wheels between the bit blocks, each spraying at one bit.

## USE OF CUTTER-WHEEL SPRAYS AT BETHLEHEM MINES CORP.

Reported results of the partial success in Great Britain on the longwall shearer drums and in the United States on both boring-type and oscillating ripper-type continuous miners prompted Bethlehem Mines Corp. to evaluate the effectiveness of sprays mounted on the cutter wheels of a continuous miner.

A Lee Norse 38H continuous miner cutter at the Ellsworth Division of Bethlehem Mines Corp. was modified to permit piping water to the cutter wheels. Since the "kidney plate" water distribution system which allowed water to be discharged in a 180° arc toward the face had proven to be a maintenance problem, it was felt that the distribution system needed to be modified. It was therefore decided that it would be more practical to have a water distribution system which would be discharged 360° through the cutter wheels. This eliminated the need for a somewhat complicated sealing arrangement, requiring only seals around the cutter wheel drive shaft.

The bit block design of this machine consisted of 28 bits on each of our cutter wheels, plus 12 bits on each of two end cutters. Initially, seven sprays were installed on each cutter wheel, except the end cutters, which because of their construction did not permit installation of sprays on the wheels. Thus, there was one spray for every four bit blocks, excluding the end cutters. The sprays which were mounted in the wheels were the normal type used, and various orifices were tried. With 28 sprays mounted in the cutter wheels 8 gpm of water were piped through the cutter wheels in addition to 10 gpm used on the normal spray system. The system was designed to allow either both the cutter wheel sprays and the normal spray system to be operated.

Employing a blowing brattice system, respirable dust samples were collected in the breathing zone of the miner operator, using midget impingers. Samples were collected only while the miner was cutting and loading. In an attempt to reduce variables such as ventilation, physical position, cutting rate, and strata, a series of alternate samples over several shifts were collected, and only matched sets of samples were used for analysis.

With seven sprays in each cutter wheel, a comparison was made of the normal spray system to the normal spray system plus the cutter wheel sprays. Results of the tests indicated that the addition of the cutter wheel sprays reduced the respirable dust concentration by 11 percent. While the results were much less than had been hoped, even a slight reduction indicated that further development was worthwhile, especially since past tests with increased water quantities added as additional sprays showed no increase in dust suppression efficiency.

Further modifications were made to the cutter wheel assembly, and the number of sprays in each cutter wheel was increased to 14. Because it was thought that 14 sprays in each wheel, if used in conjunction with the normal sprays, would result in too much water, causing tramping difficulties, it was decided to compare the cutter wheel sprays alone to the normal sprays.

With 14 sprays in each wheel, 19 gpm of water were sprayed through the cutter wheels alone. Tests were conducted over more than a 1-month period. The average of more than 120 dust measurements made comparing the cutter wheel sprays alone to the normal spray system indicated a 30-percent reduction in airborne respirable dust.

Needless to say, the operation of the cutter wheel sprays, even with a simplified seal system, created maintenance problems. On several occasions, especially with higher water pressures, the seals failed and water entered the gear case assembly. This required complete disassembly of the gear case and installation of new seals which was a rather lengthy process. However, the last seals which were installed on the unit lasted approximately 4 months before failing. Surprisingly the sprays did not plug as easily as expected and proved to be no more difficult to maintain than the regular sprays. This was probably due to maintaining the water pressure near 200 psi.

These results are believed to be quite similar to those of MRE with the earer drum. While MRE reported a reduction of 64 percent in respirable dust,

this was compared to dry cutting, while their normal spray system showed a 24-percent reduction compared to dry cutting, or a difference between bit flushing and regular sprays of 40 percent, which is not too much different from the 30 percent reported by the Bethlehem Mines Corp.

Such results were encouraging enough to warrant further development, and it was decided to proceed with placing a water spray at each bit block. Again, the cutter wheel was redesigned, and this time instead of mounting the sprays in the outer periphery of the cutter wheels a spray was mounted in each of the 28 bit blocks on the four wheels. This resulted in 112 sprays mounted in the bit blocks. The sprays were sized so that at 100 psi, 35 gpm would be discharged through the wheels.

To reduce the possibility of weakening the bit blocks small-sized sprays were installed. Inasmuch as the small sprays did not have screens large enough to remove much entrained solids, they plugged almost immediately, even though a water filter was used.

Consequently the plugging problem prohibited successful operation of the bit block sprays, and they could not be kept operational long enough to obtain any satisfactory results. Further work on this project may require a redesign of the blocks to accommodate a larger spray. It is felt that results have been promising enough on this approach, based on the work performed both in Great Britain and the United States, that further development should continue. Even though it may not be the total answer to the problem it is certainly the best approach, since it prevents the dust from becoming airborne, rather than trying to handle it after it has been placed in suspension. It also reduces the float-dust handling problems.

#### HIGH-EXPANSION FOAM FOR DUST CONTROL

Attempts have been made to control airborne respirable dust with high-expansion detergent foam. The British have experimented with foam for control of dust from rock drilling, cutting, and shearing. Most of the experiments have been abandoned because of the high cost of foaming agents, lack of foam generators, and inability to obtain the proper consistency.

Early research on the experimental application of foam for dust control (5, 6) in the United States was conducted with a volumetric ratio of 22 to 1. Preliminary tests were conducted spraying the foam through a single hose at the coal face which was being cut by an oscillating ripper-type machine. The goal of the tests was to build up a blanket of foam behind the cutter wheels of the mining machine in an effort to prevent the dust from becoming airborne. These first tests were successful enough that further development was considered.

A modified foam-generating machine was designed to produce an expansion ratio of 50 to 1. Again, an oscillating ripper-type continuous miner was selected for testing. Foam was directed to the top and bottom of the ripper head. Visual evaluation determined that the use of foam produced a much cleaner

environment in the face area. Attempts to fill the face area with foam were unsuccessful, inasmuch as the foam was very wet, resulting in water in the working areas. Foam accumulation also presented a problem in addition to finding a suitable delivery system for discharging foam to the face.

The Bureau of Mines continued its research and development of a suitable foam-generating system. The goal of this initial project was to develop a system which would include a short-lived foam (1/2 to 1 minute duration) of small bubbles, which should be unaffected by water hardness and not introduce coal-cleaning problems. The foam nozzle was designed to be mountable on a mining machine and to generate foam at a working pressure of 100 psi, or higher if necessary. Many modifications were made to the nozzles in development stages during seven field tests conducted by Bureau personnel in cooperation with several operating companies. The initial expansion ratio of 15 to 1 was increased to 300 to 1 in the final version of the nozzles.

Reports of the field testing of the foam nozzles indicated that the application of foam showed promise as an effective means of controlling airborne dust. Tests were conducted at the Cambria Division of Bethlehem Mines Corp. on a boring-type continuous miner using the foam system developed by the Bureau. These tests were made by representatives of the Bureau and Bethlehem Mines personnel. The Cambria Division is located in Cambria County, Pa. The mine at which the tests were conducted is mining in the Lower Kittanning seam, approximately 42 inches in height, employing both boring-type and oscillating ripper-type continuous miners.

The system used for generating foam, which was designed by the Bureau, consists of foam-generating nozzles mounted in a header and an arrangement for supplying them with a 1 1/2-percent solution of foaming agent and water at a pressure of 180 psi. The foaming agent is a synthetic detergent and is fed into the water supply line from a tank pressurized with nitrogen.

The foam generator is an assembly of a full-cone spray nozzle mounted in a 2 1/2-inch-diameter tube 10 inches long. A venturi throat and cone-shaped 20-mesh screen are contained within the tube. Foam is generated by water pressure and the venturi throat which induces air into the tube passing across the wire mesh, resulting in a discharge of foam bubbles. At a water pressure of 180 psi, the nozzle generates foam at a rate of 300 gpm, with a foam-water solution rate of 1 gpm. The foam is discharged in a straight line with a trajectory of 4 to 6 feet from the discharge point of the generator.

Ten foam nozzles were mounted in a header laid across the gearcase directly behind the rotating cutters. Because of very limited clearance between the roof and the top of the gearcase, it was very difficult to maintain the nozzles in operation. Limited sampling data were obtained, indicating a reduction in respirable dust by as much as 50 percent. However, it is felt that the data obtained were not sufficient to make an accurate determination of the effects of the foam. There was a noticeable visible improvement when using the foam as compared to the water sprays normally in operation. Because of the space limitations, it was decided that no further tests should be conducted on this boring-type miner.

A second series of tests were conducted on an oscillating ripper-type continuous miner operating in the Pittsburgh seam at the Ellsworth Division of Bethlehem Mines Corp. Ten foam-generating nozzles were assembled in a header and placed across the end of the head boom, aimed at the rotating cutters. With these nozzles in operation approximately 3,000 gpm of foam was produced. Comparison dust measurements were made with the foam and the regular water spray system consisting of 18 nozzles at 290 psi and 11 gpm. The purpose of the tests was to fill the entire section being cut with foam in hopes of capturing the dust as it was generated by the cutters.

Comparison of the use of the foam to the normal spray system indicated a 15-percent reduction in airborne respirable dust with foam. The foam appeared to be most effective while sumping in the coal. However, once the coal was cut and the miner began to cut down the draw slate, the foam did not fill up all the open areas, the dust concentrations increased. Due to the height of the coal and draw slate it did not appear to be a practical application. There were no problems with foam accumulation on the bottom, since the foam was readily mixed with coal.

A subsequent series of foam tests was scheduled at Beth-Elkhorn Corp. in eastern Kentucky. The tests were conducted again on an oscillating ripper-type miner operating in the No. 2 Elkhorn seam.

Tests were conducted initially with 14 generating nozzles and a flow rate of 4,000 gpm of foam. The results were quite poor and were no more effective than the water sprays normally in use. Fourteen additional nozzles were then made available and additional trials were made with 28 nozzles laid across the top of the machine. With 28 nozzles operating, more than 8,000 gpm of foam was discharged to the face. Dust concentration measurements were again made and the test results indicated a 30-percent reduction in airborne respirable dust in comparison to the normal spray system.

#### FUTURE WORK WITH FOAM

An investigation is currently in progress to evaluate other means for generating the foam. While it is possible to generate higher expansion ratios, adequate delivery systems have not yet been developed which will get the foam to the face to cover the entire face area. It was found that in order to be effective, all voids must be enclosed, or dust will come through into the atmosphere. It is believed that there is enough turbulence and mixing of the foam with the coal that the foam would not prohibit the release of methane, although this may be a problem in extremely gassy faces.

Even though a 30-percent reduction is promising, it is far from satisfactory. It will be necessary to try many configurations and locations of nozzles to more adequately improve the performance. Future underground studies will be conducted. In addition it has been found that a 1/2-percent solution may be as effective as 1 1/2-percent, thereby influencing the cost factor. With 28 nozzles at a 1/2-percent solution, assuming a cost of \$1.50 per gallon and a mining rate of 5 tons per minute, the cost would be 4 cents per ton.

The present delivery system is far from being workable, since plugging and protection from roof and coal damage are serious problems. It will be necessary to further improve upon the reduction of dust concentrations, in addition to designing a system which is compatible with the mining sequence. It is felt that further studies are in order to more accurately determine the potential application of foam for the control of airborne respirable dust.

The major question to be answered is whether the foam, if delivered in sufficient quantities, can adequately reduce the airborne dust concentrations. If this problem is overcome, then the remaining problems would be less difficult to solve.

#### USE OF WATER IN CONVENTIONAL MINING

The application of water at the point of dust origin has also been incorporated into conventional mining systems (7). One operator recently reported on the development of coal drills which are provided with water jackets. The jackets are installed at the drive end of the hollow steel auger, and water is delivered from the spray system to the water jacket by means of a 1-inch rubber hose. Water passes through the auger and discharges in the hole near the drill bit where the dust is created. A wet slurry is formed in the hole being drilled and is flushed out by the action of the rotating auger and the water. The slurry and water fall on top of the coal cuttings which were made by the cutting machine and add moisture to this material. Also the hole is automatically washed out and free of any dry dust.

In addition water is also added to cutting machines at the rear of the cutting bar. Some operators place the water spray at the front end of the cutter, piped through the cutter bar, which is reportedly more effective during a shear cut than to have it discharge at the rear of the cutter bar.

Many loading machines are also equipped with water sprays, as are other locations such as belt transfer points.

#### WETTING AGENTS

The use of wetting agents for control of dust has been a rather controversial issue. The consensus today is that the use of a wetting agent will make a noticeable difference in the larger sized dusts but does very little for suppression of the respirable dust, although some reductions have been noted (8) on coals which are hard to wet.

Wetting agents and water applied along a belt line can reduce the total quantity of water necessary since there is sufficient time available for surface contact between the wetted solution and coal. However, once the coal dust has been placed in suspension the effects of wetting agents on lowering the dust concentrations are questionable. While there has been little published statistical data most investigators have concluded that wetting agents do little to suppress airborne respirable dust.

## FUTURE WORK

While much has been done in the development of water spray systems, there is nevertheless a need for future development. One such project is the continued development of flushing cutter bits. It will be necessary to make many revisions to those currently available, and studies of flushing cutter bits should include an evaluation of their effect upon dust concentrations by measuring the respirable dust content in the breathing zone of personnel. Visible observations do give an indication of reductions, but it is necessary to make very careful measurements of the dust concentrations, and in so doing to reduce all variables which can cloud the results.

Further development of the use of high-expansion foam appears to be a worthwhile project, and its evaluation should include all factors to ensure a compatible and workable system.

Future development of water applications will need to include water as a scrubbing medium, encompassed as a packaged part of mining equipment. Application of any scrubber system must be compatible with the ventilation for the dilution and removal of gas, since the dust problem cannot be solved at the expense of methane gas liberation control.

## REFERENCES

1. Harrington, P., J. J. Forbes, F. E. Cash, E. H. Denny, C. A. Herbert, D. J. Parker, C. W. Owings, and A. U. M. Miller. Allaying Dust in Bituminous Coal Mines with Water. BuMines/Tech. Paper 593, 1939, 55 pp.
2. Godard, R. R. Dust Abatement Activities Within United States Steel Corporation's Coal Operation. Min. Cong. J., v. 54, No. 4, April 1968.
3. Anderson, Floyd, G., R. L. Evans, and R. G. Peluso. A Study of Dust-Control Methods for Continuous Mining of Coal. BuMines/Inf. Circ. 8205, 1963, 14 pp.
4. Hamilton, R. J., M. L. Levin, and K. W. McKinley. Research into the Formation and Suppression of Dust at Fast Moving Cutter Picks. Min. Engineer, June 1962, Paper No. 3921, pp. 590-600.
5. Von Stroh, Gerald. Research and Development on Dust Suppression by Foam at Working Faces. Nat. Safety Cong., 1958.
6. Alston, G. L. Preliminary Tests and Future Plans for Using Foam to Suppress Dust in Bituminous Coal Mines, National Safety Congress, 1958.
7. Parisi, C. W. Dust Abatement at Pittsburgh Coal Company, Min. Cong. J., v. 54, No. 4, April 1968.
8. National Coal Board Mining Research Establishment. Isleworth, Middlesex, England, MRE Bull. No. 6, October 1964.

DR. POTTER: The next paper will be presented by Maurice Deul, who is search Manager, Bureau of Mines, in Pittsburgh, Pa. His paper is entitled, "Water Infusion--Room and Pillar Operations".

## PARAMETERS TO BE CONSIDERED IN WATER INFUSING FOR DUST CONTROL

by

Maurice Deul

---

### ABSTRACT

The fracture permeability of coal is the single most important factor in establishing the effectiveness of water infusion. High rates of waterflow into coalbeds indicate that large fractures exist in the coal. Low flow rates at high infusion pressures indicate a low-permeability coal.

Experience with water infusion into solid coal through long holes sealed near the deep end of the hole indicates that such coal has a low permeability to water, on the order of tens of millidarcys. Very high pressure pumps are required to move a mass of water several hundred feet through a coalbed, and flow rates are usually limited to less than 10 gpm. Consequently a five-entry face area 500 feet wide may require infusion at high pressures for as long as 3 or 4 days.

Even if coal is "totally" infused along the major fracture openings, the effectiveness of water infusion in controlling respirable dust when using continuous miners is questionable, because the newly fractured surfaces formed by rapidly moving cutting bits provide the major proportion of respirable dust.

If disappointing results are to be avoided in full-scale operations, it is recommended that the pertinent physical properties of the coal be established first.

### INTRODUCTION

The infusion of coal with water under pressure as a means of reducing the dust produced during coal extraction is common practice in Europe where long-wall mining is the established method (3,2).<sup>1</sup> In the United States there are only a few reported instances of water infusion as a dust-control technique. Experiments have been conducted in water infusion to control methane emissions

---

<sup>1</sup> Underlined numbers in parentheses refer to items in the list of references at the end of this report.

at active face areas in coal mines with some success. But attempts to develop the infusion technique so that it can be applied on a predictable basis for methane and dust control have so far shown only limited success and have mainly underscored problem areas for intensive investigation.

The direct translation of European practice to United States coal mines is not possible. The reasons for this are not obvious until the different physical characteristics of the coalbeds and the differences in mining methods are considered.

#### FLUID FLOW THROUGH COALBEDS

The principal factors which control fluid flow through coal can be defined and measured. Darcy's law relates the volume flow rate ( $q$ ) of a fluid through a known cross-sectional area ( $A$ ) of coal per unit length ( $l$ ) to the permeability of the coal ( $k$ ), the driving pressure ( $P$ ), and the fluid viscosity ( $\mu$ ). Here is the general equation which states Darcy's law:

$$q = \frac{kA}{\mu} \frac{dP}{dl}$$

Assuming a uniform cross section and length and the permeability to be constant for a given coalbed at one place, the equation can be integrated to yield:

$$q \approx \frac{P}{\mu} \quad (\text{for liquids})$$

and for compressible gases converts to

$$q \approx \frac{P^2}{\mu} \quad (\text{for gases})$$

Here the volume flow rate of fluids moving through coal is shown to be directly proportional to the driving pressure (or the square of the driving pressure) and inversely proportional to the viscosity of the fluid.

Our experience until only recently has been limited to measuring the flow of methane through coalbeds and measuring the permeability of coal with respect to gases like methane at relatively low pressures; that is, less than 1,000 psi (1).

The relative ease of flow of methane through American coalbeds can be explained by a permeability of coalbeds of the order of 10 to 100 millidarcys. Horizontal bleeder holes, 2 inches in diameter, drilled into coalbeds several hundred feet long, have produced about 10,000 cubic feet of gas per day at a driving pressure of about 250 psi. Vertical boreholes, 4 inches in diameter, drilled through a coalbed about 4-1/2 feet thick have produced about the same

yield of gas per day, 10,000 cubic feet, at a bed pressure suspected to be of the order of 600 psi. What is important about these generalized data is that the coalbed, in which a 565-pound pressure has been measured from horizontal boreholes, contains water which, under the same driving pressure, blocked the flow of gas into the vertical borehole and flowed into the vertical borehole at a rate of about 1.3 gallons per hour, 31 gallons per day, equivalent to about 4 cubic feet per day. This same rate was measured many times for more than 1 year.

This will now provide some insight to what can be expected from infusion of coal by water under pressure. Infusion through deep holes, of the order of 200 feet in length, and from near the end of the hole can be accomplished in coals with a permeability of about 20 millidarcys only at very high pressures and very low flow rates. Under such conditions, at 3,000 psi, the coal will accept water at a rate of only about 12 gallons per minute, and several days may be required to adequately infuse coal ahead of a four- or five-entry face area. Water infusion on this scale has not yet been accomplished in the United States. British and European experience with infusion holes longer than about 60 feet is rare.

#### BENEFITS OF INFUSION

Now that we appreciate that coal cannot be readily infused by water we must consider what the benefits of infusion may be. This will depend entirely upon the physical characteristics of the coal to be infused, upon the gas reservoir pressures of the coalbed, and upon the possible effects of preconditioning the infusion water with surfactants.

Blocky coals with widely spaced cleats (joint planes) will not be much affected by water, with or without a wetting agent, because the action of coal-cutting assemblies of continuous mining machines is so vigorous that such blocks are broken with nearly explosive force and the new surfaces exposed are not wetted. This action was crudely simulated and is illustrated in figures 1 to 4. Even a close-cleated relatively friable coal is not adequately wetted.

Surfactants do offer some prospect for improving dust control by water infusion, but this is still only empirical because the mathematical analysis of the effects of polymeric additives to water has not yet been satisfactorily accomplished. In figures 5 to 12, inclusive, comparisons are made between the effects of putting a 10-microliter drop of water, with and without additives, on polished and naturally fractured surfaces of Pittsburgh-bed and Pocahontas No. 3 coals.

It must be understood that coals so wetted will still produce dust when broken. This is crudely shown in figures 13 to 15, where a collimated beam of light is directed across a 12-inch span sidelighting coal-dust particles in suspension. These dust clouds were formed from striking single pieces of coal (figs. 2 and 4).

## CONSTRAINING FACTORS

Even though there may be substantial improvements in the techniques of water infusion of coal, there are some significant constraints to the use of water infusion as a dust control method.

## A. Physical characteristics of the coal.

1. Fracture density.
2. Dust in the fractures formed as a result of earth movements.
3. Wettability of the coal.
4. Permeability of the coalbed.
5. Distribution and occurrence of large fractures.

## B. Properties of the infusion water.

1. Viscosity with and without additives.
2. Surface tension with and without additives.
3. Effect of soluble salts present in the coalbed.

## C. Geological environment of the coalbed.

1. Clay content of roof and floor rock.
2. Presence of "clay" veins, dikes, and vertical displacements in the coalbed.

## D. Availability of adequate equipment.

1. High-pressure pumps, compact and low capacity.
2. Reliable seals for water infusion holes.
3. Capability for drilling deep holes into the coalbed.

## E. Effects of methane and other gases in coal.

1. Resistance offered to water penetration by gas in the coal.
2. Maintenance of effective controls for methane forced out of the fracture system.

## CONCLUSIONS

Consideration of the restraining factors mentioned in this brief report indicates that water infusion can be effective if the fracture permeability of

the coal allows the infused water to be thoroughly distributed throughout the coalbed in advance of the face area. The distribution of the infused water is dependent upon cleat spacing, wettability of the coal, proper selection of surfactants, resistance to water penetration by gas in the coal, and availability of adequate infusion equipment.

Infusion may be ineffective and even dangerous if the geological environment of the coalbed is not fully known, especially with respect to barriers to water infusion such as the presence of impermeable clay veins, rock barriers, or fault dislocations. Clay in the floor and roof, when wetted, may cause serious ground control problems. And finally, methane control problems may result when gassy coalbeds are indiscriminately infused.

Ultimately, controlled experiments on full-scale operations in active coal mines will be needed to demonstrate the effectiveness of water infusion as a dust-control technique.

#### REFERENCES

1. Cervik, Joseph. An Investigation of the Behavior and Control of Methane Gas. Min. Cong. J., v. 53, July 1967, pp. 52-57.
2. Gregson, H. Deep Hole Infusion in the Kent Coalfield. Coll. Guard., May 13, 1966, pp. 599-604.
3. Rowland, G. D. E., and H. M. Thomas. Deep Hole Infusion Trials in the Southwestern Division. The Mining Engineer, July 1963, pp. 739-760.

**QUESTION:** Has the permeability of coal beds been adequately defined, and are there any data available on this? How high should the permeability be to allow adequate infusion?

**MR. DEUL:** To the best of my knowledge, there are no data--no satisfactory data--on the permeability of coal beds in the United States. We now are developing some data. In the first place, large cores must be collected and tested. This, however, is not really as satisfactory as doing the tests in situ because of pressure problems. One should drill a hole parallel to the coal bed, pack it off properly, infuse the hole with a fluid, measure the flow rate out of the other hole, and thereby determine precisely what the local permeability is.

We have already made some tests and these tests are what I base my figures on. A coal bed with a permeability of 10, 20, 30 millidarcys can be infused, provided that you have patience. These permeabilities are the kind that are encountered in water flooding of gas and oil producing horizons. If 100 millidarcys is coal beds' permeability, it may be possible to infuse these at very high pressures in a relatively short length of time, depending upon the area that you want to infuse from one hole. So, you are getting into geometry problems.



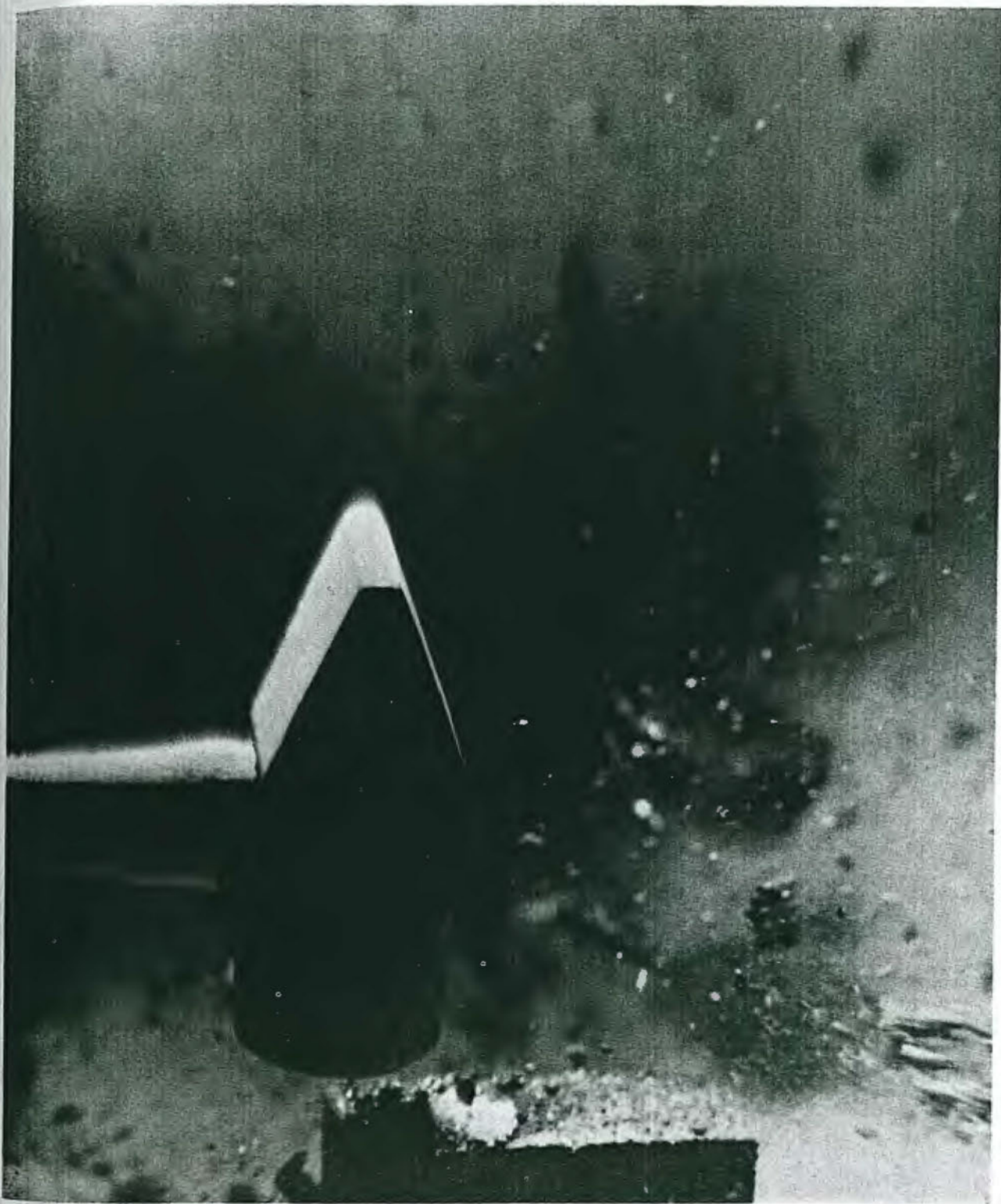
**Figure 1.—Pittsburgh-Bed Coal, Wet, With Platen and Hammer.**



**Figure 2.—Pittsburgh-Bed Coal, Wet, With Platen and Hammer, Breaking.**



**Figure 3.—Pocahontas No. 3 Coal, Wet With Surfactant Treated Water, With Platen and Hammer.**



**Figure 4.—Pocahontas No. 3 Coal, Wet With Surfactant Treated Water, With Platen and Hammer, Breaking.**



Figure 5.—Pittsburgh-bed Coal, Polished Surface, With 10-Microliter Water Droplet.

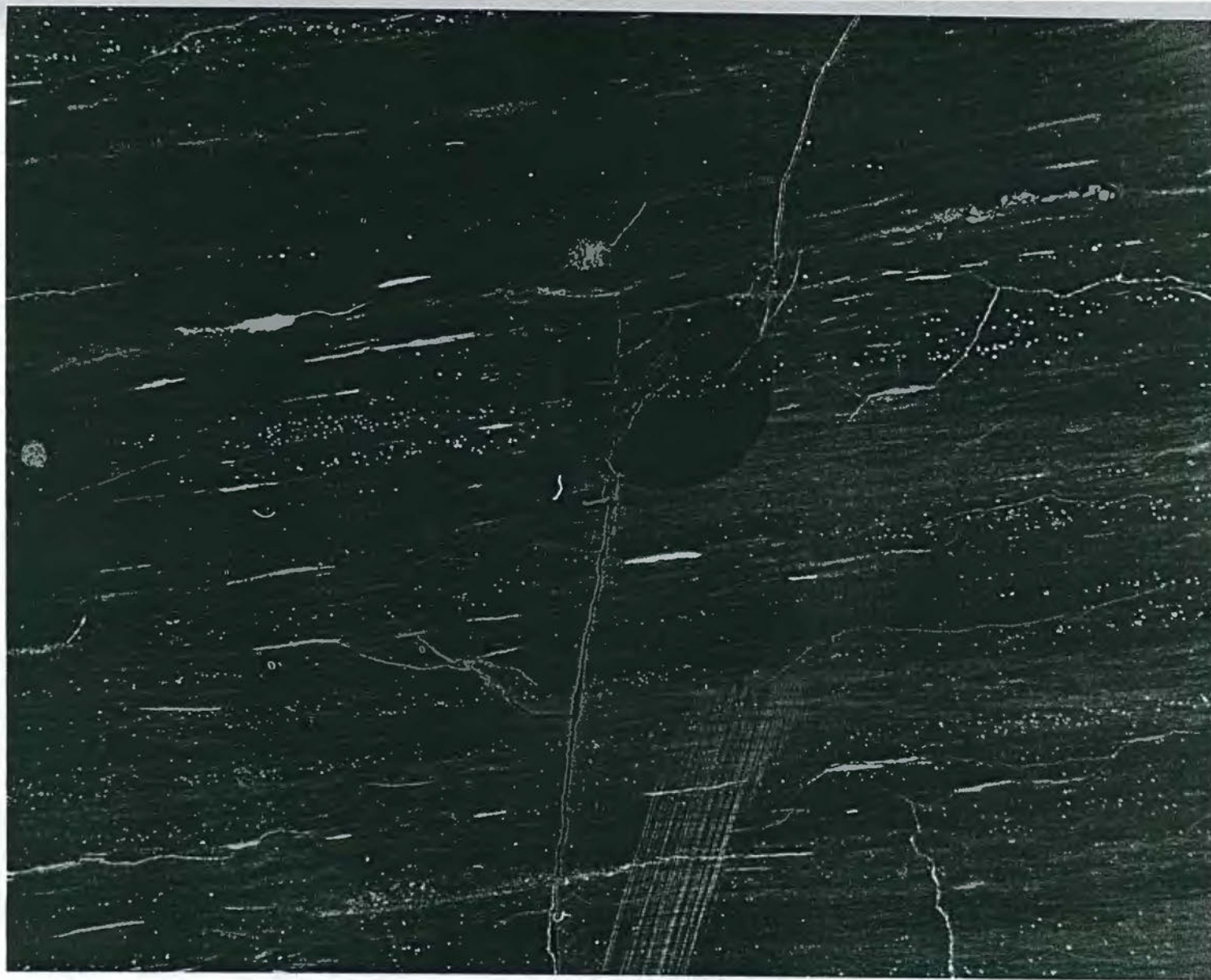


Figure 6.—Pittsburgh-Bed Coal, Polished Surface, With 10-Microliter Droplet of Water With a Surfactant.

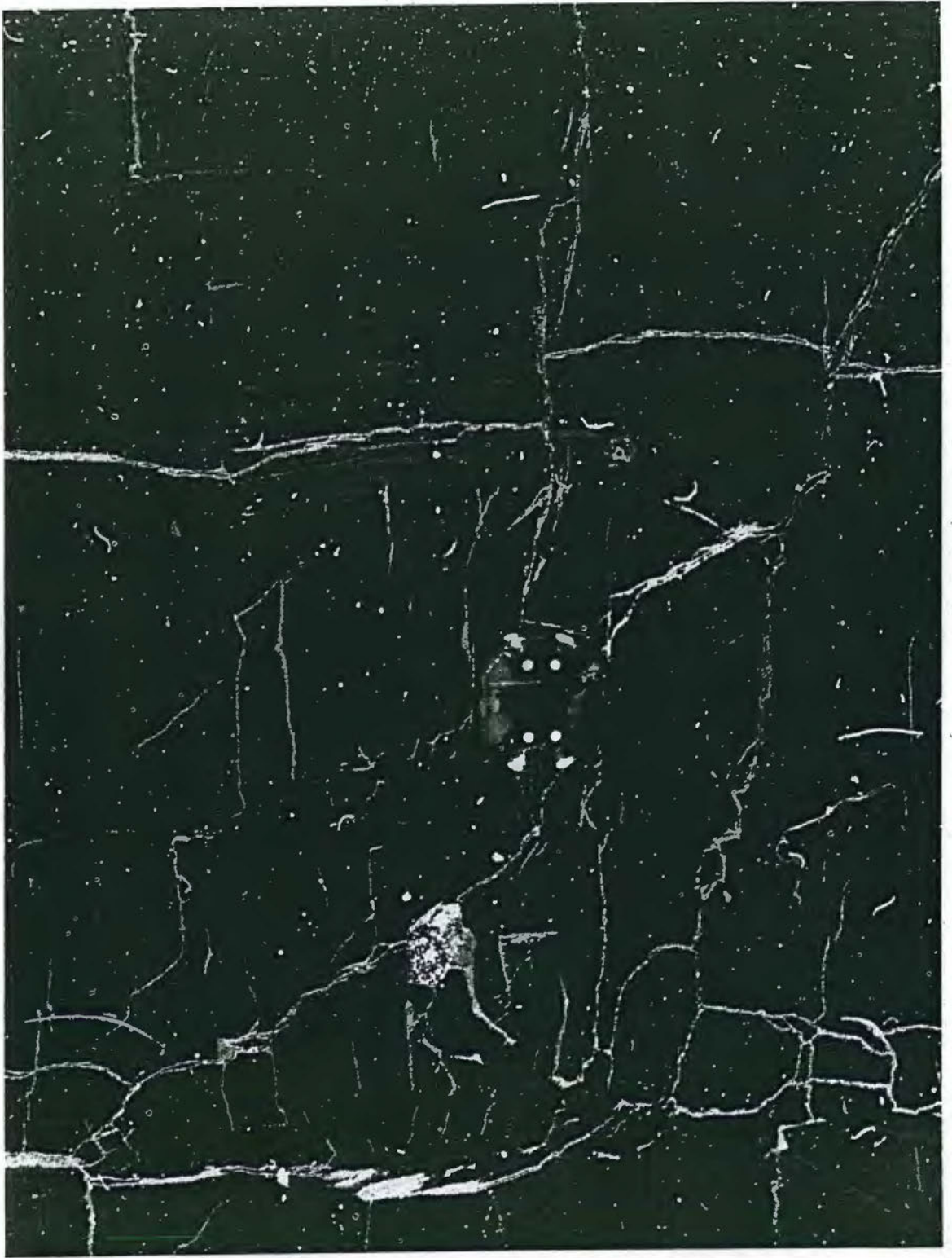
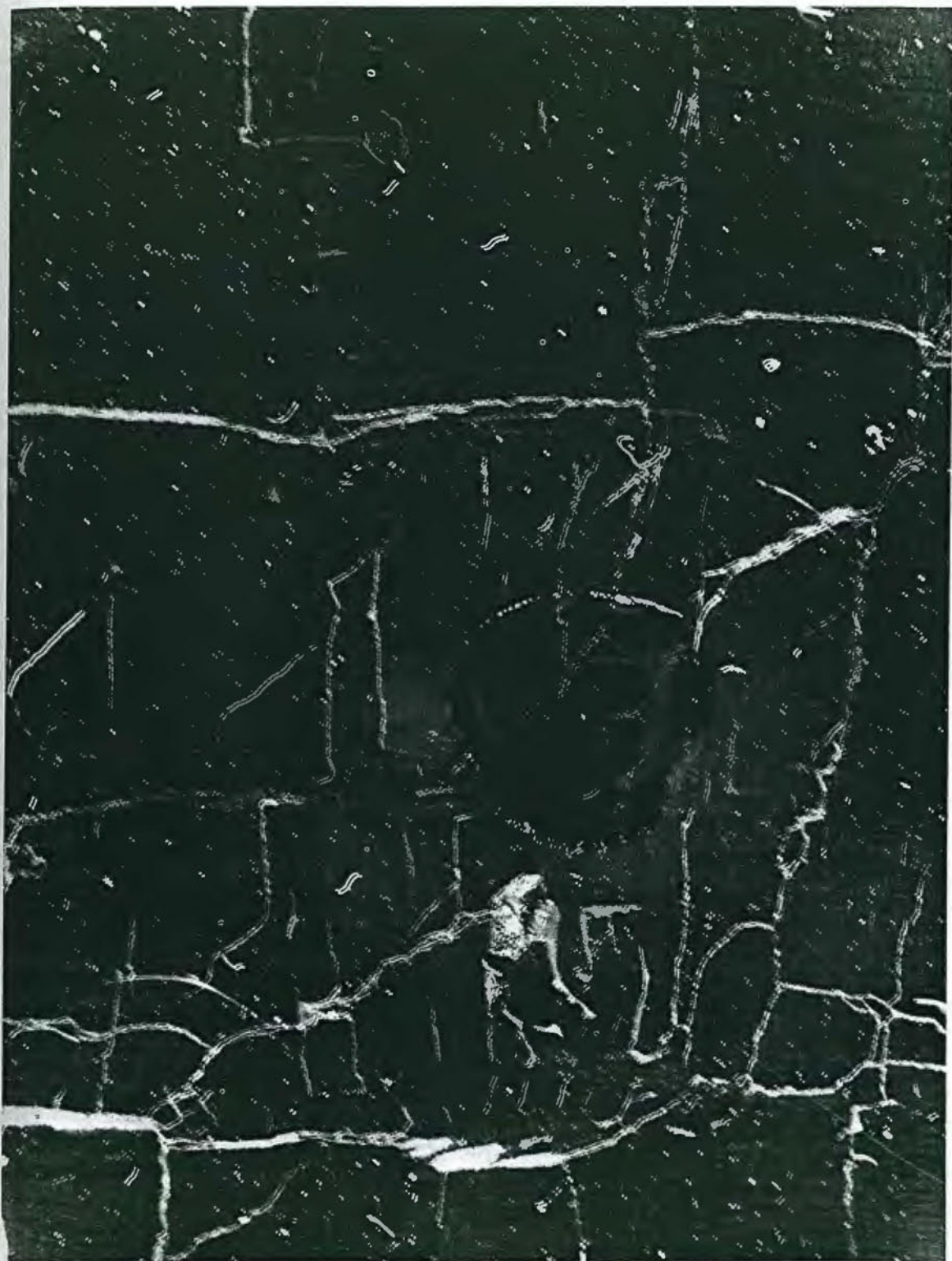


Figure 7.—Pocahontas No. 3 Coal, Polished Surface, With 10-Microliter Water Droplet.



**Figure 8.—Pocahontas No. 3 Coal, Polished Surface, With 10-Microliter Droplet of Water With a Surfactant.**



Figure 9.—Pittsburgh-Bed Coal, Fracture Surface, With 10-Microliter Water Droplet.



**Figure 10.—Pittsburgh-Bed Coal, Fracture Surface, With 10-Microliter Droplet of Water With a Surfactant.**

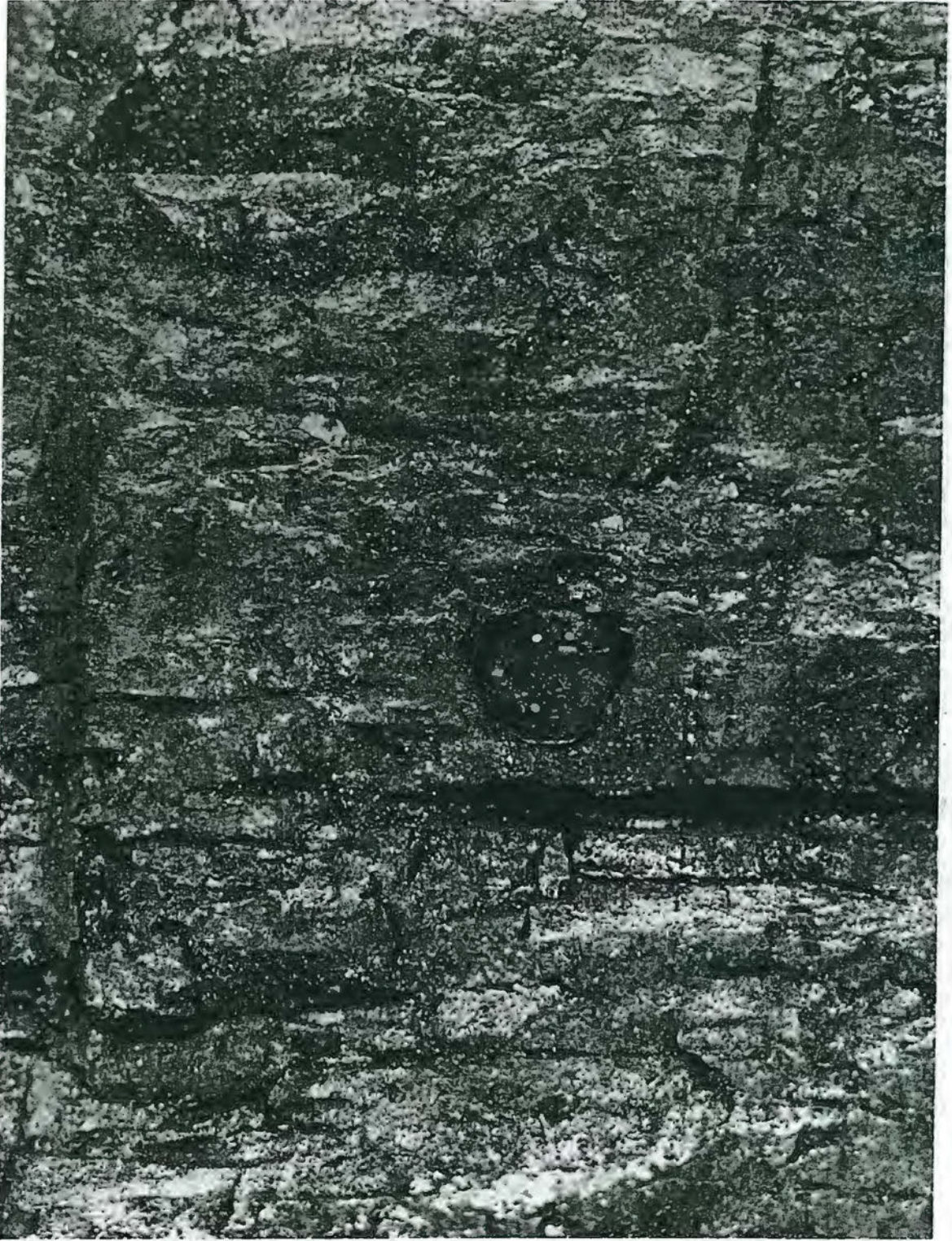


Figure 11.—Pocahontas No. 3 Coal, Fracture Surface, With 10-Microliter Water Droplet.



**Figure 12.—Pocahontas No. 3 Coal, Fracture Surface, With 10-Microliter Droplet of Water With a Surfactant.**



**Figure 13.—Pittsburgh-Bed Coal, Airborne Dust From Broken Dry Block.  
Twelve-inch span; 16-second exposure.**



**Figure 14.—Pittsburgh-Bed Coal, Airborne Dust From Broken Block Wetted With Surfactant Treated Water.  
Twelve-inch span; 4-second exposure.**



**Figure 15.—Pocahontas No. 3 Coal, Airborne Dust From Broken Block Wetted With Surfactant Treated Water.  
Twelve-inch span; 4-second exposure.**

DR. POTTER: The next paper will be a paper on water infusion in longwall operations by U. A. Cobb, General Manager of the Carbon Fuel Company, Charleston, W. Va.

## DUST CONTROL BY WATER INFUSION ON LONGWALL FACE, NO. 20 MINE, THE CARBON FUEL COMPANY

by

U. A. Cobb

---

### INTRODUCTION

The longwall system of mining in the Carbon Fuel Co. No. 20 mine at Carbon, W. Va., became operative on March 2, 1964. During the first year of operation, our concern was the mechanical operation of the unit, but we became concerned early with the problem of dust from the coal face and dust created by the falling roof behind the roof supports. Our first effort to control this dust was by the use of water on both the coal face and the gob area behind the roof support system. The water sprays not only created a humid atmosphere but also left the travelways under the roof supports wet and sloppy, both of which were objectionable to the workers.

### WATER INFUSION EXPERIMENTS

In the latter part of 1966 we started discussion and research on water infusion as a means of dust control. In January 1967 our first experiments began. The procedure was described in detail in the August 1967 issue of Coal Mining and Processing under the title "Try Water Infusion". This paper was prepared by Mr. H.C. Morton who was at that time the division superintendent of the Carbon Division and responsible for the experiment which has become a regular cycle in the longwall operation.

The seam of coal under discussion in the Big Eagle which, in the area being mined, carries a shale binder approximately 18 inches below the roof. The holes are drilled above this binder and it may be that the water only penetrates the bottom portion of the seam after this binder has been fractured by pressure. We tried infusing a hole drilled below this binder with the following results:

The water penetrated the bottom coal too freely and ran out of the rib creating an intolerable accumulation of water on the floor. I believe this has been experienced in some seams where infusion has been used to drive out methane. The water caused the floor to deteriorate. This raised the question as to whether or not water infusion is feasible in other seams that are more porous and that do not have the impervious binder such as occurs in the Eagle

seam at No. 20 mine. There is also the question of how much damage water infusion will cause in fragile roof structures since we now know that water under pressure does travel long distances through the roof and floor stratum, whichever is the most porous. We will return to this question later in the discussion.

The procedure for preparing the face for infusion and the method of pumping and addition of a wetting agent to the water has not changed appreciably from those described in the article in "Coal Mining and Processing" described above. For those who did not read this description and for review, I will briefly describe the process.

The length of this longwall face is 350 feet and the panels have varied from 1,800 to 3,800 feet in length. The infusion holes are 6 inches in diameter and 200 feet deep. The holes are drilled from the head entry parallel to the longwall face and 200 feet apart. The drill is driven by a 10-hp, dc electric motor. The auger-type drill steel is in 6-foot lengths. Needless to say, a better drill could be obtained with longer feed and better construction for maneuverability. It is also very probable that a hole 4 inches in diameter would suffice. After the hole is drilled, a 40-foot length of 1-inch pipe is grouted in the hole. The grout is composed of one part cement and one part rock dust and is placed around the pipe with a grout pump. To prevent the grout from passing the inby end of the pipe, a rubber stopper is installed on the pipe so that it can be inflated by water pumped through a 1/4-inch pipe. The rubber stopper is deflated after the grout hardens and the 1/4-inch pipe is removed. The stopper is recovered when the face reaches the hole. Our experience shows that on a new face, pumping should be started in the first hole, 200 feet from the face, about 1 week before the mining begins. Pumping is continuous. The pump is moved to the next hole 200 feet away when the face is approximately 40 feet from the hole being pumped. About one pint of coal dyne 100, a wetting agent, is added to each 1,000 gallons of water. A water flow meter is used to determine the amount pumped in each hole, which is usually about 150,000 gallons. The pump delivers 12 gpm and pressure goes as high as 400 psi. Pumping is discontinued only over weekends and is started at the beginning of each Sunday midnight shift.

Like all other cycles of coal mining, water infusion requires close supervision and attention. If the pump is not delivering the water for any reason, the coal will become dry in a few hours and will remain dry for as many or more hours after pumping is resumed. In the Eagle seam the water penetrates the strata over the coal and suppresses the rock dust created by the grinding action of the caving roof. Actually the dust created by the roof falls caused as much concern as the coal dust in the face region. Dust from the coal face after infusion varies with the roof pressure on the coal. When the coal is very hard, the rubbing action of the planer creates fine dust, especially near the top of the seam. When the coal is crushed by pressure, there is very little visible coal dust on the face. In addition to No. 20 mine, we infused the No. 2 Gas seam on a continuous miner section, and the results were very disappointing. One hole was drilled in the center of the face. The hole was 20 feet deep and water appeared over the entire face. The appearance of the water in the coal was as good or better than it is on the longwall face, but

the visible dust from the miner improved very little. We believe that the water follows the cleavage planes in the coal and when these planes are cut through dust is created. This is as observed in No. 20 mine on the longwall face when the coal is hard. The same action was observed in conventional mining after infusion. The dust created by the coal drill, from observation, was almost as much as created without infusion. The cutting machine dust was much less with infusion because water did accumulate on the floor. We found that one spray on the cutter bar was very effective after infusion. In conventional mining, however, the greatest improvement in visible dust was at the loading machine discharge into shuttle cars and at the loader head. Excellent results in controlling visible dust appear on belts, belt discharge, and loading points and in airways where infusion is done both on longwall, conventional, and even on the continuous miner. It is our experience that sprays on the face equipment accomplish very little in dust suppression in belt entries and return airways.

One of the most noticeable improvements on the longwall face, when properly infused, is the improved visibility. Even when the coal is hard and dust is raised by the rubbing action of the planer, very little dust appears when coal falls from the face into the conveyor. Another product of infusion is better planer action in separating the coal from the roof.

#### ACTION OF WATER IN OTHER SEAMS

Experiments in other seams have produced some interesting results as follows:

##### Pond Creek

Two holes were drilled 50 feet deep in a five-entry system, one in E. entry. Approximately 6,000 gallons of water was pumped into the two holes in 6 hours, starting with the midnight shift. Very little water was evident during the next two operating shifts. This continued for 3 days before the coal appeared wet. The water had traveled through the coal to a low spot or dip in the seam about 200 feet from the face at the beginning of the infusion. The accumulation was so large that we had to pump water from the face region.

##### No. 2 Gas Bed

Water penetrates the seam evenly but also runs to dips and accumulates.

##### Winifrede Bed

This seam contains a binder similar to the Big Eagle and the infusion is much easier to control. Water does run to lower points but not so much as in seams without the binder.

In the Big Eagle seam on the longwall panels the water rarely ever accumulates in the dips. This is probably because of the binder and the roof strata which convey the excess water away from the coal.

Our experience with water infusion at Carbon Fuel has shown the following advantages of infusion for dust suppression:

1. Causes no interference with production on longwall since the work is not connected with face operation.
2. One method controls the dust from the face to the surface. No sprays are needed on belts or discharge points and return airway requires far less rock dust.
3. Much less overwetting of coal than sprays. The fine coal is not soaked and the wetting of the coal is more even. The water evaporates quickly causing less trouble with screening in cleaning plants.

The question is raised as to whether or not water infusion is feasible in other seams that are more porous and do not have the impervious binder such as we have in the Big Eagle at No. 20 mine. This can only be determined, we believe, by trial. It may be that holes could be drilled from both the head and tail entries and closer together. This means that the coal would be infused nearer the face. However, if the water runs too freely in the coal and there is a dip outby the face, the water will run to the dip. Perhaps a chemical additive can be developed to slow down the rapid movement of the water through the coal—perhaps by increasing the viscosity of the water.

We realize that our No. 20 mine may be unique because of the conditions which make infusion workable. These conditions have already been described. However, we do believe that the results obtained indicate that more experimentation should be done with infusion as a means of dust control.

On June 6, 1969, the Bureau of Mines began a limited environmental dust survey on the longwall section. The dust sampling was conducted on a full-shift basis for three production shifts. Personal samplers were worn by each face workman and the foreman. Instrument packages containing three different sampling units, a personal sampler, the Isleworth sampler, and a gross sampler were placed in the intake and return airways and at a location about midpoint of the longwall face. The samples were collected on preweighed membrane filters and reweighed after sampling. The results of this survey are shown in table 1.

The results show the intake air current contained an average of 3.03 mg/m<sup>3</sup> MRE and it was determined that most of this dust was being generated by the tail pulley of the conveyor belt in the intake airway.

Table 1.--Dust survey in No. 20 slope mine

	Type of sample	6-6-69	6-9-69	6-10-69	Mean
<u>Milligrams per cubic meter</u>					
<b>Location:</b>					
Return.....	MRE	5.46	4.84	4.61	4.97
	Personal	1.98	1.86	1.51	1.78
Center of plow face.....	MRE	2.66	3.22	2.91	2.93
	Personal	0.92	0.97	1.01	0.97
Intake.....	MRE	2.44	( <sup>1</sup> )	3.63	3.03
	Personal	1.02	( <sup>1</sup> )	2.28	1.65
<b>Occupation:</b>					
No. 1 jack setter.....	.....	1.14	1.27	1.91	1.44
No. 2 jack setter.....	.....	( <sup>2</sup> )	( <sup>2</sup> )	( <sup>2</sup> )	( <sup>2</sup> )
No. 3 jack setter.....	.....	0.58	0.95	0.95	0.79
No. 4 jack setter.....	.....	( <sup>3</sup> )	0.96	0.90	0.93
No. 5 jack setter.....	.....	1.27	1.25	1.14	1.22
Head operator.....	.....	0.64	1.35	1.31	1.10
Head operator helper.....	.....	( <sup>1</sup> )	1.94	1.76	1.85
Tail operator.....	.....	2.01	3.28	1.97	2.42
Hand loading stall.....	.....	1.74	1.71	1.92	1.79
Repairman.....	.....	( <sup>3</sup> )	0.65	0.77	0.71
Foreman.....	.....	0.85	1.18	1.08	1.03
<b>Miscellaneous:</b>					
Tonnage.....	.....	880	825	750	818
Operating time, minutes.....	.....	207	275	240	241
Percent of operating time...	.....	58	76	67	67
Tons per minute of operating time.....	.....	3.14	2.25	2.35	2.85

<sup>1</sup> No sample<sup>2</sup> All samples contaminated<sup>3</sup> Contaminated

Source: No. 20 slope mine, The Carbon Fuel Co., Carbon, Kanawha County, W. Va.

DR. POTTER: This concludes the formal part of the program this afternoon. There has been a request by several members in the audience to have the Bureau of Mines representatives answer several questions on Technical Progress Report No. 19.

QUESTION: I wonder if you would comment on the horsepower used.

MR. KINGERY: I will explain the confusion regarding this horsepower. We were requested to evaluate the effectiveness of face ventilation methods for effective respirable coal dust control. At our first test in a commercial coal mine, we did not get the air velocity needed, because the auxiliary ventilating system used did not have sufficient horsepower.

It became evident that if we were to make a series of studies under varying conditions, we needed auxiliary ventilation equipment with unusually high horsepower.

It was not possible to obtain a 25-horsepower certified motor for this auxiliary fan with which to continue studies. We had a large two-stage auxiliary fan used for research studies at our experimental mine. This fan, while not designed for field use, could be utilized. It was powered by a 60-horsepower certified motor.

We felt that the need was pressing. Consequently, we utilized this special 60-horsepower unit fan for underground studies. We obtained help from the American Brattice Cloth Corporation to supply tubing, and with the assistance of various mining companies, we conducted the series of face ventilation studies reported upon at this symposium.

The 60-horsepower motor was rated horsepower; actually the fan was too large for this service. Consequently, the actual horsepower developed ranged somewhere in the neighborhood of possibly 15 to a maximum of maybe 27 horses.

QUESTION: Can you describe your noncollapsible tubing?

MR. KINGERY: Noncollapsible tubing is a spiral-wrapped tubing, reinforced in such a way that it can withstand negative pressures up to 6 or 7 inches of water.

We did, however, collapse tubing during these studies because of the high pressures developed. We used tubing ranging in diameter from 24, 20, and 18 inches, which was the smallest.

QUESTION (WOODS G. TALMAN): Were any tests made in the mines splitting at the face?

MR. DALZELL: Yes, tests were made. We were carrying the air up the center entries and splitting it. Yes, tests were made in which the intake air was taken up the center, split to the right and left in the face region, and carried back to returns.

QUESTION: What did the tests indicate happened to the other split?

MR. DALZELL: There was very little effect on the other split, mostly because the volume of air was in excess of the capacity of the fan as it was operated during the tests.

QUESTION: Were these tests reported in Technical Progress Report 19?

MR. DALZELL: I don't believe so.

QUESTION: Did you conduct any tests on pillaring sections?

MR. DALZELL: The scope of the tests which were carried out this time dealt with continuous mining on development at entries. It was limited to this.

MR. TALMAN: Development only?

MR. DALZELL: That is right.

MR. TALMAN: When you were not splitting at the face, what was the intake loading going to the people working downwind from the fan?

MR. DALZELL: Do you mean the intake? It was considerable. I believe it ranged from 1 milligram per cubic meter up to about 2-1/2 milligrams per cubic meter. This was a function of the activity that was going on out by the production area.

MR. TALMAN: I thought I heard Henry say awhile ago around 2 milligrams was the intake going to the continuous miner.

MR. DOYLE: That was for one of the mines in our study. It was by no means the average.

#### PROCEEDINGS

MR. CRENTZ: It is my pleasure to chair this third session of the dust symposium.

For those of you whom I have not had the pleasure of meeting, my name is Bill Crentz. I am with the Bureau of Mines, and I work in the area of coal research.

Today we have what appears to be an interesting session involving two aspects of coal technology: machine design and dust collecting equipment, and a separate session on respirators and life support systems.

After each speaker concludes his presentation there will be a brief question session. May I again request that those questions only involve points which will enable the speaker to clarify his paper, and that you refrain from any technical discussion of his paper until later.

Our first paper this morning is one on the theory of machine design and will be presented by R. J. Hamilton, Head of the Dust Group, National Coal Board, Isleworth, England.

# PRINCIPLES OF MACHINE DESIGN AND OPERATION RELATED TO DUST PRODUCTION AND CONTROL WITH PARTICULAR REFERENCE TO LONGWALL MINING IN THE UNITED KINGDOM

---

---

by

R. J. Hamilton

---

---

## INTRODUCTION

The production of some fine dust is inevitable in virtually every mining operation, but under typical conditions fortunately only some 5 percent of the potentially respirable dust made is dispersed into the air. Attention paid to reducing the make of dust and its dispersion can often be much more effective than the use of conventional dust suppression measures and should always be regarded as the first step in an effective dust control programme.

A high level of dust production is usually related to inefficient use of energy, and the lowest dust concentrations are not infrequently found in the highest productivity coal faces. In this paper most of the references to various mining operations are those occurring on longwall faces, since this method of mining is that most widely used in the United Kingdom. However, the principles of breaking down coal with cutter picks and the mechanics of dust dispersion are common to both British and American mining methods.

## DUST FORMATION

Figure 1 illustrates the size distribution of the debris produced by a mining machine such as an Anderton shearer. The potentially respirable dust and float dust form a more or less constant fraction of the minus 100-mesh particles for all types of breakage, depending only on the material broken, with relatively more finer material when the material is sandstone or shale rather than coal. A reduction in dust production is best achieved by increasing the top size of the product, as happens, for example, when the depth of cut taken by a pick is increased (fig. 2). As it is forced through the coal there is crushing at the pick point until breaking off to a free surface occurs. At a greater depth of cut, although the amount of material crushed to dust is not very different, it becomes a smaller proportion of the total breakage product. Blunt picks give rise to more crushing, and therefore greater amounts of dust for a given depth of cut, and require the use of more energy. The National Coal Board 'large pick' shearer drum (fig. 3) has taken to its logical conclusion the concept of deep cutting and gives rise to only about one-half of the dust from conventional shearer drums.

## DUST DISPERSION

Although increasing pick speed results in no greater production of dust, provided the depth of cut is kept the same, the proportion of this mass of dust which is dispersed into the air increases roughly proportionally with pick speed, shown in figure 4, which illustrates the results of laboratory experiments. Tests also carried out with several types of mining machine underground have confirmed these results. Coals also tend to differ in the amounts of dust thrown up into the air by a given cutting process, stronger coals breaking more 'explosively' than weaker ones.

The reduction of pick speed is the most important simple step in bringing down the dust concentration arising from a mining machine. Pick speed is commonly unnecessarily high and a reduction of this by one-half can often be achieved with a reduction in cutting speed (or haulage speed on a longwall face) or increase in the power required. If this is done, the depth of cut is doubled and the dust concentration approximately halved - resulting in a reduction of about 75 percent in dust concentration. There are two limitations to the extent to which haulage rate can be increased and pick speed reduced on a drum. The first is the obvious one - the amount of torque available and the strength of machine component and picks, the second the capacity of the drum to clear broken coal. Optimum dust conditions and productivity exist when the drum is kept well filled with coal, without being 'throttled'. An additional dust problem, which is possibly confined to longwall working, results from the projection of dust across the ventilation stream when the drum is lightly loaded with coal. Drums which are being used to 'trim' corners are particularly prone to give rise to dust in this way, and in a high ventilation velocity the resultant coarse dust (in addition to respirable dust particles) can be most unpleasant. The ultimate in reducing dispersion is probably achieved by the 'coal plough', which is widely used in French and German mines, and to some extent in the United States and Great Britain. It virtually consists of a single low-speed pick, which when used in level seams, where there is little dust from falling coal and from the waste, gives rise to very little dust indeed.

## PRACTICAL OBSERVATIONS

### Longwall Faces

Figures 5, 6, and 7 show the dust produced by a number of Anderton shearers or 'roadway ripping machines' in routine use. There is no less than a 500-to-1 difference between best and worst conditions. Horizontally mounted drums have very shallow depths of cut at floor and roof, and most of the dust production arises from these zones. Cutting into shale or sandstone also gives rise to more dust than cutting in coal (because of the relatively greater amount of fines in the break-product) and, when the rock is harder than the coal, often results in a slow-down of the machine and an additional reduction in the depth of cut. On longwall faces these difficulties are being to some extent avoided by the introduction, first, of improved manual control of cutting horizon on Anderton shearers, and second by the application of nucleonic sensing of the rock-coal interface to allow automatic steering to keep the machine in the coal seam.

### Coal and Rock Headings

Although there has been much less experience with heading machines of the types used in the United States, some interesting observations have been made. The (M. & C.) Norse Miner cutter disk commonly used in the United Kingdom has a number of picks with small lateral spacing distances from those ahead. These trailing picks 'track' when working in a hard coal, and give rise to vibration and 'coring'. Under these conditions, it has been found on several occasions that removal of 25 to 30 percent of picks on the disk can give a significant improvement in coal sizing and a reduction in dust concentration. Similar improvements have been achieved with the NCB Dosco 'dint-header,' a machine equipped with a cutter mat. In a hard shale arcing-over speed was brought down to 2 feet per minute - with excessive dust and vibration. Figure 8 shows a fragment of shale with clear evidence of inefficient cutting. Removal of 50 percent of the picks to avoid 'tracking', and a reduction in pick speed, allowed 12 feet per minute cutting speed and a remarkable reduction in dust.

#### FACTORS IN THE DESIGN OF CUTTER PICK MACHINES

For optimum cutting efficiency, using the lowest specific energy and at the same time giving a good breakage product and minimum dust make, the lateral spacing between picks should be approximately equal to twice the designed depth of cut, to allow adequate 'breaking out' and to make use of the brittle fracture properties of coal measure rocks. This principle has been applied in the pick lacing pattern of the NCB large pick shearer drum, which together with the resultant breakage patterns at different cutting horizons is shown in figure 9. This drum has 11 or 12 two-inch-wide picks, and has proved successful when it is used to cut in a homogeneous coal seam. However, when there are hard bands in the seam, or other difficulties such as the need to cut roof or floor occasionally, the small number of picks evidently proves to be a disadvantage. The use of a greater number of narrower picks seems to be more successful.

From our limited observations, it appears that the lacing pattern of picks in a 'cutter mat' should ideally follow the same general principles as those stated above for shearers, but the same principles do not necessarily hold for narrow kerf chain cutters - where the removal of coal for the kerf is also carried out by the picks.

Measurements of dust production from different forms of cutter pick have shown that sharpness is the most important feature, with little difference between various pick shapes. General rules are that 'front rake' angle of about  $15^{\circ}$  seems to give a good compromise between cutting efficiency and pick strength, and a 'clearance angle' of more than  $5^{\circ}$  is necessary. Both 'point attack' and radially mounted picks are in use. The former have the advantages of greater strength, but the traditional cone-shaped 'point attack' pick has the disadvantage of a negative clearance angle and poor performance in hard material.

## DUST FROM TRANSPORT SYSTEMS

Under modern conditions, the mining machine itself may not be the major dust producer. High rates of production and the associated high ventilation rates required to dilute methane can result in transport systems becoming more dusty. In practice measures needed to control the 'intake pollution' arising from the transport system may be simpler and easier to implement than those necessary to reduce dust from the mining machine even further.

Conveyor belts themselves can be sources of dust which may be dispersed by the high relative air speed, particularly where conveyors are in intake airways. Although extra air volume dilutes dust, when air velocities over the belt rise above 600 to 800 feet per minute, dust is blown from the moving belt, and inadequately sealed joints between lengths of conveyor, lack of cleaning return belts, and peaking of the coal load can make matters worse. Conveyor transfer points and mine car loading points are well-known dust sources. Here the fall of coal must be avoided if possible, and if the provision of a chute fails to reduce dust to acceptable levels, it may be necessary to enclose the transfer or loading point from the main ventilation current. When rapid intermittent loading of a mine car from a bunker or hopper takes place, an enclosure of internal volume at least equal to that of a mine car, placed round the loading point, can be effective in avoiding the dispersion of the dust-laden air displaced from the car.

Water sprayed onto coal on conveyors is most effective if it is applied as early as possible, to allow effective mixing of water and coal before disturbance at transfer and loading points. Sprays used for this purpose should have coarse droplets and be chosen to give uniform coverage over the conveyor. The dust suppression is effective if the water is present as 'free moisture' on the surface of the coal.

## THE APPLICATION OF WATER ON MACHINES

External water sprays are in widespread use on all types of mining machines. There is now general appreciation that sprays should be sited to wet the dust 'at source,' rather than be used to produce a finely atomized curtain of water, which has been shown to be ineffective in removing respirable dust. Measurements of the effect of water sprays fitted to a number of different types of machine show that a typical external spray system in good working order reduces respirable dust by up to 25 to 30 percent, compared with dry cutting. The removal of coarse dust is somewhat more efficient, and the wetting of the coal at the machine, by whatever means, results in the reduction of the dust produced on the transport system. Sprays should, for maximum effect, project coarse droplets at the dust source, and it has been found that the mounting of such sprays in cowls close to the disk or drum increases their effectiveness.

The provision of water feed to the actual cutters themselves is now becoming more general, and sprays mounted on the barrel of a cutter drum are more effective than are external water application systems. Sprays of the

fishtail pattern which can be rotated to vary the width of water projection appear to be the most suitable type, and they can be mounted behind pick boxes for protection. The efficiency of such a system is better than the normal run of external sprays, typically reducing respirable dust by about 50 percent.

A more sophisticated technique of using water to flush the faces of individual cutter picks is showing some promise (fig. 10) and gives higher efficiency of respirable dust suppression than either external or barrel-mounted sprays (about 70 percent on respirable dust). This system may also be used with a phasing arrangement to restrict water flow to the cutting side of the disk or drum, although for this to work it is necessary to have a stationary datum inside the drum itself (achieved on Anderton shearer drums by carrying a fixed pipe through the centre of the shaft to the face side of the drum). Difficulties have been experienced with this pick face flushing technique from two causes: the blocking of water jets and the breakdown of rotating seals. However, these problems now seem to have been overcome satisfactorily.

Water jets within the picks themselves have not so far proved very successful, since the water injected in this way cannot be made to flow up the leading edge of the pick without placing the jet in a vulnerable position, and achieving separate shrouded, nonblocking jets mounted just ahead of the picks themselves has proved to be the most effective and trouble free arrangement. The external shroud is necessary to avoid damage and blocking by coarse broken material. The jet itself must be in the form of a hole in a thin plate, to eliminate adhesion of particles to the wall of the hole, and in addition it is necessary to incorporate a small screen behind the jet to avoid blockage from particles in the water supply arising from corrosion inside the drum itself. Figure 11 shows such a nonblocking jet which is proving to be successful on a number of installations.

The optimum rate of feed of water to machines appears to be between 1 and 2 percent by weight of the coal extracted (2 to 4 gallons water per ton of coal). The flow pressure at the mining machine should be not less than 150 psi. A problem in the past in U.K. coal mines has been the difficulty of providing adequate flow and pressure at the machine. The availability of 1-inch-diameter hose pipe in long lengths, avoiding the restriction of frequent hose connections, has virtually removed this difficulty. It is also necessary to provide a simple mesh filter at the beginning of the hose to remove contamination in the mine water and also at the machine end of the hose to protect the sprays from blockage by dirt introduced into the line when the hose is disconnected or broken.

#### EXHAUST VENTILATION

Dust control on heading machines is in general best achieved by exhaust ventilation, with, if necessary, filtration of the exhausted air. In Great Britain, where the majority of the headings are narrow, this is typically achieved by bringing up exhaust tubing to the front of the machine, supported along the side of the roadway by the almost universal arches or roof girders. A major problem is the need for the ducting to pass alongside the machine, where there is often little space. There would be advantages for such heading machines

incorporate in their design a ventilation duct, brought through the machine a position close behind the cutters. The cross-section of this duct should be of the order of 2 square inches per square-foot section of heading, in order to allow a minimum air velocity forward in the roadway of 50 feet per minute. In some cases it has been possible to fit existing machines with permanent ventilation ducting, but difficulties with modifications of this type are the limited room usually available, resulting in the use of too small section ducting, and the almost inevitable sharp bends, which together result in high resistance to airflow.

Clearly the incorporation of an integral exhaust duct has less obvious application to the large machines making multiple entries over a short period, unless it were possible for a machine of this type to carry its own dust filter in it.

A dust control system which is being used with some success and has certain advantages over the conventional exhaust ventilation method in long headings where there is not a severe firedamp problem, is the overlap system. This consists basically of a forcing ventilation duct which is overlapped at the end by a short exhaust duct with filter and fan carried forward with the mining machine. The forcing duct is terminated by a diffuser (figure 12) with a variable aperture or shutter. When this is opened fully the heading is adequately ventilated by forcing air alone. When the exhaust system is used to control the dust from the machine the opening at the end of the diffuser is adjusted to allow the exhaust ventilation to work in the absence of interference from high velocity forcing air. The forcing ventilation exceeds the exhaust air by a factor of between 50 and 100 percent.

#### Acknowledgments

The writer is grateful to his colleagues at the Mining Research and Development Establishment, in particular Mr. D. Whittaker, Mr. J. S. Barker and Mr. A. G. French, for their help in the preparation of this paper.

It has been written by permission of the National Coal Board, but the views expressed are those of the author and not necessarily those of the Board.

QUESTION (Mr. Anson): On one of your first slides on your experiment relating to the pick's speed and the production of dust, the dust in milligrams per cubic foot was labeled as airborne. Was that airborne?

MR. HAMILTON: This was total airborne.

MR. ANSON: Twenty microns and below, then?

MR. HAMILTON: Yes.

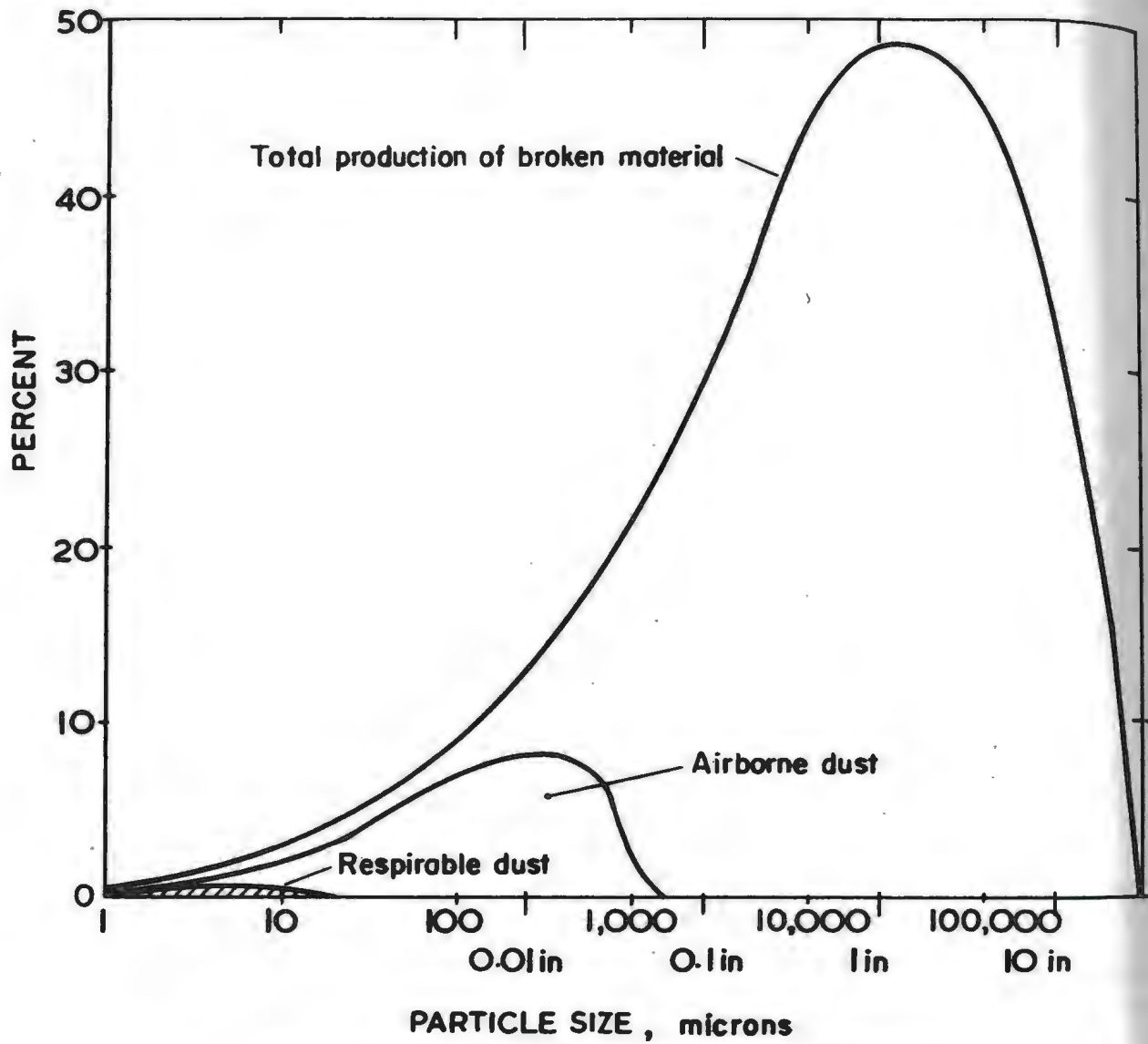
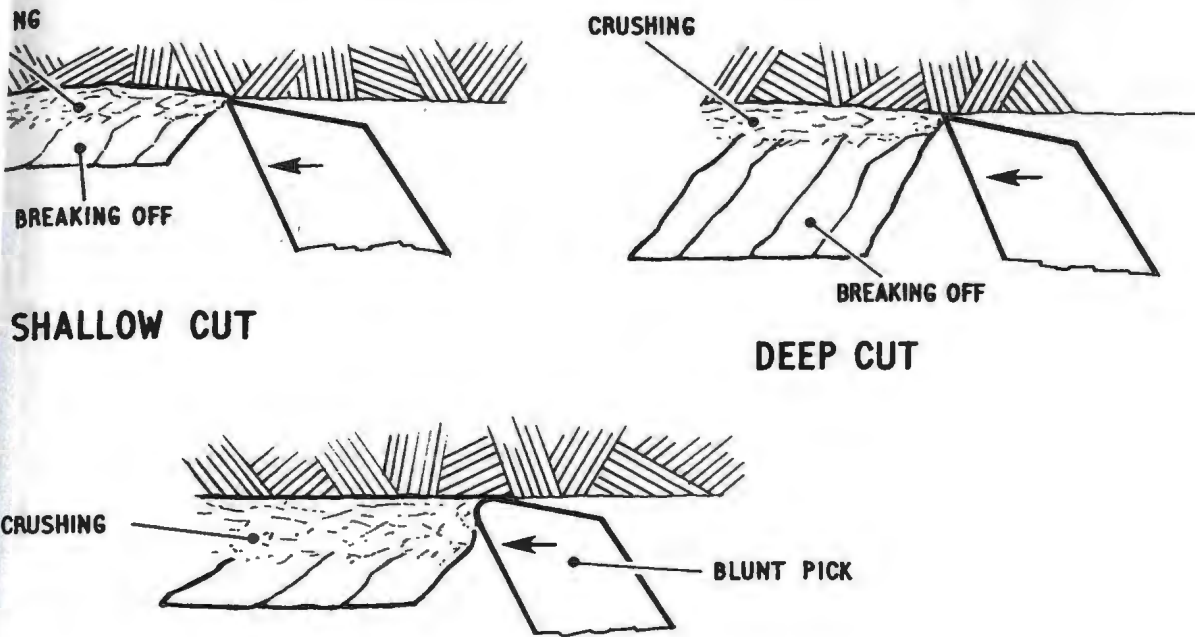


Figure 1.—Typical Size Distribution of Breakage Product From Mining.



**FIG. 2 DUST MADE BY CUTTER PICKS**

Figure 2.—Dust Made by Cutter Picks.



Figure 3.—The NCB Large-Pick Shearer Drum.

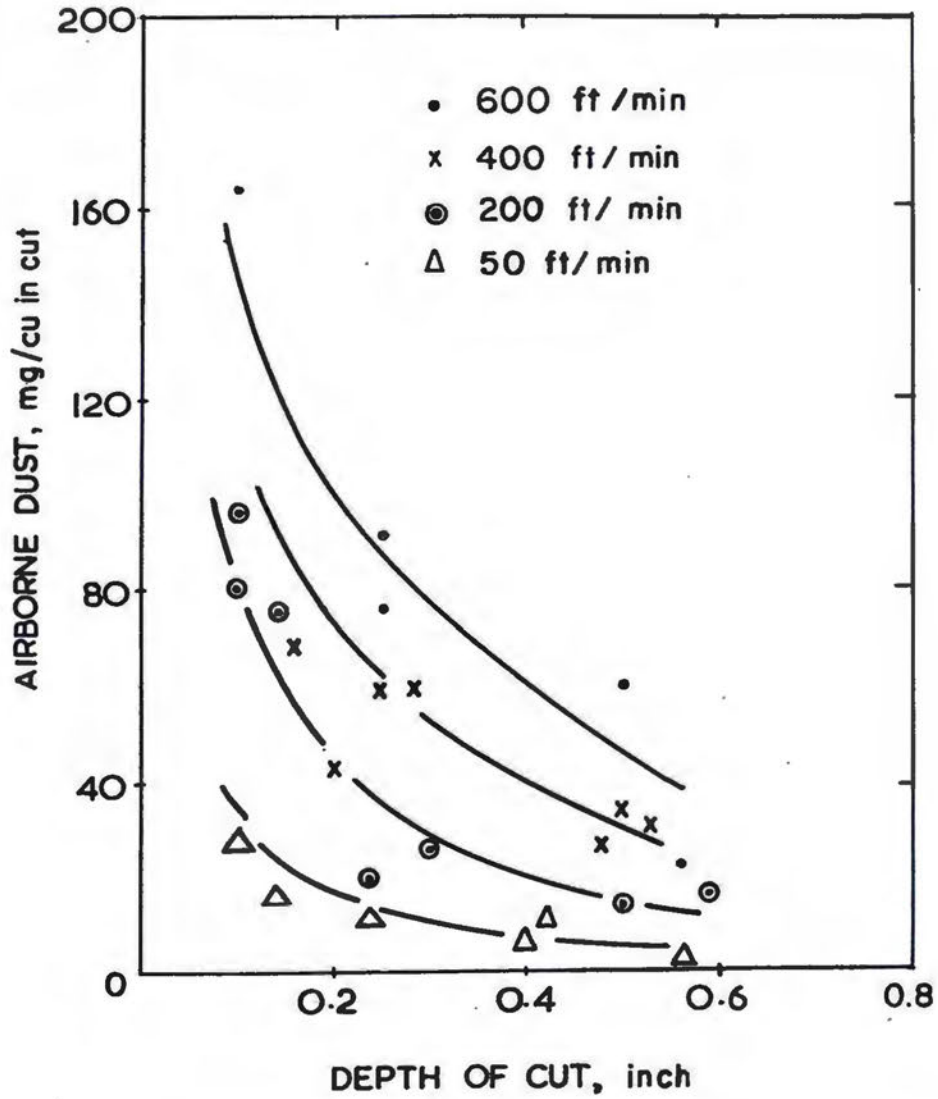


Figure 4.—Dust Dispersion From a Single Pick.

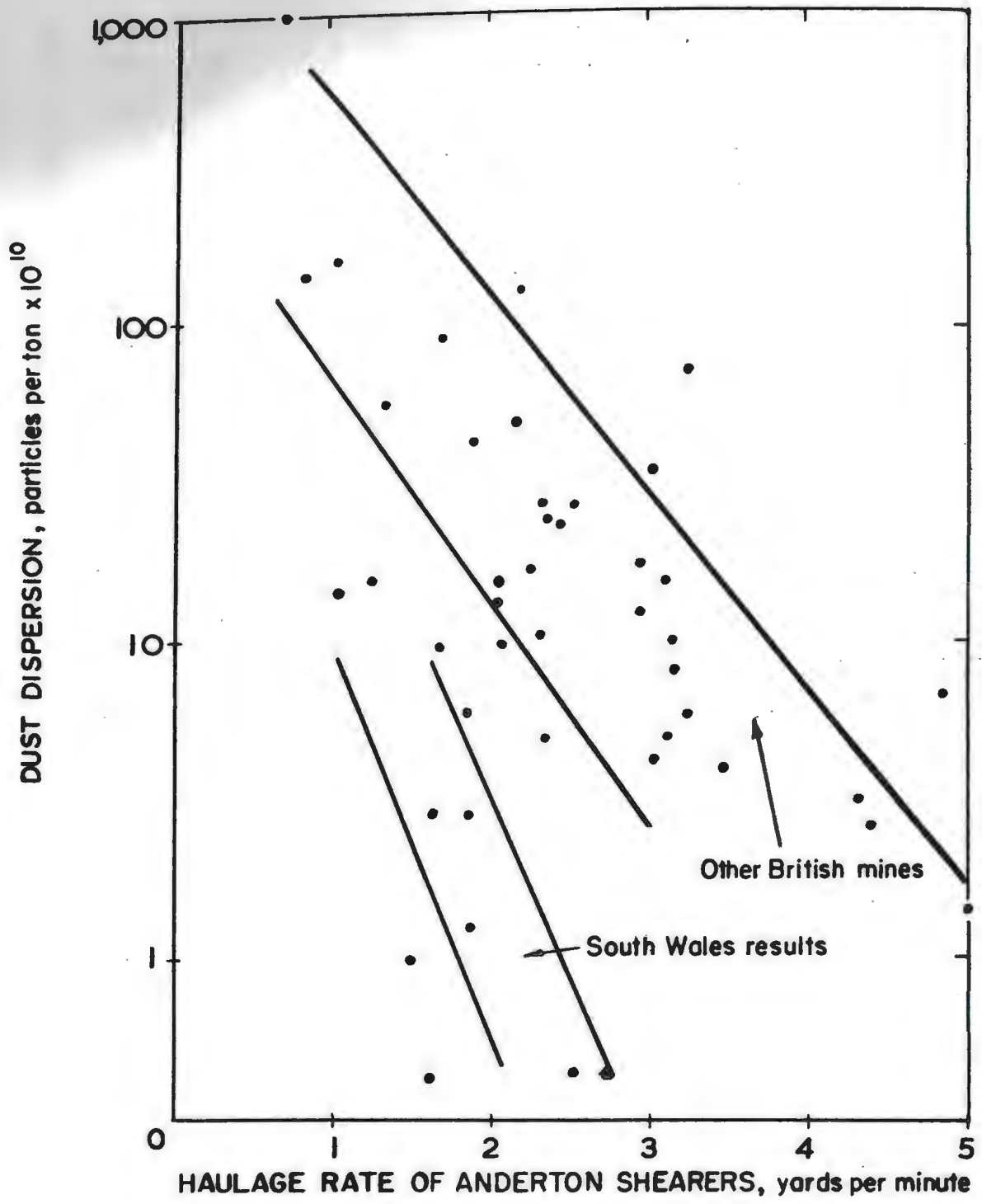


Figure 5.—Underground Measurements of Dust Dispersion at Different Haulage Rates by Anderson Shearers.

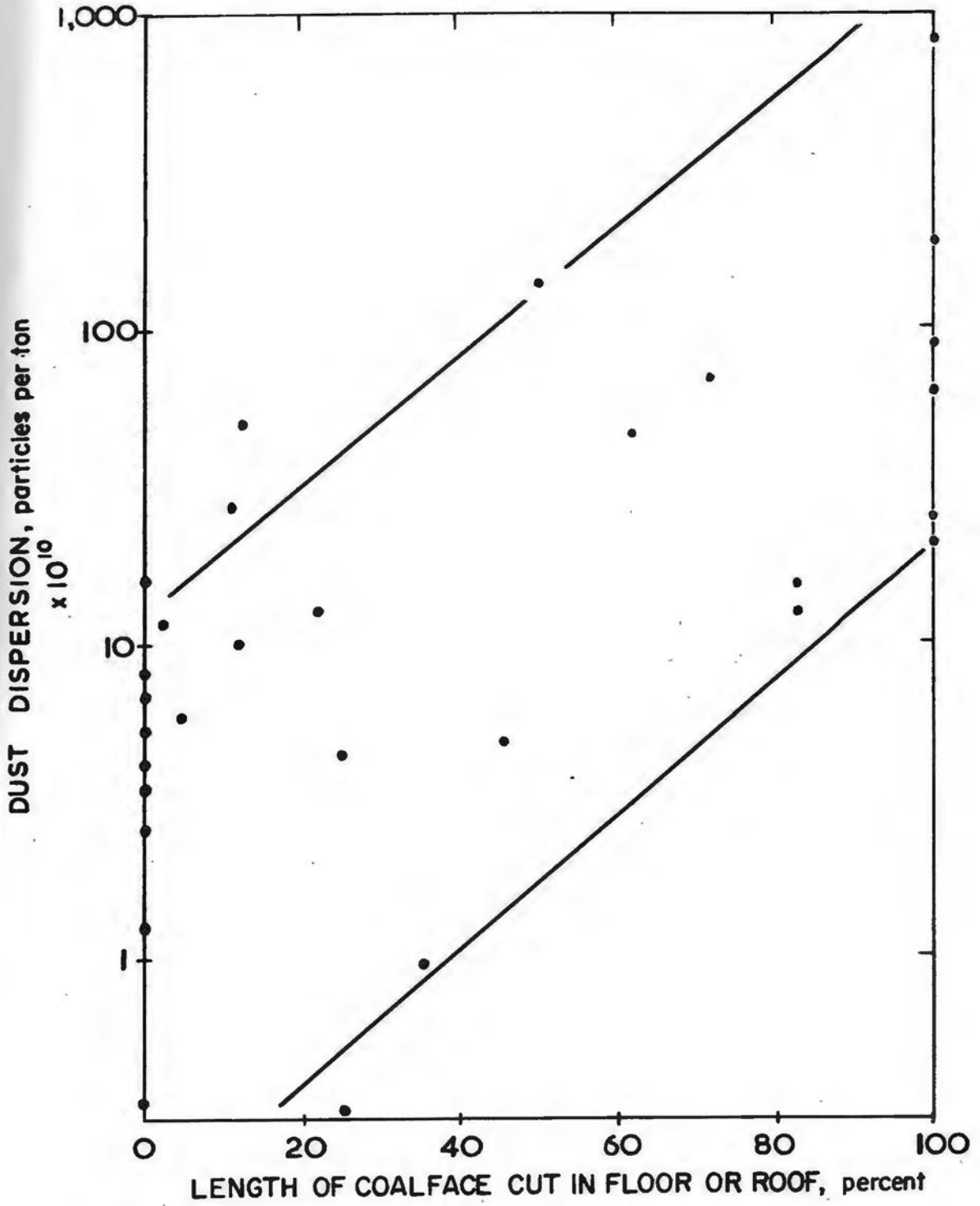


Figure 6.—Respirable Dust Dispersion and Cutting in the Floor (Anderson Shearers)

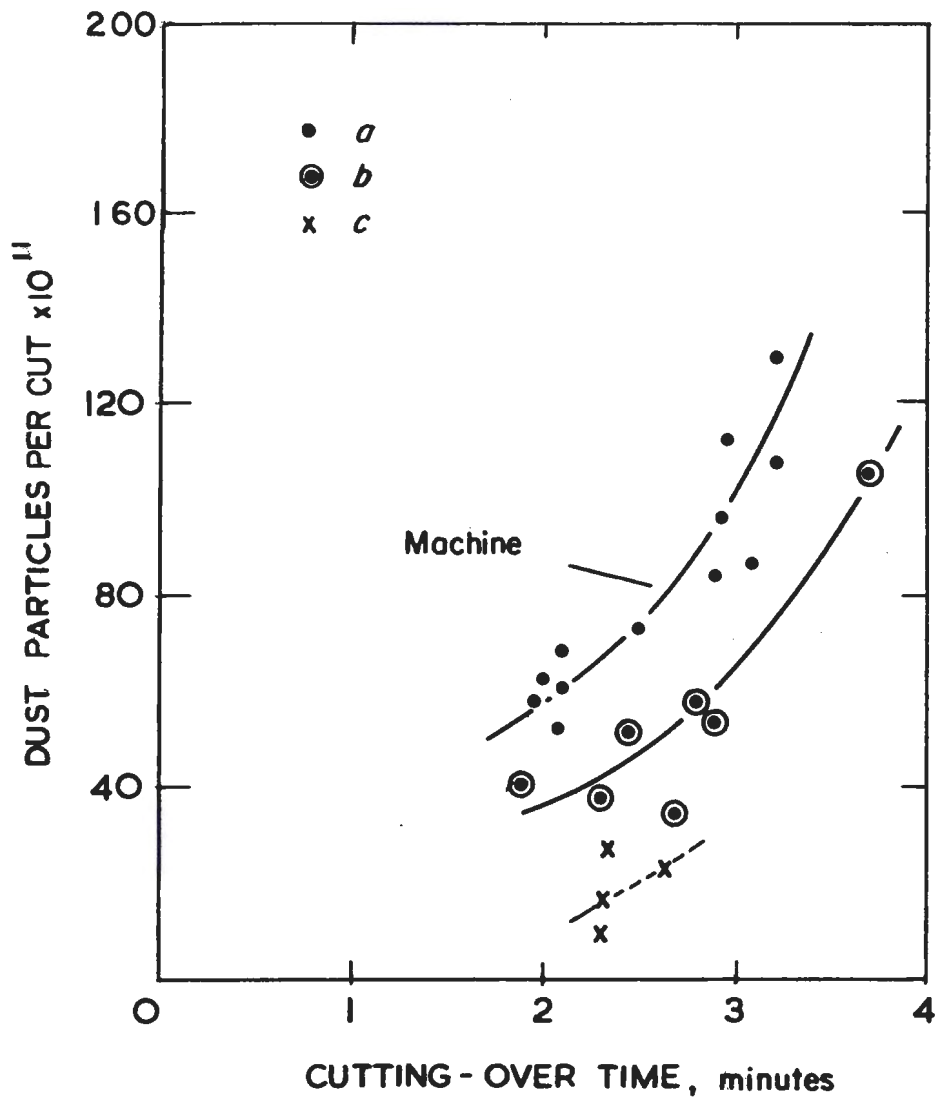
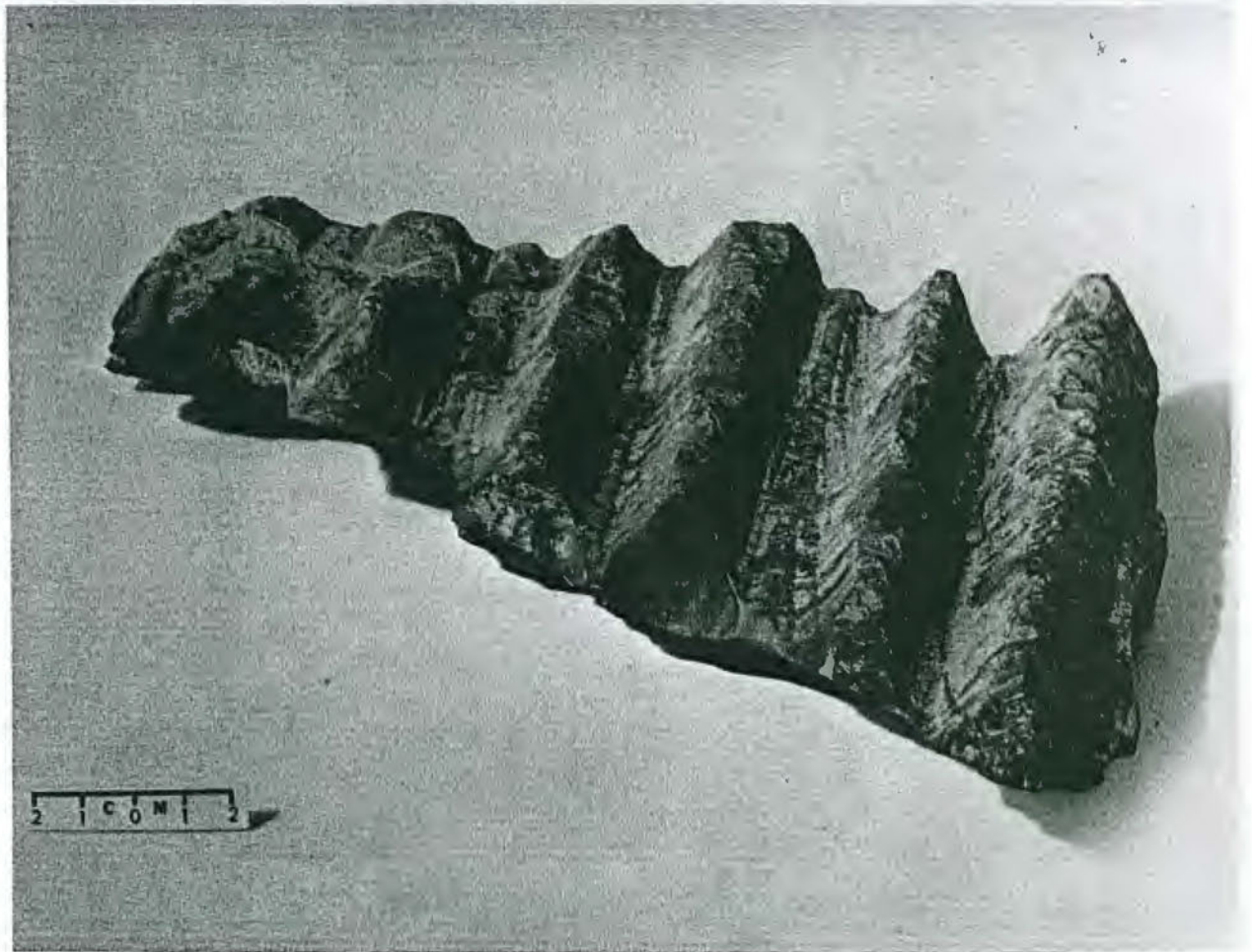


Figure 7.—Relationship Between Cutting-Over Time of a Roadway Ripping Machine and Respirable Dust Dispersion.



**Figure 8.—Shale Fragment From Roof Showing Coring (With High Dust Make) by  
“Dint Heading Machine.”**

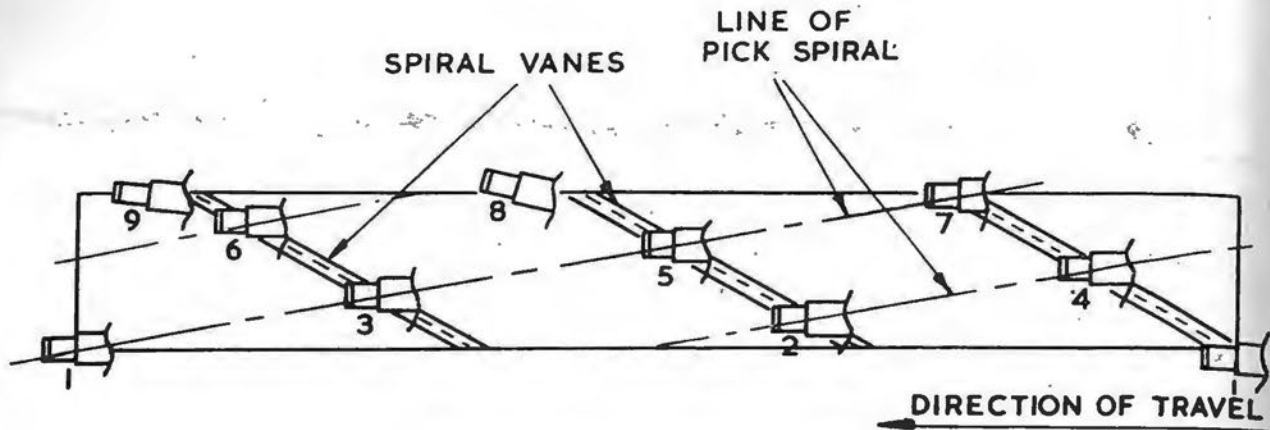


Figure 9A.—MRE Large-Pick Shearer Drum.

Picks 1, 3, 5, 7 First pattern  
 Picks 2, 4, 6, 8 Second pattern  
 Pick 9 Additional clearance pick

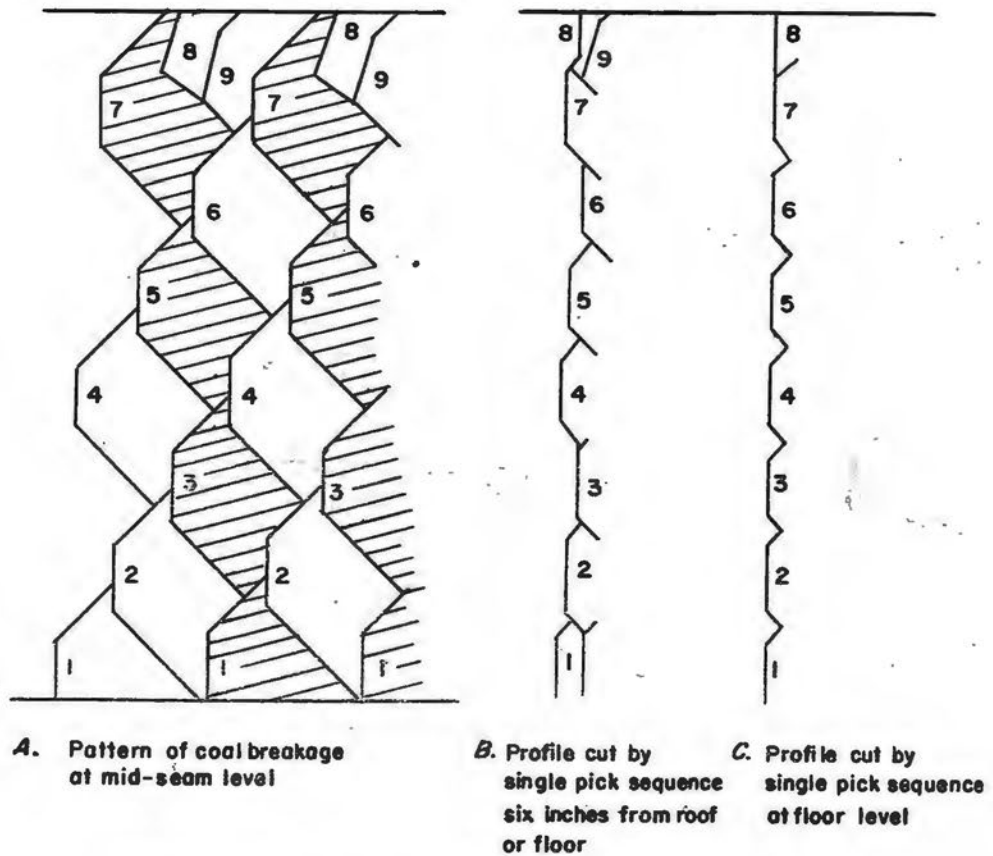


Figure 9B.—Breakage Pattern of Large Pick Drum at Midseam Height.



Figure 10.—Pick Face Flushing. A point-attack pick fed from a nonblocking jet.

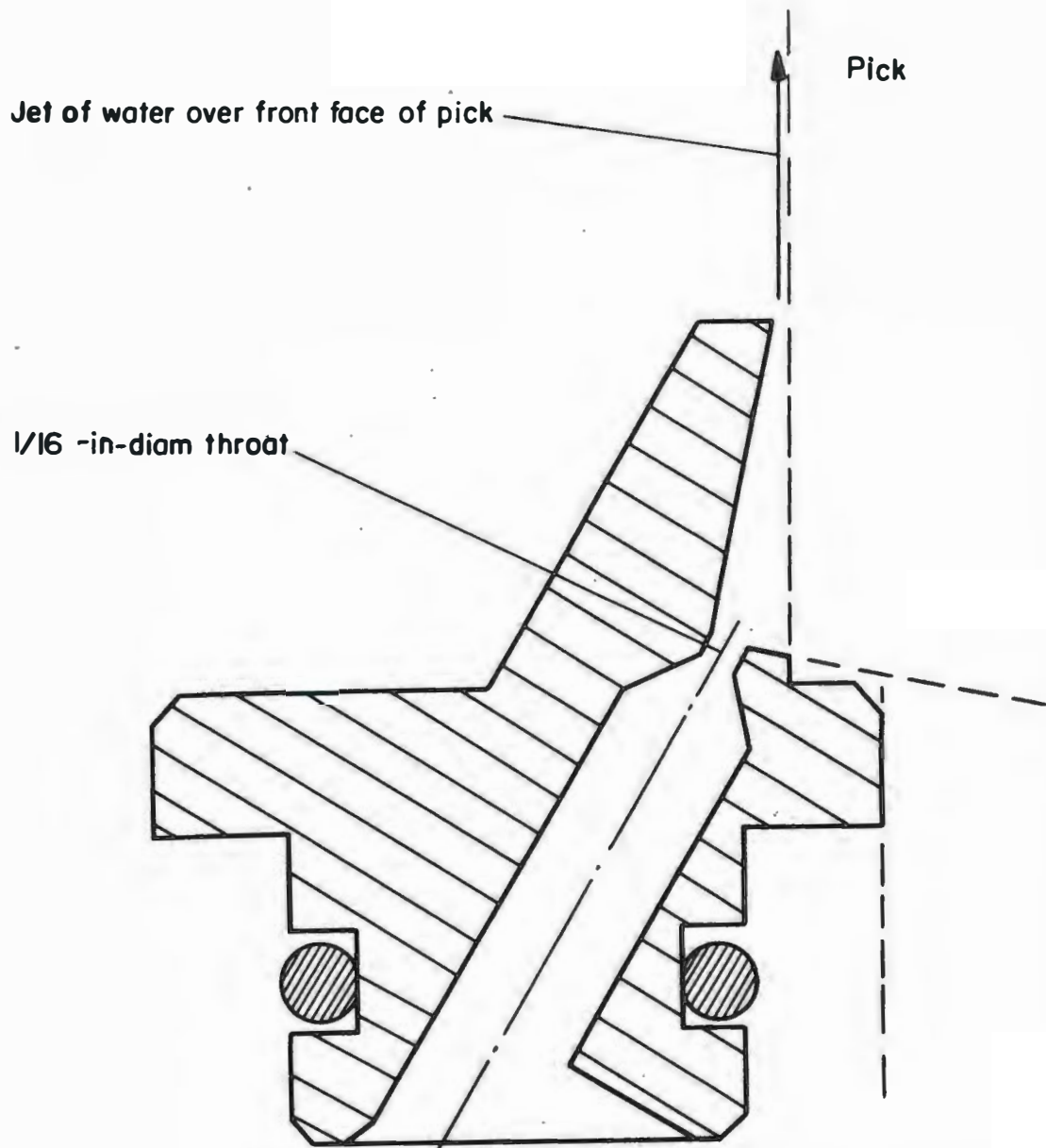


Figure 11.—Non-Blocking Water Jet.

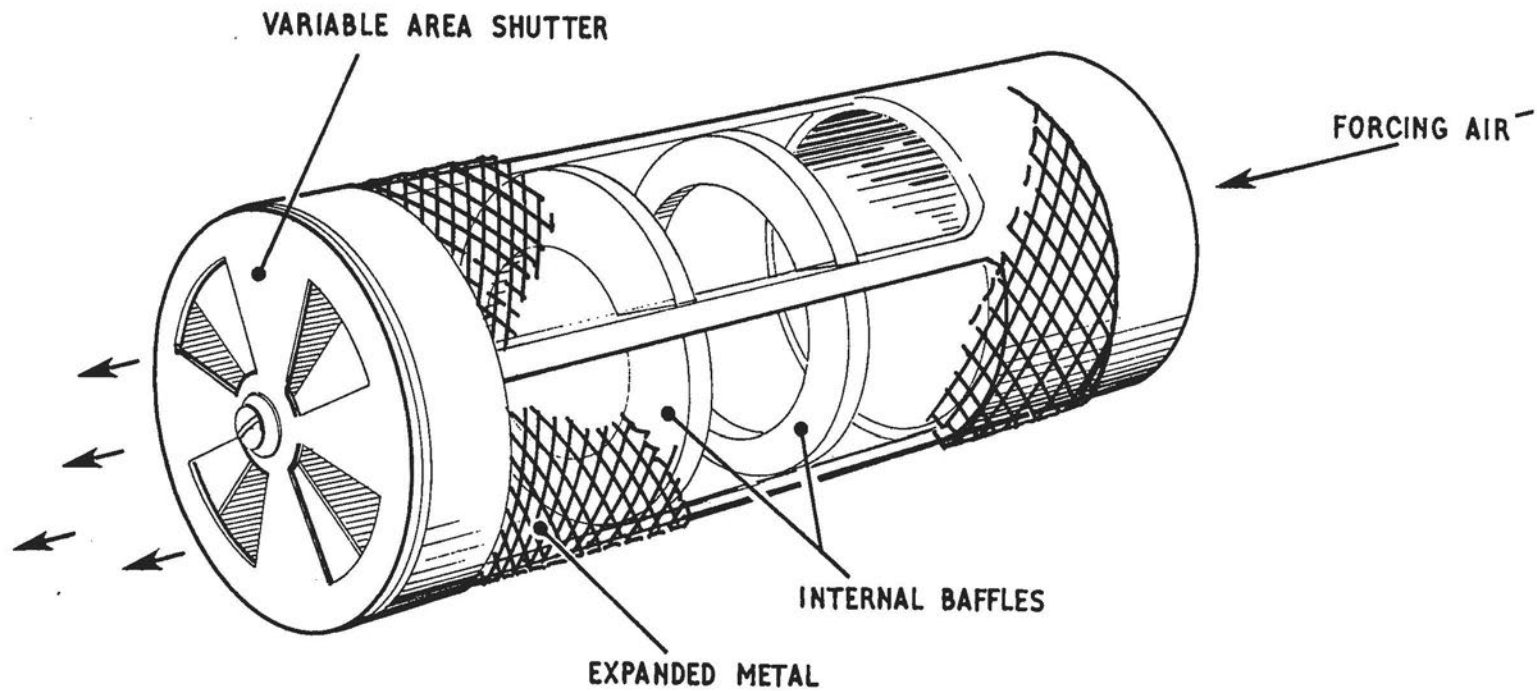


Figure 12.—Diffuser at End of Forcing Duct.

MR. CRENTZ: We now go to the state of the art of machine design, and we are very fortunate to have with us Rolf F. Arentzen, President, Lee-Norse Manufacturing Company.

## MACHINE DESIGN: STATE OF THE ART

by

Rolf F. Arentzen

---

---

My part of this program consists of identifying the state of the art of machine design. It would be very presumptuous of me to tell you that I understand fully what is expected. I expect to make many errors, both of omission and commission. However, I beg your indulgence. I will try to touch upon machine designs in order to stimulate interest in the areas already partially explored, plus the possibility of opening up new areas for examination.

To simplify the presentation, I have arbitrarily limited my thoughts to face machinery. Further, to reduce confusion, I have arbitrarily classified the face machinery into three broad groups of mining practice --- conventional, continuous, and longwall. You can see, also, that my concern with this study is only about underground face equipment.

The conventional mining machines that I will discuss are as follows: loaders, cutters, face drills, face transportation (which includes shuttle car, mine car, and conveyor), roof drills, and the last part of the mining cycle, use of explosives or Airdox or Cardox shells.

When we discuss loaders as 'dust generators,' the gathering device on the face end of the machine, the conveyor that dumps the coal into the transporting device, and finally the crawler track that moves the loader throughout the mine, are the parts of the machine involved. The various speeds at which gathering mechanism is operated do not significantly seem to change the amount of dust generation until the gathering device is used to maneuver and clean up the floor rib. High speeds on the loader's conveyor can cause dust only if the coal that is being transported is allowed to spew through the air into the transportation device such as the shuttle car, because while the coal is spewing through the air, the light particles of dust are separated out and remain suspended. The crawler track mechanism for moving the loader is not a dust generator except that it pulverizes and grinds the coal remaining on the floor, and if the grinding is sufficient, the small particles can easily be stirred into suspension. It might be remarked here that ineffective loader cleanup can allow a larger amount of coal on the floor to be crushed into powder.

The cutting machine (and in this case, I would like to confine my discussion to the universal type that can cut both top and bottom and shear) has as its dust generator the cutting chain which travels at various speeds. There are

many lacing designs and numerous kerf widths. Bug dusters are one of the first examples of dust suspension mechanisms because by not rapidly crushing the cuttings, the coarse particles do not become dust and go into suspension. Water sprays injected on the chain and water through the cutter bar, plus other ways, are used to reduce the dust produced.

The face drill has the auger as the dust generator and, being much smaller than a cutting machine's bar and chain, does not have a very difficult problem. Water injected as a spray and through the auger, etc., is used to contain any significant dust.

The face transportation method can be examined because the shuttle car, as it discharges at dumping points, does so very rapidly and allows its load to spew through the air, putting the smaller particles into suspension. The wheels that move the car crush the remaining coal of the roadway and under dry conditions can also be a source of dust. Here it is not only the coal dust but also the rock dust used to dilute and minimize the explosive nature of the coal dust.

Mine cars and conveyors, whether chain or rubber, all can have designs that generate dust if their loads are allowed to spew through air, because the smaller particles then go into suspension and we have what we call "dusty" conditions.

All of these machines can grind up coarse particles and reduce them to the size that can become airborne dust. The roof drill is a piece of machinery that is used to drill holes in rock, sandstone, etc. For this reason, dust collecting devices are always applied to the drill steel. Water injection through the drill steel is also a very popular dust suppression method. Any material coming out of the coal drilled in the roof is afforded maximum opportunity to have the air contact the smaller particles and put them into suspension.

Briefly, the last part of the conventional mining cycle is shooting, where either explosives, Airdox, or Cardox, are used in the face drilled openings. The use of water stemming is just an example of a design method that might reduce dust. I don't feel any machinery discussion can be involved in this area; I only include this paragraph for completeness of the mining cycle. Again, I could say that the machinery used for rock dusting has very special problems and I feel these should be discussed separately.

Continuous mining practice has developed using various types of mining machines --- the ripper, Colmol, and borer. Each of these machines uses some type of face transportation very similar to conventional mining practices, except that in some cases a loader or surge car is introduced between continuous miner and the face transportation. Roof drilling can be done separately, but in some cases, roof drills are mounted on the miner. As far as dust generating machine parts, these are all the same as with conventional mining practices.

The miner, however, has special machine problems. First the ripper, with a series of chains running on a bar similar to a cutting machine shearing from bottom to top, moves the coal into a loading machine-type conveyor with or without benefit of a gathering mechanism. These multiple chains have a like problem to cutting machines as dust generators. Water sprays and water injection in the

cutter bar close to the cutter chains have been applied, using the art of the cutting machine. The rotating/oscillating miner is constructed with cutter disks that mill by intersecting cusps in the coal face. Here, water sprays and water injection as close as possible to the cutter bits mounted in the disks are used.

The Colmol is a multiple-rotor boring machine. The dust generators are boring arms and again water spray is used to knock down any dust. Larger boring machines, similar in concept to the McKinley entry driver, also generate dust with boring arms. Added, however, to each of these were trim chains or trim bars, which originated from cutting machine practice. The Colmol was used to test a vacuum dust cleaning system because the boring arms, which were the dust generators, were confined by the machinery head, and there was only one avenue of escape for dust. In general, the machinery design problems are identical to the loading machine of conventional mining except for the addition of the various mining-type heads.

Longwall mining practice is just beginning in the United States, and the machines used are not manufactured in this country. However, the equipment usually consists of a miner, either shearing type or plow, mounted on an armored conveyor which is fixed to heavy yielding roof supports, and a stage loader to move the coal up from the armored conveyor into the entry conveyors. All these conveyors again are dust generators only if the coal spews through the air while being transferred from one to the other. The shearer is much like the continuous-miner cutting drums and, as a dust generator, has similar problems. The plow is unique, and I am sure other speakers will discuss how water injection directly through the plow teeth, or cutting tools, has been used.

With this brief background, you will recognize that most efforts for dust control relied upon applying water. I do not, however, want to minimize the many, many changes that have been made in ventilating schemes so that dust is removed from the immediate working area. For example, there are numerous continuous-mining machines operating where the ventilation is designed to carry fresh air toward the face with line brattice on the right or left hand rib directing the return. Into this fresh air is sprayed a steady amount of rock dust so that in the return air course the rock dust dilutes the float dust and eliminates an explosive hazard. This, of course, means that the particular operating crew is free from dust and all the dust problems are in the return air areas. Protection of people operating mines from being engulfed in dust and unable to see their work has usually been most readily solved by rearrangements of ventilating schemes. To a machine designer, this would mean that the machine should occupy the least volume of space in the entry and maximize the area available for ventilation. It would also mean that any device on the machine, such as fans on electric-cooled motors, which might disturb or alter the planned ventilating scheme, should not be encouraged. Planned diffusing and air moving methods are being studied, but each of these must be cognizant of the fact that we are also not only dealing with coal dust and rock dust but also with methane.

Early in machine design when water sprays were introduced, the mine supply system was usually a sump with a stationary water pump. Almost all machine designs today include a pressure-boosting water pump on the machine, and the mine water system is usually clean. Certain mines have water available at sufficient

pressure that the boost is not required. During this symposium I am sure that you will hear from the experts that once dust is in suspension it is very difficult to knock it down with water or any agent added to water. It's like the old story -- "Don't let it get started!" Every new machine design is directed to coarser cutting of the coal. Tool designs and gathering means are all geared to maximize the 3/4-inch size. Reducing the rotational speed of various cutting elements will not, however, increase coarseness. Increasing rotational speeds does not encourage dust, except when rates are excessive to effective cutting.

In conclusion, the following aspects are receiving major attention:

1. More effective cutting with an increase in coarse particle mining methods.
2. Reduction in the bulk of machinery to allow more effective automatic ventilation control.
3. Introduction of effective water-spray systems at the point closest to dust generators to minimize the amount of dust that gets into full air suspension.
4. Coordination of all these factors with the problem of diluting methane and avoiding explosive mixtures.

Necessarily, this presentation has been very brief. The "state of the art" of machine design always reflects the needs of the customer. When his needs are satisfied, the manufacturer makes a sale. The coal industry is small enough that there is a great deal of coordination between the planning of new mining systems and the introduction of new machinery. I have purposely refrained from discussing machines operated from the surface with no men in attendance underground. This was done because I believe that a dust symposium is concerned with the hazards for individuals working in this environment.

There are many, many people working hard to eliminate dust, not only because of its health hazard but also because dust obscures the working area and therefore persons operating machines cannot see what is happening.

I would like to answer any questions you might have, to the best of my ability, but I assure you there are more knowledgeable people sitting among you than I, standing here receiving your attention.

**QUESTION (Joe Good):** There appears to be one contradiction between the two speakers. Mr. Hamilton stated that reduction in rotary speed will greatly reduce the fines produced, and Mr. Arentzen says the opposite: in other words, it has no effect. What evidence is there on that?

**MR. ARENTZEN:** This question depends upon defining some other parameters. If you notice from Mr. Hamilton's speech, most of the dust was generated from rubbing and not from cutting. In other words, there was a trailing bit, or the trailing block that was causing the major portion of the dust. At high speeds this is true. Any rubbing action or misuse of cutting elements will cause

greater dust. Eliminating bits is a practical method for reducing the dust, if it is possible for you to have only one tool cutting an area, and when it breaks, the area will not remain standing. Therefore, as a practical experiment, cutter disks are laced so that you have at least two or possibly three tools traveling the same area. If they are not properly placed, and the rotational speeds are not properly synchronized, they will rub and cause dust, and the excessive speeds will cause greater dust with the rubbing bits.

MR. HAMILTON: We have found almost always that reducing pick speed does reduce dust, but obviously there are limits to this. The first is the strength of the picks, and the second is the amount of torque available, but since a bigger depth of cut uses less energy, it is often quite a surprise to operators and, I might say, to some machine designers at the gains that can be given by this approach. It is the old story of trying to steer a car out of a skid. If you do not really understand that you have to steer into the skid, you go the wrong way, and end up in a ditch. There is a great tendency to feel, "Well, we will put more picks on, and make it go faster, and we will get that coal out of the face," but, in fact, the other way, the general way of doing it rather slower and having fewer picks, can often pay off quite remarkably. I do ask you to try it some time.

MR. ARENTZEN: I quite agree with Mr. Hamilton that you should try it because, of course, you are going to discover exactly what tools are working on your machines. There is another factor that he has completely ignored. This is one that has come to our attention within the last 6 to 9 months.

We find that just like a crosscut saw cutting wood, there are only about two teeth of that saw that are doing the work, and the other teeth are being used to clear the cuttings out of the cut. We are discovering that by proper positioning and eliminating the cuttings, high rotational speed clears cuttings faster. The slower the speed, the slower the cuttings get out of the kerf, the longer time they take to get out of the way.

So there are several factors concerning speeds that have not been studied very carefully yet.

You realize that we are both talking about preliminary results. We are asking you to be good observers, and we are trying to point out several things;

Number one, in both cases we feel that you are not using your cutting tools to the best advantage on any of these machines.

Number two, you are using tools that are rubbing instead of cutting, and they should be eliminated or repositioned.

Number three, please look to see if you have any problems of not being able to clear the cuttings fast enough by improper use of the cutting speeds or by improper use of deflectors or shields or guides.

There are quite a few experiments going on throughout the whole country that are shaking people up quite a bit. We can show changes in penetration rates

of almost 100 percent with some very simple changes in cutting arrangements, and we really don't understand fully yet what is responsible, but we are working on most of this.

MR. CRENTZ: We come now to the section on dust collection equipment, and our first paper under that particular heading will be from Mr. Henning Soderberg, Regional Sales Manager, American Air Filter Company.

## DUST COLLECTION EQUIPMENT – THEORY AND OPERATION

by

Henning E. Soderberg

---

---

### INTRODUCTION

A dust collector is a piece of mechanical equipment, well-designed, using one or more of the six basic dust collecting principles to separate the maximum amount of dust or fume from a contaminated air stream. It may be wet or dry, operating at varying conditions of temperature, inlet moisture, dust loads, and type of dusts. It may also be designed to meet a specific outlet grain loading or specific dust collection efficiency and sometimes opacity requirements.

Before we review the various types of collectors and how they function, we must define at least one term used in the dust industry and that is the term micron. A mesh size of 325 is 44 microns, with 1 micron measuring 1/25,400 of an inch. To relate a comparison which helps to show how small a micron is, the average human eye can see only an individual dust particle of 10 to 20 microns. The average human hair, while small in diameter to most people, can be between 50 and 100 microns. To some authorities, 1 micron is the reference point that distinguishes between fume which is less than 1 micron and dust which is larger than 1 micron.

### TYPES OF DUST COLLECTORS

This discussion will be limited only to the theory and operation of dust collectors as applied to particulate matter. There are four general types of dust collectors:

1. Dry centrifugal (mechanical) or inertial collectors.
2. Fabric collectors.
3. Wet collectors, low- to medium-pressure drop and high-pressure drop venturi scrubbers.
4. Electrostatic precipitators.

Settling chambers will not be discussed, as their effectiveness on the finer dust particles is poor, plus requiring large operating space.

## DRY CENTRIFUGAL (MECHANICAL) COLLECTORS

As the name implies, centrifugal force is the principle used in this type of collector. It has no moving parts (except one special type, discussed later) and makes use of particle inertia to separate the particles from the air stream when there is a change in direction or when directing the particle in a circular path. The centrifugal force applied to a particle varies as the square of the inlet velocity and inversely as the radius of the cyclone. This can be expressed as follows:

$$SF = V^2/rg,$$

where SF is separation factor, V = inlet velocity ft/sec, r = cyclone radius in feet, and g = gravity constant of 32.2 ft/sec.<sup>2</sup>

There are a number of different designs of cyclone collectors using this basic principle but with different variations. The large-diameter single cyclone, almost always mounted in a vertical position, provides the spin, due to its round shape (fig. 1). The particles tend to move toward the outward wall in a downward direction finally ending up collected in a hopper. The decreasing diameter of the cyclone tapered hopper increases the centrifugal force. There is also an inner spiral of air up the center of the cyclone through the cyclone outlet. The large-diameter cyclone has a low pressure drop, 1.5 to 2.0 inches of water, with approximately 50-percent collection efficiency by weight on 20-micron dust particles. A variation of this type of design is the skimmer and hopper combination where the air enters top horizontal and the contaminants are "skimmed off" into the hopper through a slot on the bottom of the skimmer. The air leaves with a 90° change in direction, but still in a horizontal direction (fig. 2).

Reducing the diameter of the cyclone, increasing the length of the cone or body, and increasing the height of the inlet with corresponding reduction of the width of the inlet to the cyclone will all increase the efficiency of the single-tube collector. The pressure drop is between 3 and 5 inches of water with an efficiency of approximately 80 percent on 10-micron particles (fig. 3).

To further increase collection efficiency, multiple-tube cyclones of smaller diameter are used, operating in parallel in a common housing and having a common air inlet and outlet. The inlet flow pattern of this type is different from that of the large cyclone as the air enters at the top of the collector tube through spin vanes instead of tangentially as in the large-diameter cyclone. The spin vanes impart a swirling action or centrifugal force on the dust particles. Tube diameters usually range in size from 4 to 30 inches with collection efficiency by weight on 7.5-micron dust particles of approximately 90 percent at a pressure drop of 3 to 5 inches of water. (fig. 4).

There is another type of multiple-tube dry centrifugal collector using a series of small tubes, 4 to 9 inches in diameter, which requires a secondary dust circuit completely independent of the main air circuit. The secondary

circuit is complete with collector tubes, fan, and motor. Efficiencies are high and can be further improved by providing a higher percentage of secondary air which normally is 10 percent of the primary air. The secondary air is continuously recirculated back into the main collector inlet. This design is unique as it provides constant efficiency down to 50 percent of nominal rating which is not true for other cyclone designs. (fig. 5).

For cyclones, the efficiency will increase with an increase in --

1. Gas inlet duct height in relation to duct width.
2. Particle size or density.
3. Gas inlet velocity.
4. Cyclone body or cone length.
5. Ratio of body diameter to gas outlet diameter.
6. Lower gas viscosity (lower temperature).

The next type is a dry centrifugal collector with a rotating wheel which serves both as a dust collector and an exhaust fan (fig. 6). The rotating wheel creates centrifugal forces on the dust particles, causing them to ride off the end of each blade tip into a dust circuit in the housing which goes into the hopper. The hopper is vented back to the fan circuit continuously to compensate for the entrained air that flows with the dust.

On all dry cyclone collectors with the fan on the clean air side, a good seal must be provided on the hopper outlet to maintain high collection efficiency. Collection efficiency of a multiple-tube collector may not be quite as high in comparison with an individual tube of the same size due to reentrainment of dust from the hopper if not properly designed or applied.

#### FABRIC COLLECTORS

Fabric has been used for years as a means of collecting particulate matter and fume. The fabric collector has been referred to as a baghouse, bag collector, cloth arrester, or cloth collector. General acceptance would probably refer to the "on the job" erected large cloth installation as a baghouse and smaller assembled or partially assembled collectors, shipped to a jobsite, as a cloth collector.

The fabric used in the cloth collector is normally woven to provide a tight weave, although under close examination the weave would reveal rather large open spaces. Felted material would have fewer openings in the fabric structure. Because of the collection ability of woven fabric media, the filtering process cannot be only a straining or sieving process.

The fabric used in cloth collectors can vary in type of material and weave. With clean cloth, the resistance to air flow is a function of the permeability which in turn is affected by the type of fiber, the weave, and the thread count. A tighter weave offers more resistance than a loose weave, other things being equal. Permeability is defined as the flow rate (cfm) that can pass through a square foot of clean cloth media at a pressure drop of 0.50 inches of water. The usual range of values is from 10 to 80. Other factors used in cloth evaluation are weight of fabric in ounces per square yard, strength of fiber (Mullan burst strength), and tensile strength.

The material used for the cloth bags varies widely because of the different conditions encountered in industry such as dust characteristics, temperature, dust load moisture, and possible chemical reaction. The most common fabrics are cotton, wool, the synthetic monofilament thread of nylon, orlon, and dacron, and siliconized glass fiber. The normal temperature limitation and degree of chemical resistance is shown in table 1.

TABLE 1.--Temperature limitations and chemical resistance of fabrics used in cloth collectors

Fabric	Recommended maximum safe continuous temperature, ° F	Chemical resistance	
		Acid	Alkali
Cotton.....	180	Poor	Fair
Polypropylene.....	225	Good	Good
Wool.....	200	do.	Poor
Nylon.....	225	do.	do.
Orlon.....	275	do.	Fair
Dacron.....	275	do.	Good
Siliconized glass.....	550	( <sup>1</sup> )	( <sup>1</sup> )

<sup>1</sup> High concentration of both acids and alkali will damage coating or glass. Glass fabric extremely poor on HF.

Collection of the dust on the fabric initially starts by the straining or sieving action plus diffusion, impingement, interception, and gravitational and electrostatic forces.

Diffusion is the condition where very small micron particles, less than 0.20 micron in size, increase the chance of contact between particles and collecting surfaces because these particles no longer follow streamline paths. Their erratic movement, called Brownian movement, causes collision with gas molecules and increases the chance of contact between particles and the collecting fiber surfaces.

Impingement or impaction occurs when a particle flowing in an air stream approaches a target object. The gas must diverge to flow around the object but the inertia of dust particles approximately 1 micron and larger tends to

keep these particles on their original course providing the possibility of collision.

When the small particle remains on the streamline as it diverges around the object, the streamlines become closer together. Interception is the process where a collision will occur if the dust particle's center misses the target by any dimension less than the particle radius.

Particles of sufficient size and density to be susceptible to gravitational forces offer no difficulty for collection in a cloth collector. Electrostatic forces will provide an attraction between the dust particles and the fabric and agglomeration between the dust particles aiding in the collecting process.

Once the dust particles start to form on the cloth surface, the fabric then acts only as a screen and quickly builds a layer of dust or fume particles that actually do the filtering.

The resistance through the media in a cloth collector is expressed as follows:

$$R_f - R_i = R = \frac{K L T V^2}{7,000},$$

where  $R_f$  = maximum resistance at end of any given operating period in inches of water;  $R_i$  = initial resistance in inches of water;  $R$  = increase of resistance in time  $T$ , in inches of water;  $K$  = specific resistance or resistance factor of the deposit, inches water gage/pound dust per square foot cloth area per foot per minute filtering velocity;  $L$  = dust loading in air coming to filter, grains per cubic foot;  $T$  = time in minutes;  $V$  = filtering velocity, fpm.

From that formula, we can see that the pressure drop or resistance will vary as the velocity squared if the dust loading and particle size distribution remains constant, and there will be a linear variation of resistance with variation of dust load when the volume is constant.

New media when installed in a cloth collector or baghouse will have an extremely low initial resistance because the inner voids or openings of the cloth fabric have not been closed off and no "cake" has formed on the fabric surface. This is why on some applications there is a slight visible discharge after initial operation of new fabric. It has been reported that the instantaneous efficiency of new cloth fabric can be as low as 80 percent by weight on some fume applications. After the fabric has been cleaned, its resistance will never return to that of new fabric because of dust left in the body and on the surface of the fabric which is referred to as "residual resistance". When designing a dust system, these variations must be remembered plus the pressure drop across the cloth fabric prior to cleaning, which is in the range of 3 to 8 inches, if design air volume is to be maintained.

The air-to-cloth ratio or fpm velocity employed through the cloth media is a function of the dust loading application and design of cloth collector. Competent manufacturers of dust control equipment have this information available. In general it will range between 1.5 to 4.0 fpm velocity for all types and designs except reverse and pulse jet.

The size and shape of the filter element used in a collector is a function of the type of cleaning method used, the practical recovery or usage of as much filter media from the source of supply as possible, and as much cloth area in a fixed space as possible. Shaker collectors generally use 5- to 8-inch-diameter bags, reverse jet collectors 9- to 10-inch-diameter bags, and reverse flow or collapse collectors 11 1/2-inch-diameter bags when made of siliconized glass and dacron material. Bag lengths are from 8.5 feet to 22 feet long for shaker collectors using 5- to 8-inch bag diameter and 30 to 34 feet for reverse flow (collapse) and reverse jet collectors.

The cleaning of fabric will fall into one of five basic and generally accepted types. They are shaking, reverse jet, pulse jet, simple collapse, and reverse air back flow.

In a shaker collector the bags are flexed and moved slightly by a hand- or motor-driven mechanical shaker which provides a shaking movement to the bags. This cleaning can be done only when the air flow is cut off to the section that is to be cleaned or the entire collector is shut off. The collected "cake" is then shaken off the cloth media during this fairly violent cleaning cycle of about 1 to 2 minutes (fig. 7).

The cleaning in a reverse jet collector occurs when a traveling blow case which completely encircles a bag or cloth tube runs continuously up and down the tube. Cleaning with this design can be done while the collector fan is running and air is flowing through the cloth. Normal air flow from each blow case for each bag is 50 cfm at 25 to 30 psig at the blow case. The action of the case going up and down along the bag length breaks the dust "cake" formed inside the bag and displaces it toward the hopper. Slightly more effective cleaning is obtained during the downward direction. Air to cloth ratios of 5 to 15 fpm are standard in this design of collector. Also heated air can be supplied to the blow case to permit operation for applications which are borderline due to high moisture content (fig. 8).

Another type of design in the same cleaning category is the pulse jet principle where the cloth tube encircles a wire form and the dust collects on the outer surface of the bag. A periodic discharge of compressed air down the center of the bag on the clean air side causes a pulsation in the cloth fabric which results in a cleaning action when the collector is in operation. Air to cloth ratio in this type of collector design is 5 to 15 fpm (fig. 9).

The fourth method of cleaning is a simple bag collapse in which small quantities of reverse air cause the bag to collapse. Collectors using this method of cleaning must operate when the section is taken off the air stream. The normal fabric used is siliconized glass or dacron, shaking can be incorporated in conjunction with bag collapse, but extreme care must be employed

using glass fabric due to its being very fragile. Support rings sewn into the media at certain spaced intervals along the length of the bag will cause the bag distortion and better cleaning. The normal cleaning cycle is 1 to 3 minutes with several reinflations and collapses built into the cleaning cycle, required, before the bags are finally fully inflated and brought back on the line.

Reverse air flow (back flushing) incorporates the design of taking outside air and blowing through the media in a reverse direction. This accomplishes continuous cleaning with only a minimum of pockets taken out of service at any one time. This type of design can also use heated "blowback" air for prevention of moisture or condensation problems in the collector itself.

Normally design pressure drops for any of the types of cloth collectors except reverse jet or pulse jet will be about 4 to 5 inches of water before cleaning and 1.5 to 2.0 inches after cleaning. Cleaning cycles are normally fully automatic on a timer or pressure drop (resistance) basis for the collapse and mechanical shaker collector. The reverse and pulse jet are continuous cleaning and will maintain nearly constant operating resistance.

The life of cloth media is a function of many variables, but if the collector and system are properly designed and maintained, media should last from 12 to 24 months on nearly all applications and longer. The collector efficiency will be 99.9 + percent by weight with no visible discharge, but there is still some measurable dust in the discharge gases. There can be a slight variation in cloth collector efficiency depending upon the type of cleaning method used. The collapse or reverse flow is the best, with efficiency of the shaker method being slightly lower due to the more violent shaking.

#### WET COLLECTORS

A wet collector is a device for removing contaminants from the air stream with the use of water or other scrubbing liquids. There are many varied designs and principles used to accomplish this intermixing of the air and water. One basic mechanism used is wetting of the particulate matter by contact with the scrubbing liquid. This is accomplished by some of the same collecting forces that were discussed under cloth collectors, which are diffusion, impingement, interception, gravitational force, and centrifugal force plus condensation. The effect of condensation improving the efficiency of a wet collector only applies where the system is handling hot gases or high-humidity air. Gas cooling below the dewpoint results in condensation which can use the dust as the nuclei for condensation. This increases the size of the dust particle making it easier to collect. The overall effectiveness or improvement of efficiency is small however. The effects of humidification and electrostatic forces aiding in wet collector performance to date show little effect, although it is not fully understood.

Since designs are varied in the many wet collectors that are manufactured, they can be broken down into several general types. There may be slight variations to this classification in different texts but this is intended for the classification of collectors designed for the removal of dust:

1. Spray (chamber or tower).
2. Wet centrifugal.
3. Wet dynamic.
4. Orifice.
5. Mechanical scrubbers.
6. Fogging or high-pressure spray.
7. Venturi.

The spray chamber or spray tower is a simple collector with low to medium efficiency of 70 to 90 percent on 10 microns. Water is introduced through spray nozzles into the collector and gas stream at water pressure from 10 to 100 psi. Higher water pressures will take it into a different category which will be discussed later. In the spray tower, the air can either enter tangentially or "straight in" near the bottom. In both designs water is added normally against the direction of air flow (fig. 10).

Pressure loss of these collectors range from 1/2 to 2 inches of water, and water requirements, not including evaporation, run 2 1/2 to 6 gal per 1,000 cfm. Recirculation of water is permissible if nozzles are modified for such use since fine atomizing mist is not required.

The wet centrifugal collector is one of the types where a centrifugal force is used to accelerate the dust particles and impinge them on a wetted surface. The continued wetting action results in the collected dust flowing from the collector as a slurry. The normal water rate, not including evaporation, is from 2 1/2 to 5 gal per 1,000 cfm at low water pressure of from 10 to 20 psi, as water is introduced into the air stream by open pipes with the water flowing down by gravity and the resulting induced water is picked up by the air stream. Water can be recirculated to a maximum of from 5 to 10 percent solids. The pressure drop of this general type collector is in the range of 2 1/2 to 6 inches. (fig. 11).

The wet dynamic collector is unique as it is a combined fan and dust collector. The dust particles are impinged onto the number of wet blades of the wheel by centrifugal force. The water is supplied to the collector by a flat and hollow cone spray nozzle. While there is no internal pressure loss in this design, the mechanical or blower efficiency is lower than a conventional fan. Water requirements are much lower in this type of design, requiring only 1/2 to 1.5 gal per 1,000 cfm. Recirculation of water is not feasible on this design because of the spray nozzles' pluggage and wear (fig. 12).

The orifice collector is a heavy-duty residual water bath collector. Water and air flow through a fixed shape or orifice where the air and water intermixing occurs. The collecting efficiency depends on the pickup or delivery of large quantities of water to an area where centrifugal forces, impingement, and collision occur causing wetting of the particulate and its removal from the air stream. The actual water quantities in motion run from 10 to 20 gal per 1,000 cfm without the use of spray nozzles or recirculation pumps (fig. 13).

Because of its basic design simplicity, the absence of ledges for build-up, moving parts, and restrictive passages, this type of design has considerable appeal for applications involving explosive dusts and for sticky or fibrous materials.

The pressure drop varies from design to design but will range from 3 to 6 inches. Water requirements are low, being from 1/2 to 2 gal per 1,000 cfm at low water supply pressure.

A collector using a mechanical device such as a rotary paddle wheel or cage to fragment and atomize the liquid can be classified as a mechanical scrubber. Water is usually recirculated. Because the spray is generated in a restricted passage, there is extreme turbulence which increases the chance for collision between the particles and the spray droplets (fig. 14).

Pressure drop for this collector is lower, from 2 to 4 inches of water, than other wet collectors of the same degree of collection efficiency range. However, power is required for the mechanical wheel or cage, so total power input is comparable to other types of collectors in the same efficiency range. Water requirements are similar to those of the orifice scrubber. The collection efficiency of wet collectors under types 2 to 5 is basically the same - about 99 percent by weight on an 8- to 10-micron particle.

The fogging or high-pressure spray collector is a design using sprays and impingement plates. It employs the use of finer water droplets resulting from high-pressure sprays. Increasing the pressure at the nozzles increases the collection efficiency by creating more and smaller droplets, plus giving them more force. Water consumption can vary between 5 and 15 gal per 1,000 cfm at pressures from 100 to 300 psi and higher. The actual pressure drop across the collector is low by wet collector standards as it ranges from 1 to 2 inches of water, but additional power is imparted to the supply water. This design does show slightly higher collection efficiency for the total horsepower consumed as compared with other high-pressure drop collectors, but the high maintenance on the nozzles from wear and pluggage, the high rate of water usage, and the limitation of water recirculation make this type of collector not as readily acceptable as other comparable collectors.

The venturi collector provides a very flexible design for a high degree of efficiency on fine dust and fumes. It has an opening, circular or rectangular, where water injected into the throat at pressures between 20 to 40 psi at the water flow rate of from 5 to 10 gal per 1,000 cfm is shredded by the incoming air into a multitude of fine droplets (fig. 15). The velocity of the

dust particle is imparted to the water droplet and caught. Increasing the pressure drop across the throat increases the velocity of the incoming air and dust particle and the efficiency of the venturi. Pressure drops can vary from as low as 5 inches to as high as 100 inches of water.

The throat section is only a mixing box for the air and water and must be followed by a water eliminator (fig. 16). Water can be recirculated to at least 10 percent solids on most installations. Designs incorporating variable throat areas can be easily provided making this collector a very flexible type requiring minimum space requirements with high efficiency and low maintenance.

### ELECTROSTATIC COLLECTOR

In the electrostatic precipitator, electric forces are used for the collection of dust particles. The electrical force can be applied directly on the particles, whereas for mechanical collectors, the entire flow, gas and, particles are subjected to the forces. The obvious advantage of this is the lower power which is considerably less for the electrical precipitator than for the collector using mechanical forces.

The principle for electrostatic collection is well known. The particles are given an electrical charge negative or positive. Under the influence of an electric field, the charged particles will migrate toward the electrode with an opposite charge. The collecting electrode is often a grounded plate with the ability to collect the dust and discharge it into a hopper (fig. 17).

Precipitators come in different designs, but for simplicity let us discuss the operating principle of the tube-type design. The collecting surface is a tube, surrounding the high-voltage wire in its center. The gas to be cleaned enters at the bottom, flows up the tube and the cleaned gas is discharged at the top. Regular ac power is transformed to high-voltage dc. current, filtered through a rectifier set, and sent to the discharge electrode in the center of the tube. The tube or collecting electrode is connected to ground. As dust accumulates on the wall of the tube, the tube is intermittently vibrated to discharge the dust into the hopper underneath the bottom of the tube.

Negative as well as positive discharge electrodes can be used for precipitation. Positive corona is used primarily for air-cleaning purposes (air-filter installations). It creates less ozone in the gases, which is important when air is recirculated. For dust collection applications, negative corona is preferred because of the more stable corona and higher current densities and voltages that are possible.

There are primarily two mechanisms involved in the charging process of a particle. In field charging, particles are charged because of the impact of gas ions flowing from the negative to the positive electrode. In diffusion charging, particles are charged by the thermal energy of the gas ions. The time required for charging a particle is only a matter of fractions of a

second. This means that the dust particle is charged within the first few inches after entering a precipitator.

The next step in the precipitation process is to transport the charged particles to the collecting electrode. This is accomplished by electrostatic or coulomb force on the particle. The charged particles in the precipitator will therefore migrate toward the electrode with a polarity opposite the charge on the particle, which is the grounded tube. It is now apparent that the wire-tube electrode system provides the two basic requirements needed for electrostatic precipitation: (1) the corona required for charging the particle and (2) the field to make the charged particle migrate toward the collecting electrode. These two functions need not necessarily be carried out in one stage. In a so-called two-stage precipitator the charging is carried out in one stage and the collection in a second stage. One-stage precipitators are, however, by far the more common.

The force resisting the migration of the charged particle is primarily the friction of the gas. The normal migration speed is about 30 feet per minute.

When the particle arrives at the wall or collecting surface it retains its charge to some degree preventing re-entrainment to the gas stream. When an appropriate layer is collected, the material is dislodged into the hopper by rapping.

The formula for collection efficiency is the well-known Deutsch formula:

$$\eta = 1 - \frac{1}{e^{\frac{WA}{V}}},$$

$\eta$  = collection efficiency,

where  $W$  = migration velocity, fpm;  $A$  = collecting electrode surface, ft<sup>2</sup>;  $V$  = gas flow, cfm; and  $e$  = 2.7182.

The Deutsch formula is valid for some ideal conditions. However, in the operating field many factors influence the actual performance. The equation, therefore, indicates maximum performance rather than expected performance. Some of the disturbances are turbulence, dust resistivity, dielectric properties of the dust, re-entrainment, electric wind, and others. To take care of these, values based on experience are used for the value of the migration velocity,  $W$ .

There are other types of precipitator designs. The most common industrial precipitator is the duct type. The gas is evenly distributed at the precipitator inlet by the use of a perforated plate. The collecting electrodes are primarily flat plates, arranged in ducts. Between these ducts hang the high-tension wires from a frame at the top, kept taut by the use of weights at the bottom. To keep the wires well aligned to the plates, the weights are positioned by a frame at the bottom.

The equipment supplying the high-voltage current consists of transformers, rectifiers, and control equipment. The purpose of the transformer is to provide high-voltage current from low-voltage supply.

Until recently only mechanical rectifiers were used and are now in use on most precipitators today. The next type developed was rectifier tubes. The advantage was lower power cost, but they are more expensive than the mechanical type. The latest development type is the silicon rectifier. It costs more but requires less maintenance and power.

From the efficiency and migration velocity equations, it is shown that the higher the voltage, the better the efficiency up to the limiting factor, excessive arcing. Some arcing or sparking is acceptable, but if the spark rate is too high, too much power will be dissipated by the sparking. To maintain proper voltage modern precipitators are provided with spark control units.

One important factor required for successful collection of the dust is resistivity, which simply defined is the capacity of resistance of the collected dust which is attached to the collecting electrode. High resistivity means the collected dust has poor conductivity and the voltage drop in the collected material can become so high that the corona discharge on the ionizing wires ceases to function and then the efficiency falls off.

Low resistivity is just the opposite where the charge in the collected material doesn't remain in the material which causes re-entrainment of dust back to the air stream. Too high or too low resistivity is normally remedied by supplying chemical additives to the gas.

If conditioning is not possible, a different design may have to be used, such as a wet precipitator. This type is used for collection of some high-resistivity metallurgical dust where water is supplied to collecting plates providing the proper conductivity and at the same time washing the collected material off the plates.

From our past discussion we can say that the smaller the particle size the harder it is to collect either for the dry centrifugal or the wet collector. We can also say that space requirements for these four general types of collectors preclude their general use underground. Some special types of wet collectors of medium efficiency look promising but will have medium to low efficiency on the minus 2-micron particles. Industry is still trying however, to come up with a practical design of satisfactory efficiency for this underground mining dust problem.

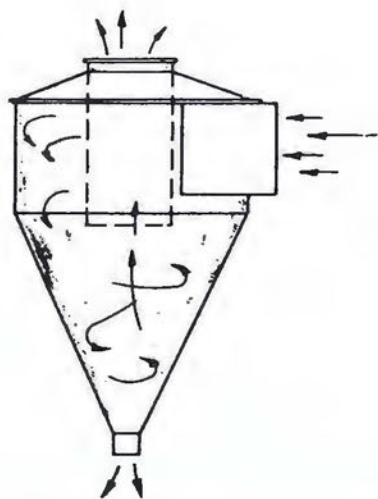


Figure 1.—Low-Pressure Cyclone.

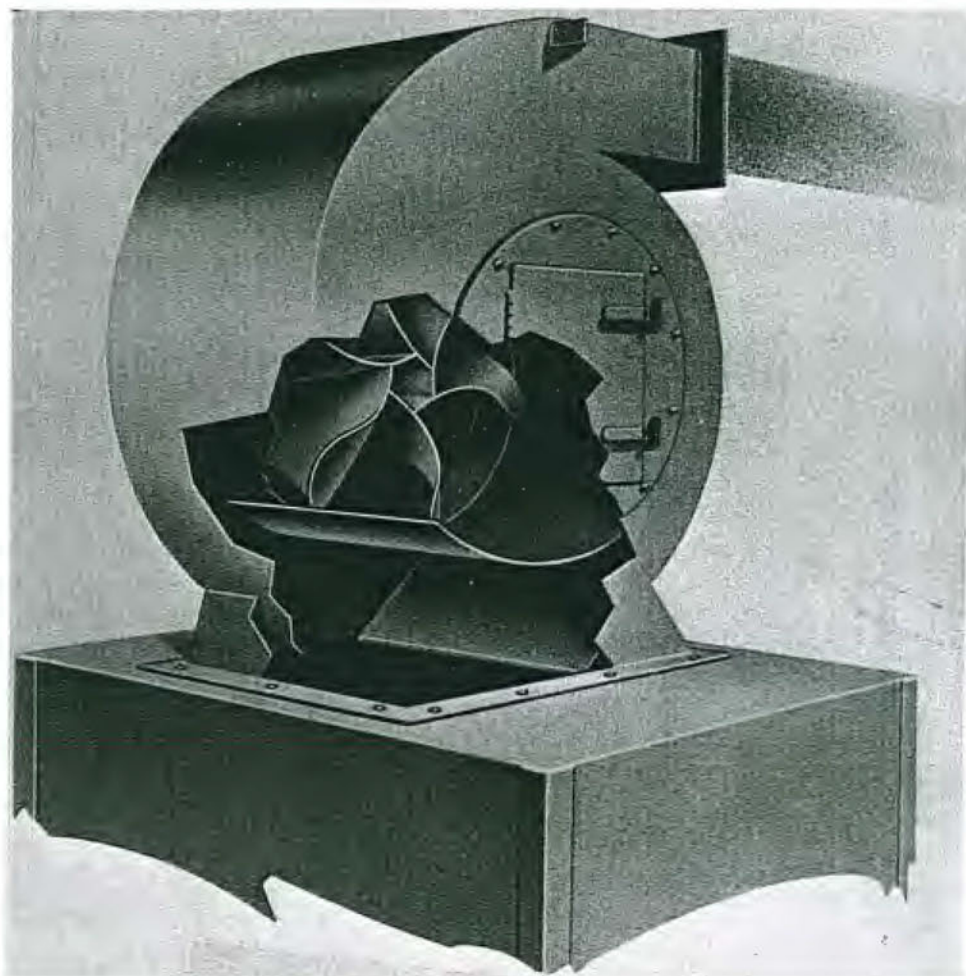


Figure 2.—Skimmer Precleaner.

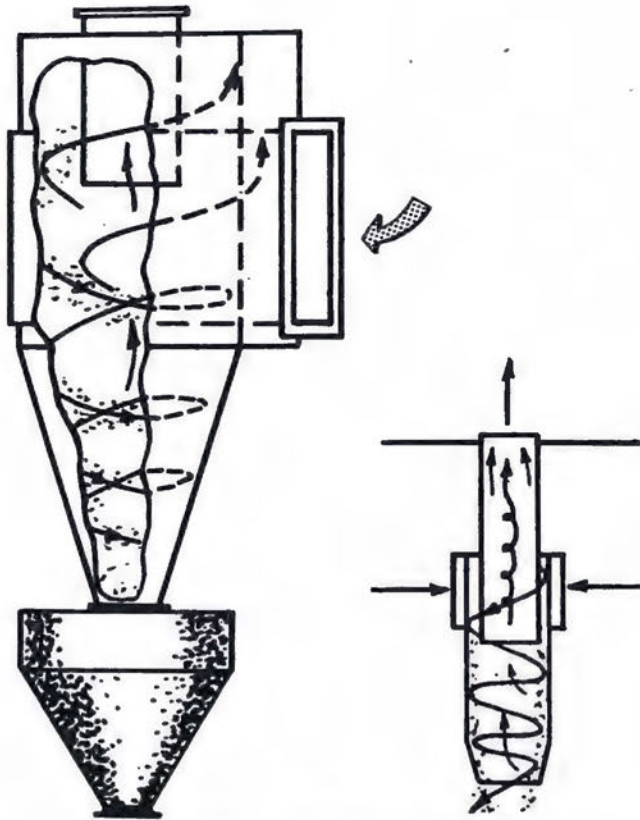


Figure 3.—High-Efficiency Centrifugal Cyclone Collector.

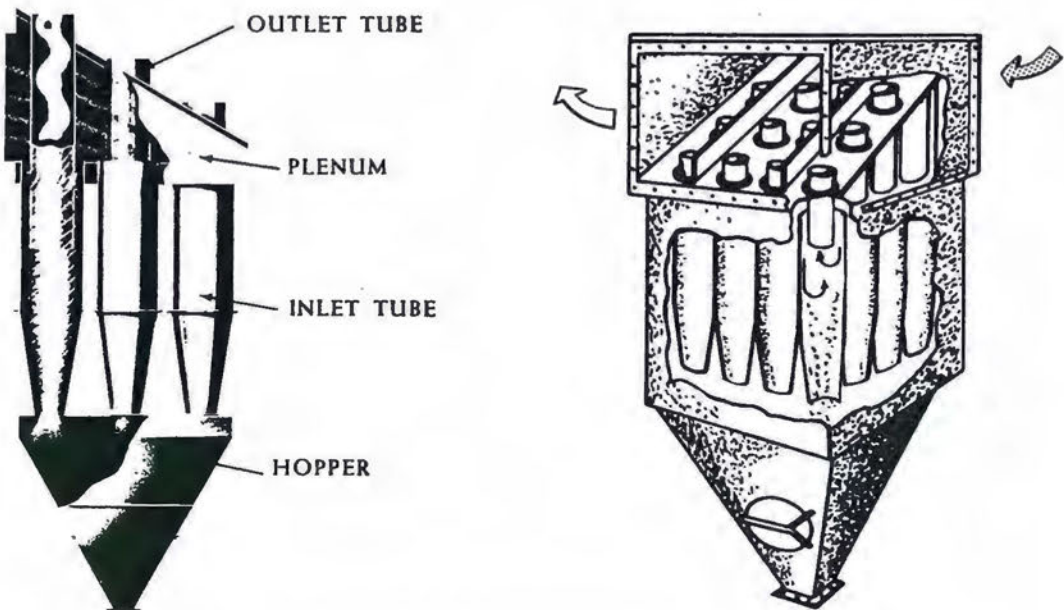


Figure 4.—Multiple-Tube Cyclone Collector.

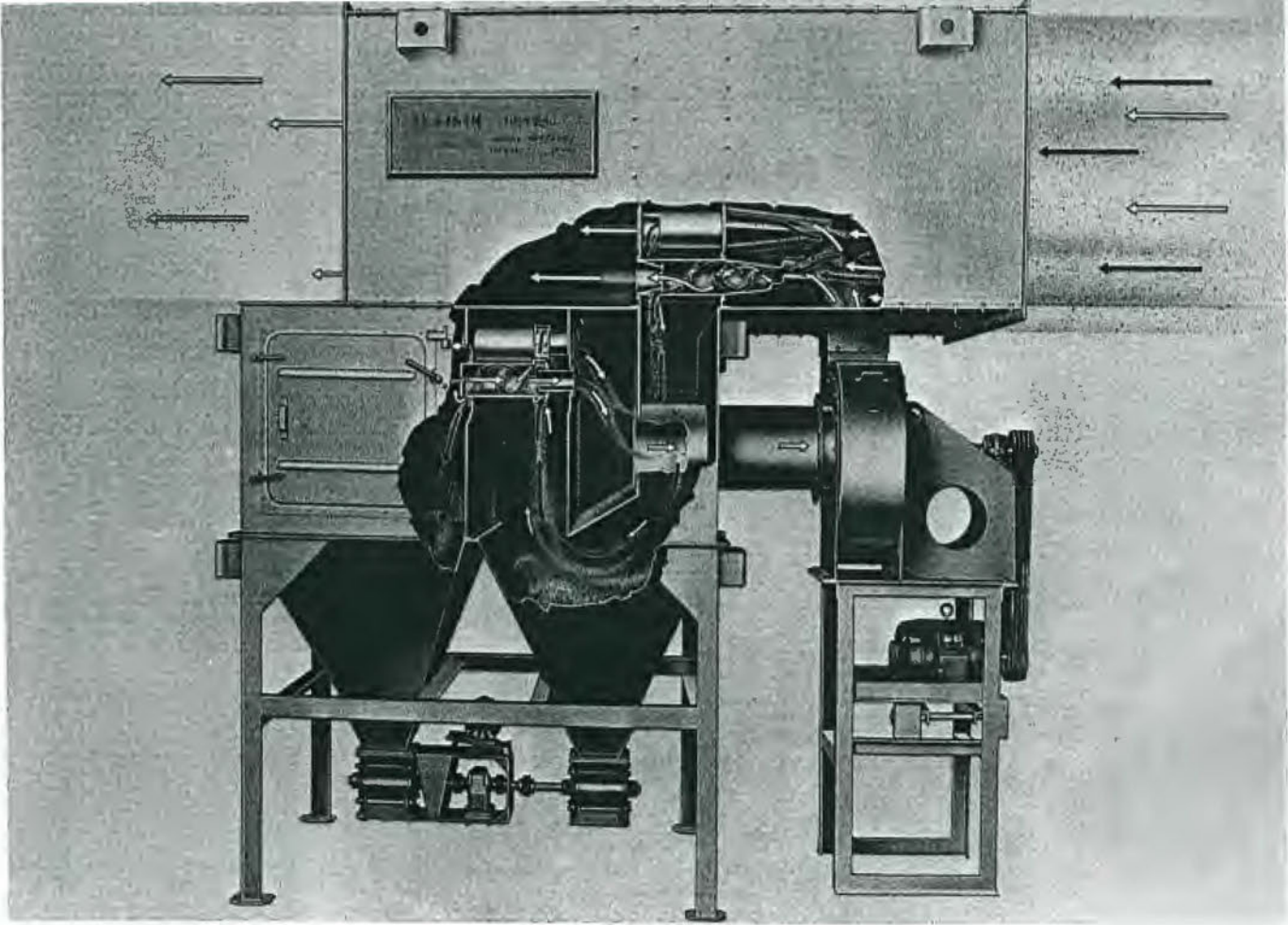


Figure 5.—Multiple-Tube Dry Centrifugal Collector With Secondary Dust Circuit.

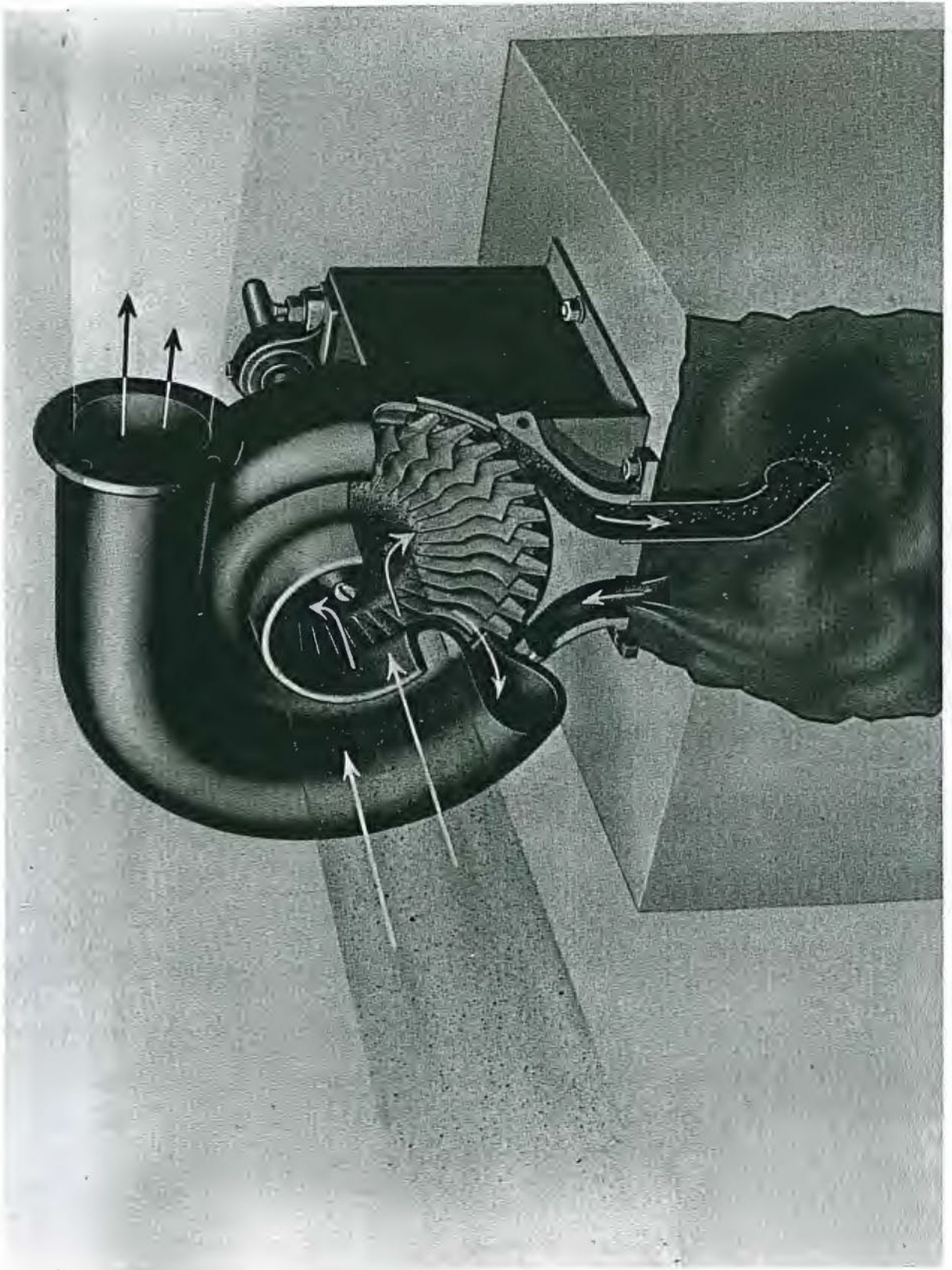


Figure 6.—Dry Centrifugal Collector With Rotating Wheel.

Symbols	Parts
A	Clean air outlet
B	Reverse air blower
C	Reverse air nozzle (jet)
D	Reverse air cleaning action
E	Dirty air inlet
F	Dust hopper
G	Hopper valve and/or dust feeder

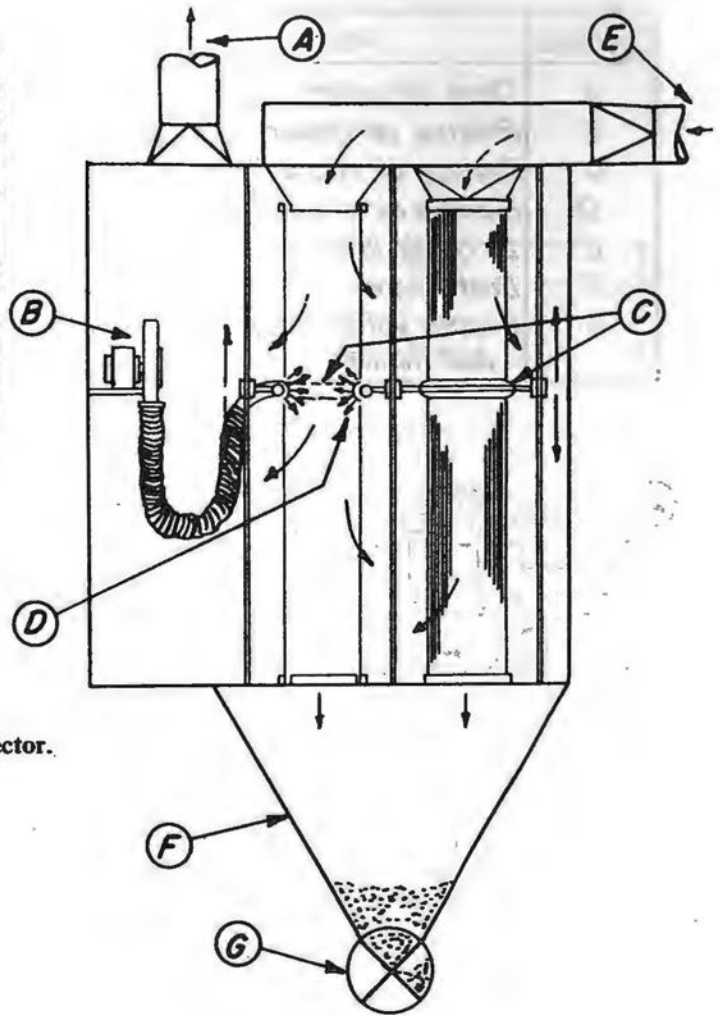


Figure 7.—Shaker Collector.

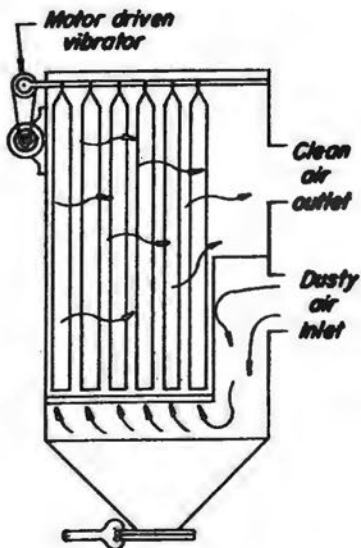
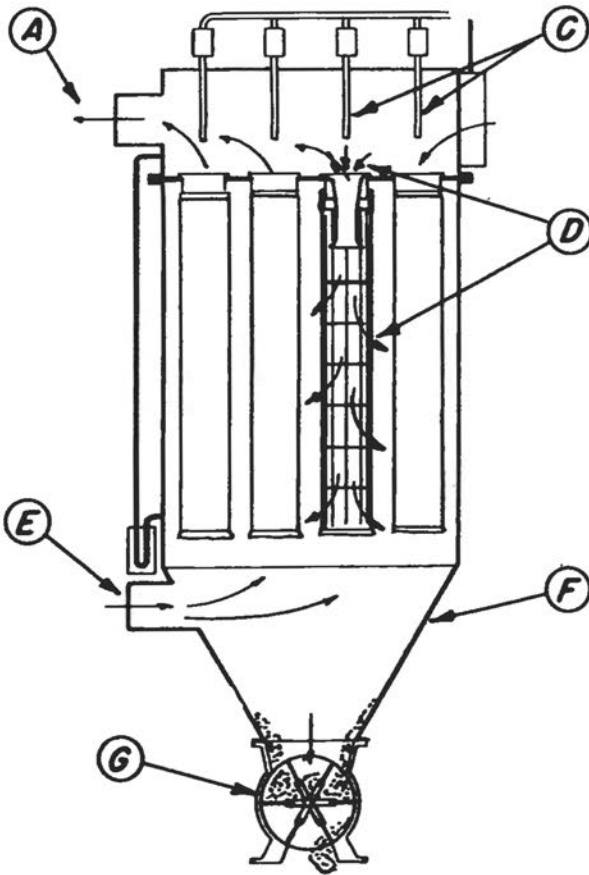


Figure 8.—Reverse Jet.

<i>Symbols</i>	<i>Parts</i>
<i>A</i>	<i>Clean air outlet</i>
<i>B</i>	<i>Reverse air blower</i>
<i>C</i>	<i>Reverse air nozzle (jet)</i>
<i>D</i>	<i>Reverse air cleaning action</i>
<i>E</i>	<i>Dirty air inlet</i>
<i>F</i>	<i>Dust hopper</i>
<i>G</i>	<i>Hopper valve and/or dust feeder</i>

Figure 9.—Pulse Jet.



- A Clean Air Outlet
- B Spray Nozzle Headers
- C Dirty Air Inlet
- D Water and Sludge Drain
- E Supply Water Piping

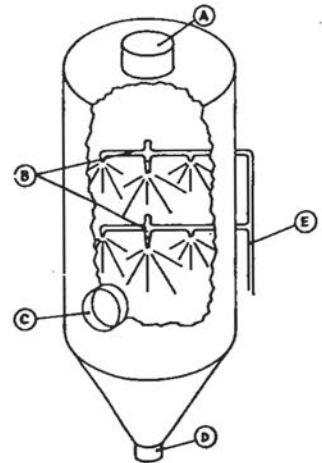
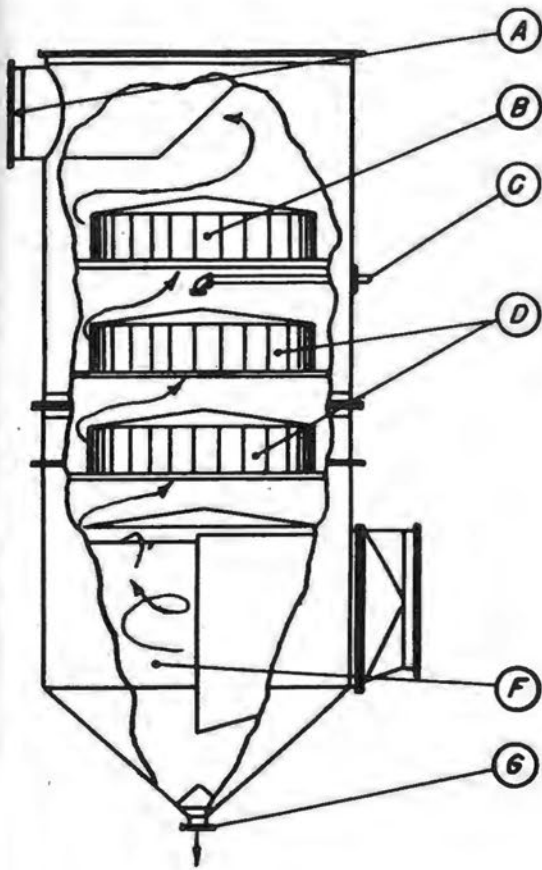


Figure 10.—Spray Tower.



<b>Symbols</b>	<b>Parts</b>
<i>A</i>	<i>Clean air outlet.</i>
<i>B</i>	<i>Entrainment separator.</i>
<i>C</i>	<i>Water inlet.</i>
<i>D</i>	<i>Impingement plates.</i>
<i>E</i>	<i>Dirty air inlet.</i>
<i>F</i>	<i>Wet cyclone for collecting heavy material.</i>
<i>G</i>	<i>Water and sludge drain.</i>

Figure 11.—Wet Centrifugal.

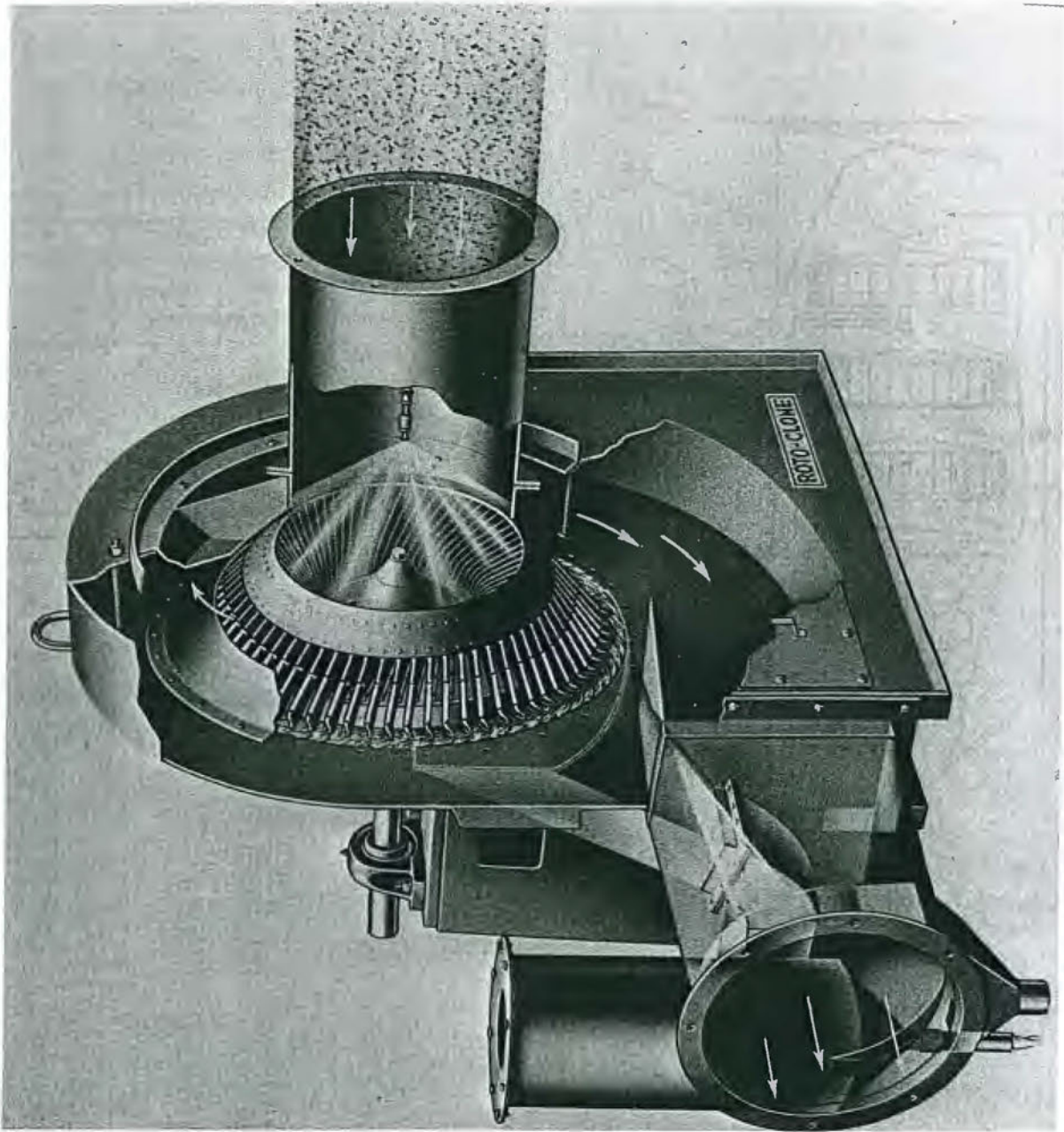


Figure 12.—Wet Dynamic Collector.

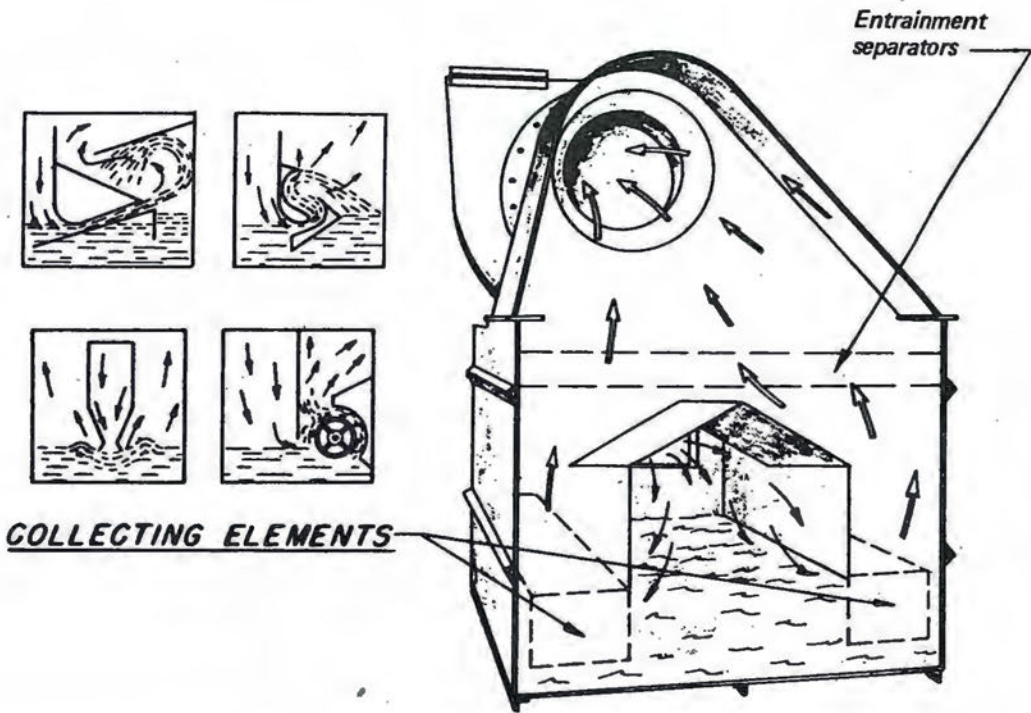


Figure 13.—Typical Wet Orifice Type Collector.

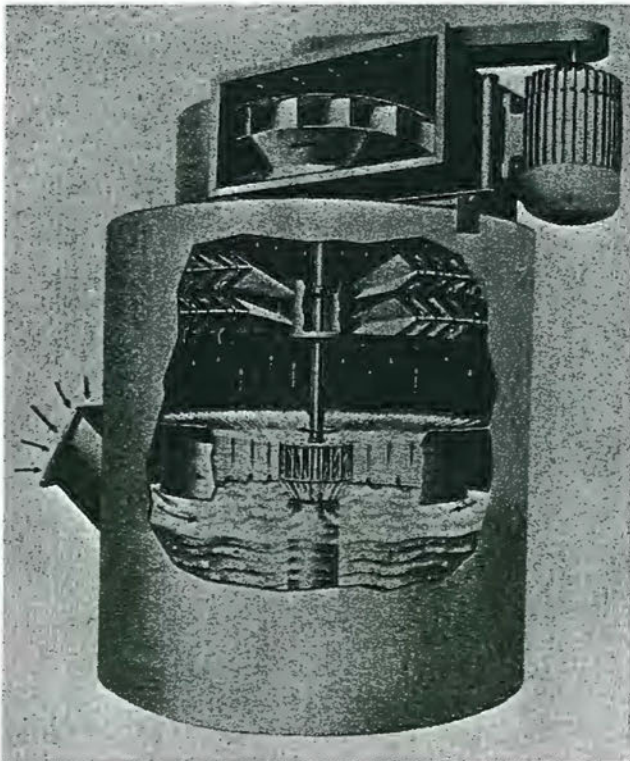


Figure 14.—Mechanical Scrubber.

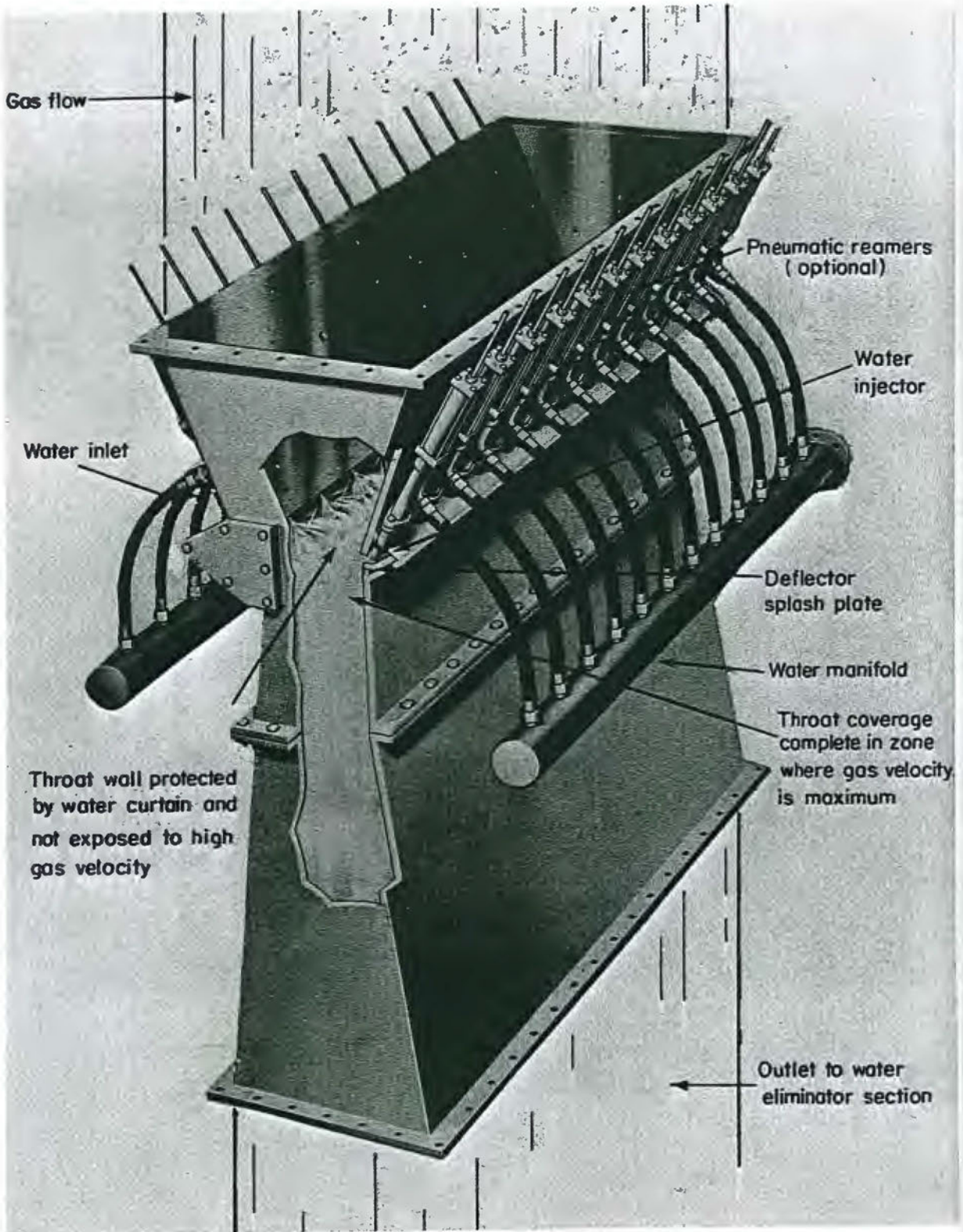


Figure 15.—Venturi Collector.

<i>Symbols</i>	<i>Parts</i>
<i>A</i>	<i>Clean air outlet.</i>
<i>B</i>	<i>Entrainment separator.</i>
<i>G</i>	<i>Water inlet.</i>
<i>D</i>	<i>Impingement plates.</i>
<i>E</i>	<i>Dirty air inlet.</i>
<i>F</i>	<i>Wet cyclone for collecting heavy material.</i>
<i>G</i>	<i>Water and sludge drain.</i>

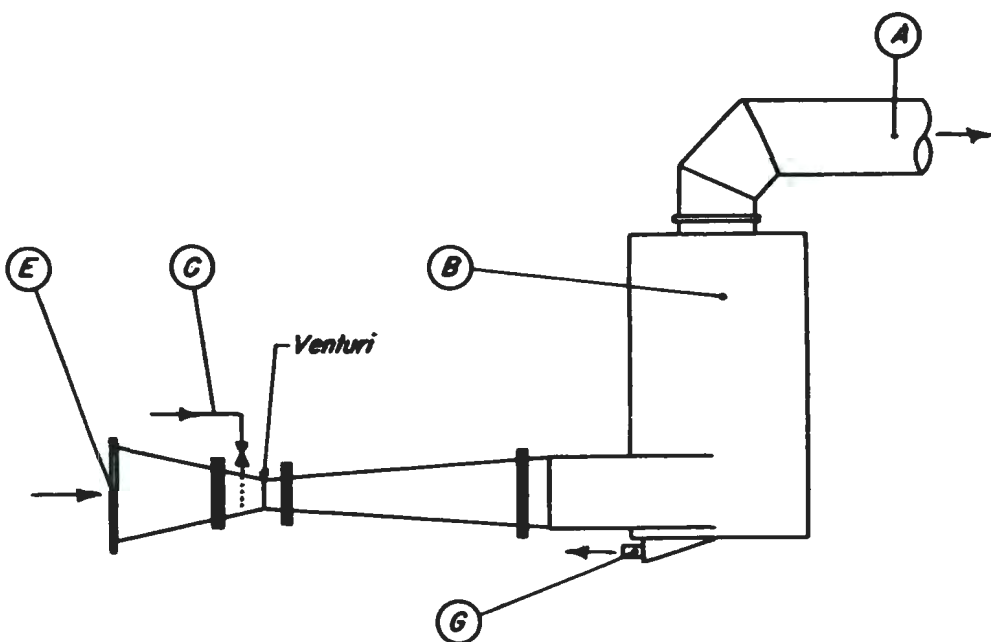
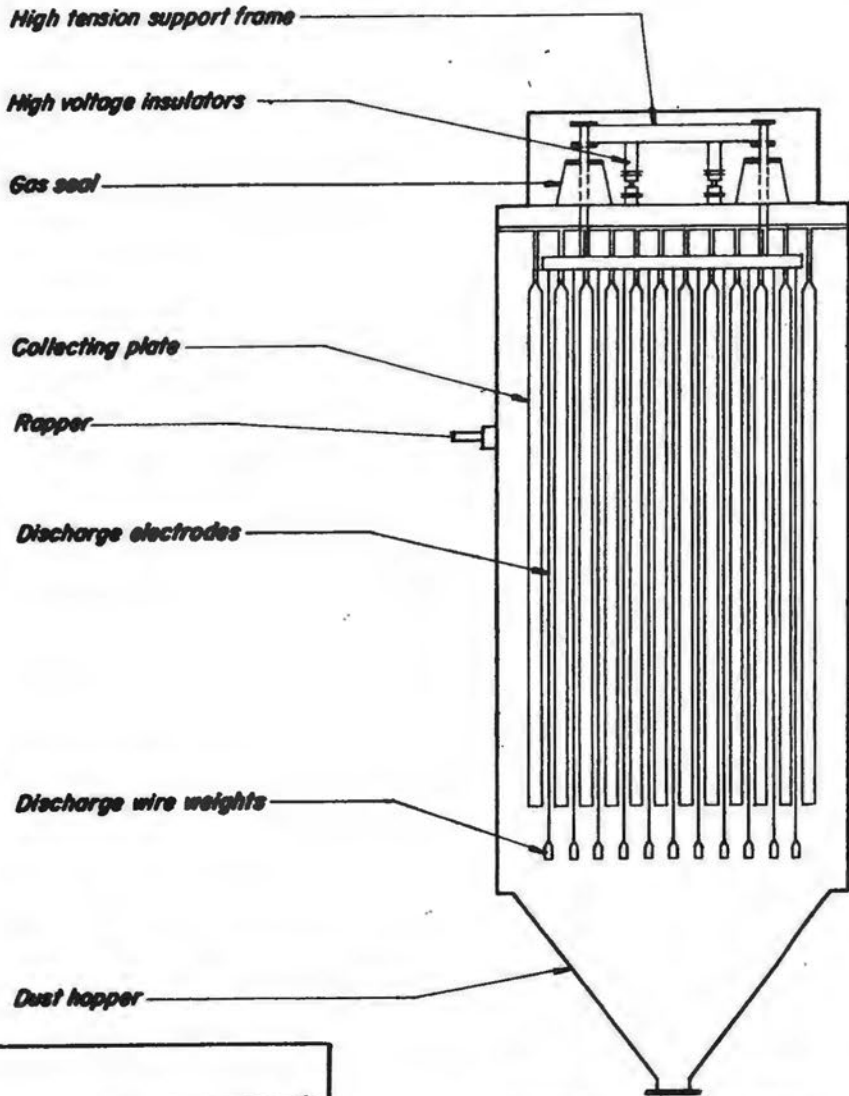


Figure 16.—Venturi Scrubber.



High tension support frame

High voltage insulators

Gas seal

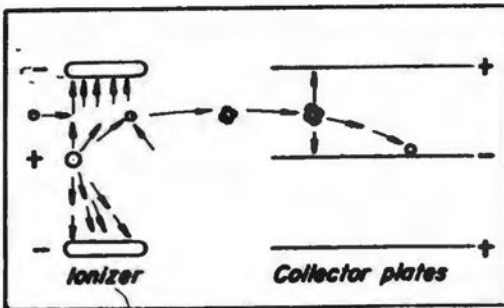
Collecting plate

Rapper

Discharge electrodes

Discharge wire weights

Dust hopper



**LOW VOLTAGE DESIGN**

12,000 to 13,000 volts on ionizer  
6,000 to 7,000 volts on collector plates

**HIGH VOLTAGE DESIGN**

Discharge electrode (normally negative)  
30,000 to 75,000 volts. Collecting plates are usually grounded.

Figure 17.—Electrostatic Collector.

MR. CRENTZ: The concluding paper on the dust collection portion of the program is on the state of the art, presented by A. Lee Barrett; Corporate Technical Consultant, Joy Manufacturing Company.

## DUST COLLECTING EQUIPMENT, STATE OF THE ART

by

A. Lee Barrett

---

---

Dust collection in the operating section of coal mines is a problem of mammoth proportions. Dust concentrations are high, frequently running to 500 million particles per cubic foot of air. There is a great deal of fine material, a representative test showing a geometric mean size of 1.7 microns by particle count. Limited space is available for the installation of dust-collecting equipment, the average mine room size today being 5-1/2 feet high and 12 to 14 feet wide, occupied by a continuous-mining machine 7 to 8 feet wide and 4 to 4-1/2 feet high. The front end of the machine is usually wider and is moving about the place in such a way that it is very difficult to enclose it to improve dust collection. Space is needed for the operator to see and for roof supports. In the interest of maximum health protection, the dust collector must have a good performance in the minus 5-micron range. Thus a difficult task of dust collection must be approached in an equally difficult environment.

Coal mining companies attempted meaningful dust collection at least as early as the 1940's. My employer, the Pittsburgh Coal Co., was very much concerned with dust collection in the 1930's. In the early 1940's serious work on dust collection was done with both the type "W" and type "N" Rotoclones built by the American Air Filter Co. The performance of these machines was good, but space problems precluded their use. At that time also experimental work was done with a variety of filters. One such filter was a large bag approximately 3 feet in diameter and 30 feet long into which dusty air was blown. The bag was unwieldy and next to impossible to clean, altogether unsatisfactory for mine service. Flat and folded filters were also experimented with at this time and gave a good performance but, because approach velocities to such devices must be low, became unwieldy, and in the end all experimentation seemed to lead back to dust control by water and by ventilation.

The introduction of the continuous miner in 1948 again concentrated attention on the control of the dust at the face. As first introduced without water, the dust was unbearable. In addition, visibility was reduced to a level such that general safety and productivity was affected. The Joy Manufacturing Co. in 1950 launched a major campaign to learn the mechanics of dust formation and its control and launched an effort to develop a dust control system which would be effective and practical. First approaches to control were ventilation and water sprays, including the use of detergents. Existing dust collecting devices, including filters and scrubbers, were experimented with, but in all cases, while operating characteristics were generally satisfactory, space occupied made the devices completely impractical. During the search for a smaller, more

compact, dust collecting device, work done by the Anaconda Company in Butte, Mont., came to attention. Jack Warren, of that company, had for years been experimenting with new dust-collecting devices in the face of the silicosis problem. An impingement device had been developed which was doing a good job. The impingement section of this device consisted of four 1/16-inch plates spaced 1/16 inch apart (fig. 1) provided with 1/16-inch slots staggered in relationship with each other, the air flowing serially through the plates with impingement. In the impinging areas, the dust was contacted by water on the plates which was sprayed into the collector upstream of the plates. After mixing with water, the dust particle came away from the plates in a water droplet usually 100 microns or more in diameter and was relatively easily collected in a standard zig-zag water eliminator. Collection efficiency was good, but size was excessive from a coal mine point of view (fig. 2).

At about the same time, a device was viewed at one of the Old Bend mines. This device consisted of an axial flow fan with a stream of water directed radially along each blade, such that the blade surfaces were wetted fore and aft and as they whirled through the air, slicing the air into thin sections contacting a considerable portion of the dust in an inertial field so that the dust was contacted by water and would flow away radially from the fan, water borne. Efficiency was low and the free water discharge was a problem.

The Warren collector had an efficiency of approximately 98 percent at 5 microns, and the pressure drop across the impingement plates and the water eliminator was only 4 inches of water. A velocity through the slots of less than 3,000 fpm was required to maintain this pressure drop and with 30 percent open area, this resulted in a face velocity ahead of the plates about 1,000 fpm, 10 ft<sup>2</sup>, for a 10,000-cfm collector. A great deal of effort was put into experimenting with other impingement devices and water separating means in order to improve this situation. The set goal was a 4,000 fpm minimum duct velocity and a cleaning device equaling the Warren performance. Among some of the better impingement forms tried were American Air Filter pads normally used for coarse dust collection shown in figure 3. Z-shaped configurations were built in an attempt to provide more open area through the impingement device while maintaining good impingement characteristics, figure 4. One of the better configurations was a General Motors radiator (fig. 5) which had splitter tabs formed on the fins dividing the air as it flowed through the radiator, reducing dust-particle travel distance and providing a better opportunity for the dust particles to contact the wetted surface. It was soon recognized that dust collection and heat transfer had many points in common and that, in effect, the desire was to contact the molecule or a small particle having at least some of the characteristics of a molecule. Small inertial effects and high particle drag indicated that if good impingement was to be achieved, the moving air would have to be divided into many slices and that the air should in its travel pass around a short radius obstruction placing the individual dust particle in a strong centrifugal field and providing a short distance to impingement. The impingement device finally adopted consisted of a folded mesh material having 20 to 40 wires per inch, folds being so formed that all air must turn in its path through the screen in order to pass (figs. 6-8). The small diameter of the wire furnished the high impingement force as  $\frac{v^2}{R}$  became maximum as a result of the small radius.

At the same time, it became necessary to consider a better means of separating the dust-laden water from the air. Since water begins to reentrain at air velocities slightly over 1,200 fpm, it was soon determined that a small water eliminator could not be produced using ordinary mist eliminators and water collectors. It was decided that in an axial system, the best approach to the problem might be an axial cyclone water collector. It appeared that this would not be difficult since the droplet size of water leaving the impinger screen was quite large, for the most part, greater than 100 microns, figure 9, due to the low velocity of departure. However, it was quickly found that after inducing a 45° angle turn in the air-water mixture by turning vanes which generated a good centrifugal force, the water drops approaching the outside of the structure and entering the boundary layer received little further encouragement to contact the outer wall. In addition, at drain slots, as a drop left the edge there was no force tending to send it into the water receiving zone, and approximately 50 percent of the water became sprayback into the interior of the water eliminator. This problem was approached by using a number of sequential slots, thereby catching an additional percentage of the water as it passed each slot. This worked well, except that air tended to flow into the first circumferential slot and out of later ones, thus carrying the water back into the airstream. In order to achieve a high percentage of water collection, it was necessary to seal the various circumferential slots from each other to drain the dust-laden water out of the system by barometric seals from each water collecting zone. Additional problems were encountered on the inner portion of the collector, as here the water tended to follow along the inner core as a result of surface tension and ride through the collecting device. Various gap, wires, and other devices failed to eliminate this problem which was finally solved by using a streamlined cone at the end of the turning vanes, the angle of the cone being such that a stalled zone was created on its surface. This formed, in effect, a rotating doughnut around the cone with the inner portion of the doughnut flowing opposite to the direction of air flow in the collector. Thus the water was forced into the major airstream and did not reach the center of the collector where it could ride through. The completed collector is shown in figures 10 and 11.

Performance tests were continuously made on the various configurations and, as finally developed, the collector could produce 99+ percent efficiency at 5-micron particle size and up to 67 percent collection at 1 micron. It is possible that these laboratory tests might have been slightly optimistic due to agglomeration, but field test over a considerable period of time indicated that they were substantially accurate. Figure 12 shows an efficiency curve for this collector. And figure 13 shows an evaluation of the typical dust being collected. Many tests were made with a 30-hp, 12,000-cfm portable model of this collector as shown in figure 14. This model was built specifically for underground tests in a continuous miner section and with the two-stage fan had enough pressure to exhaust through a considerable length of tubing. Figure 15 shows a mining setup under which this dust collector was tested. Isokinetic samples were taken fore and aft of the collector, and the samples were evaluated both by weight and by count to determine performance. Collection efficiencies averaged 99 percent by weight and 90 percent by count. These figures represent grain loadings of 0.1282 and 0.0018 grains per cubic foot and 60 and 6 million particles per cubic foot in and out of the collector, respectively.

While the performance of this collector was commendable, the problem still existed as to an acceptable method of use. The machine was too large to be placed in proximity to or on the continuous miner. The location of the dust collector at the discharging end of a 100- or 300-foot duct also had serious disadvantages as a much more complicated duct was necessary and leakage losses in the duct reduced the amount of air removed from the face mining area. If the collector discharged directly into a return airway, it might be convincingly argued that there was no need for a dust collector if a trickle rock duster was installed at this point (See appendix 1).

As a result of this experience, two prototypes were built of an even smaller dust collector which used the same mixing screens constantly wetted by a water spray but took the discharged water-dust mixture immediately to a mixed-flow fan which discharged the mixture of water and dust into a channel at its periphery, the air traveling on in an axial manner. Figure 17 shows an exploded view of the interior of this dust collector. Figure 18 shows this collector mounted on a continuous miner where it collected dust from the face area and discharged it to the rear of the continuous mining machine. This model contained a high-speed 20-hp motor, the capacity was approximately 6,000 cfm without discharge duct, and it was 19 inches in diameter and 54-3/4 inches long. It produced 10-1/2 inches of water pressure so that it was possible to discharge through a duct without serious reduction in capacity. The pressure drop through the impingement screen was higher than in collectors previously built since a higher velocity had been chosen, in order to minimize the size of the collector. Three to 4 gpm of water were fed into the machine, a major portion of which discharged on the conveyor of the continuous miner, but 0.1 to 0.2 gpm traveled out with the discharge of the collector as mist. It is believed that this is the smallest dust collector, in terms of performance, built to date, but it also faced a problem of successful physical application. In high seams, it would seem possible to find a place for an object 19 inches in diameter and 54 inches long, but certainly in lower seams it is very difficult to find such space. As a result of these space difficulties, no real application of either of the collectors has been made in this country. There have been a number of them applied in the longwall mines of England.

We now have new impetus to improve dust collection at the face, and once again the industry is surveying the tools available to see what may be used, what may be modified, and what may be developed to meet the need. The conditions are essentially the same as they have always been. We have the same coal, the same too-small room in which the machine is operating, we have a machine which is more powerful and perhaps larger than those in the past, consequently, we have more dust. With new knowledge as to the effect of dust on men, we have a new requirement for collection in the smaller particle-size ranges. None of these factors makes improved dust collection any easier. However, we do have better ventilation than in the past and judicious use of this ventilating air together with water has somewhat improved the situation.

To review the dust collectors which apparently might be used in the coal mining environment, the first candidate is always the dry inertial collector, a simple flexible mechanical device. The most sophisticated development known has been made by Sikorsky Aviation to clean the air entering their helicopter

engines, which in bad dust conditions without dust collection may have an operating life of less than 100 hours. As assembled by Sikorsky, small cyclones about 1 inch in diameter are placed in the periphery of a semiconical unit approximately 18 inches in diameter and 3 feet long. Engine intake air flows through the small cyclones into the conical plenum and thence into the engine intake. The conical arrangement has a double wall from which air is evacuated or scavenged by a small fan. The efficiency of this arrangement is reported as 88 to 90 percent by weight, and the pressure drop is quite low. It is likely that the collecting efficiency in the minus 5-micron range is quite low, though tests have not been made in this particular area since particles of this size do not represent a hazard to turbojet engines. This scavenged heavily dust-laden air is about 5 percent of the total. If the system were used in a mine, this air would have to be cleaned up in some manner, perhaps through a small scrubber or a filter. It is at the very least, an interesting development since with these small cyclones, an envelope of any shape could be configured to fit the available space on the mining machine, that is, it could literally wrap around control cases, hydraulic pumps, etc., to achieve a very snug dust collector. There remains the requirement for a fan to provide the operating pressure; since fans somehow always seem to be circular in configuration, even finding a place for an adequate fan could be a problem.

Filters, as always, offer good collection efficiency, 99+ percent at 1 micron. They are not particularly expensive, but even the best of them have low face velocity requirement, a maximum being something like 20 fpm or 20 cfm through 1 square foot of filter surface. If one would like to build a filter for 10,000 cfm of air, which might be required for good dust control on a high-performance continuous miner, 500 square feet of filter surface would be required. If this surface were furnished by a filter consisting of 6-inch-deep folds spaced 1 inch apart in an 18 inch wide frame, the length of the frame would be 31 feet. Similarly, if the approach is to deepen the fold, an 18 by 18 square inch collector would have to be about 10 feet deep. These dimensional problems seem to eliminate the filter from consideration.

Venturi scrubbers have good efficiency, 99+ percent at the 1-micron level. They however, have pressure requirements of 10 to 30 inches of water plus that required in the collection duct. They also require from 3 to 10 gpm of water per 1,000 cubic feet of air cleaned so that if 5 gpm water per 1,000 cubic feet were used in a 10,000 cubic foot collector, 50 gpm of water at the mining machine would be necessary and means for its disposal would also have to be considered. A recirculated water system might be considered, but this calls for extra apparatus in a place where little room is available. It is also not known how pressures of 15 inches or 20 inches of water could be developed in or near a mining machine to provide the activating energy.

Finally, we come again to the wet scrubbers as a possible solution to the mine dust problem. Their efficiency is apparently adequate for the job, and power requirements for the scrubbers are also in a practical range. Size becomes the major problem of the scrubber, its water eliminating section, and the fan which will move the air through the system. As far as is known, the only devices available to the industry today are the American Air Filter Rotocclone and the Joy Microdyne, neither of which in their present size provide

a good solution to the problem. They do however, represent hopeful routes for further research and investigation. In such an investigation, a number of factors should be given consideration. The collector must have the ability to handle large pieces of coal and rock or else a precleaner will have to be provided. It should be designed to use a minimum quantity of water and to require minimum pressure drop, in order that these service requirements do not increase the system size. Keeping in mind that dust collection in the minus 5-micron range is not unlike heat transfer, maximum advantage should be taken of high acceleration rates around small radii in order that  $\frac{v^2}{R}$  for the particle may be very great in the face of the viscosity of the air.

A recent short test with the Joy mixed-flow Microdyne on a Lee Norse machine in Illinois confirmed that there is hope in this direction. The collector was mounted directly on the continuous mining machine discharging its air rearwardly on the opposite side of the room from the operator. Sampling was done with the Unico C110 personal sampler and tests on consecutive days showed an average of 5 milligrams per meter for the operator, helper, and observer with no dust collection and an average of 1.91 milligrams per meter for the operator, helper, and observer with the dust collector operating the following day. There was at least 3,500 cfm of dust flowing through the dust collector with reasonably good intake manifolding around the front end of the machine. It was reported that the injection of the air from the dust collector greatly increased the outflow of air from the brattice which was on the operator's side. Visibility was increased significantly in an atmosphere which was showing 170 million particles per cubic foot on the side of the room opposite the operator.

Existing dust-collecting systems are too large for satisfactory application to most presently operating mining machinery. There is hope however, that with further development, significant results in dust control may be realized. Exploitations and further development in the multiple minicyclone area and in the impingement scrubber area offer the greatest promise of success.

#### APPENDIX 1

The disposition of the air-borne dust fraction after it leaves the face area is of considerable importance and the following table shows some of the concentrations of distinct sizes at various distances down wind of the course expressed in percentages of the original concentration:

Particle Dia. (microns)	Distance down wind (feet)						
	60	120	300	600	1,200	3,000	6,000
5	99.8	99.7	99.1	98.3	96.6	91.7	84.1
10	99.3	98.7	96.7	93.5	87.6	71.6	51.3
20	97.4	94.8	87.5	76.6	58.6	26.2	6.9
50	85.2	72.6	44.9	20.2	4.1	0	0
100	57.3	32.9	6.2	.4	0	0	0

Over 50 percent of the air-borne fraction by weight has settled out within 300 feet. The minus 5-micron fraction will remain airborne throughout the return air courses of the mine. Referring to the weight curve on the lower right in figure 13, the minus 5-micron fraction represents 1.2 percent of the total air-borne fraction.

QUESTION (D. KINGERY): Lee, there have been wonderful things done with hydraulically driven fans, small sized and of high capacity. Have they been considered for any dust collection?

MR. BARRETT: None that I know of, Don. The hydraulic approach could be of interest, because we can pack more power into a given size package with a hydraulic motor than we can with an electric motor. This will give us a chance to put the motor at a different location and reduce size.

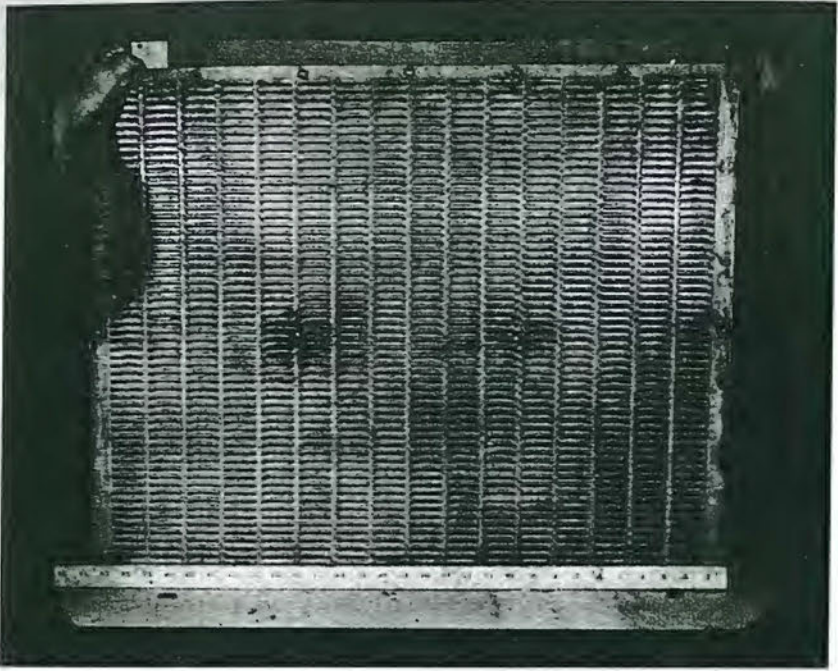
QUESTION (KEN SUTER): When you had your scrubber located remotely from the machine, why is this approach left out? Was it because it is too hard to run the duct work?

MR. BARRETT: This can certainly be done. In my opinion, however, with duct removal of air from the face zone, we might as well use a fan as a dust collector. If we are going to run a duct from the machine out to an air mover, we have already removed the dust from the face environment.

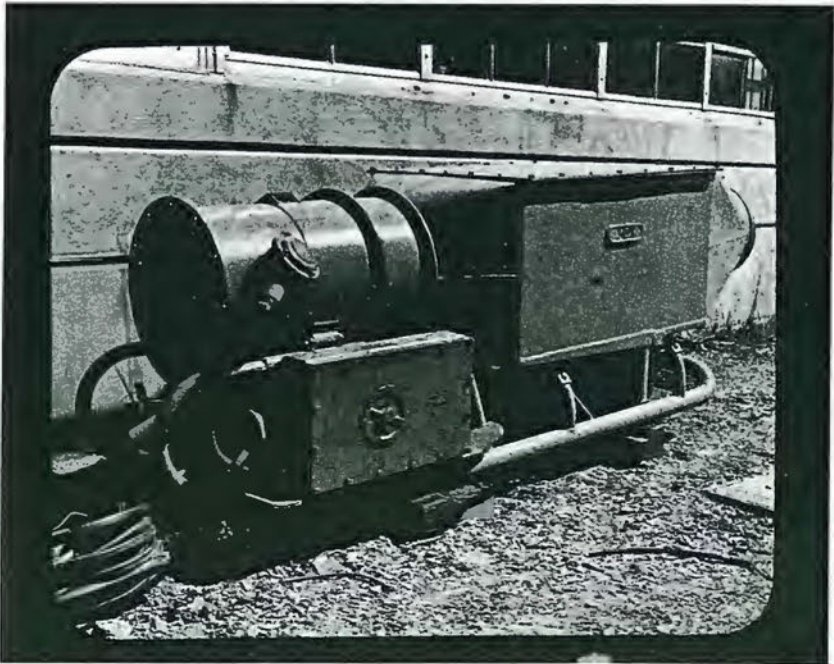
The reason for collecting this dust now becomes a completely different one, to eliminate rock dusting, since the return air way will not be occupied by men. One might consider at this point a dry cyclone or some other type of collector which would take the float dust out; the five-micron dust will go out of the mine with the air currents and does not represent an explosive hazard.

My pet approach to this problem is to develop an ultralight fan located at the beginning end of a pressure ventilating tube with additional ultralight fans at every 100 feet along the length of the tube.

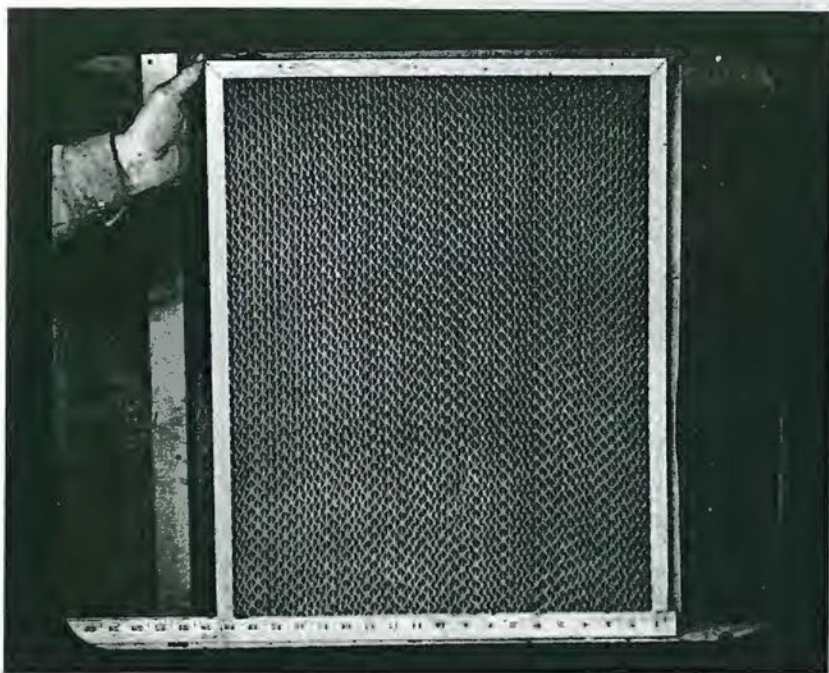
We can thus extend the collection duct with the machine; hopefully, we can keep the gathering opening at a point where we can get all of the dust -- perhaps we can get it all without applying water. A blowing duct is much lighter and more efficient than an exhausting duct which is always trying to collapse.



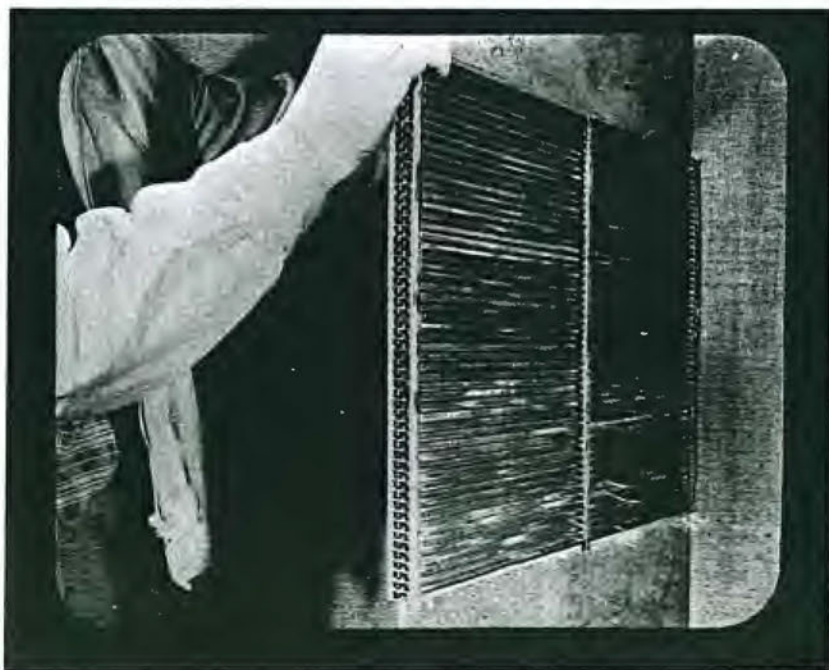
**Figure 1.—Impingement section, Early Joy Dust Collector**



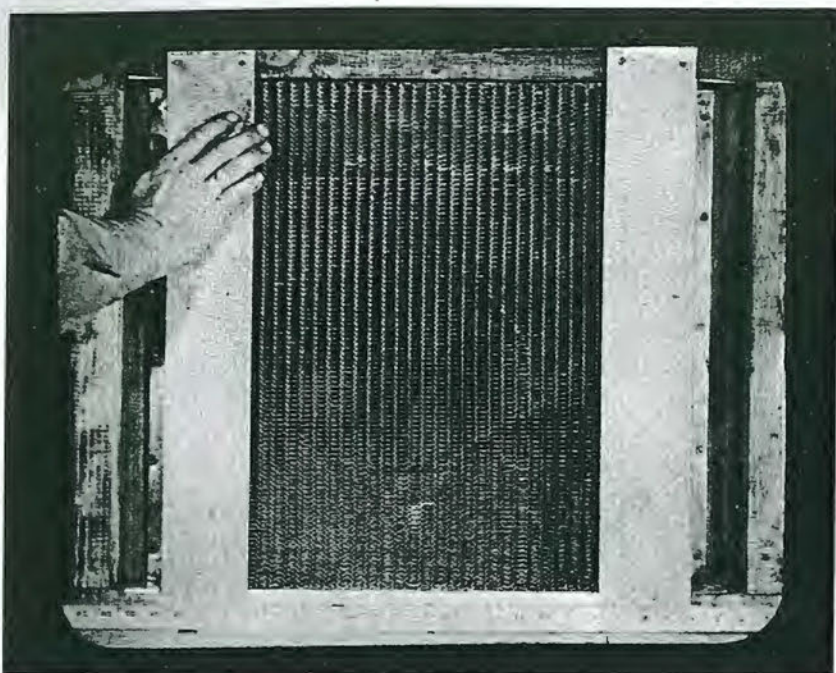
**Figure 2.—Early Joy Dust Collector**



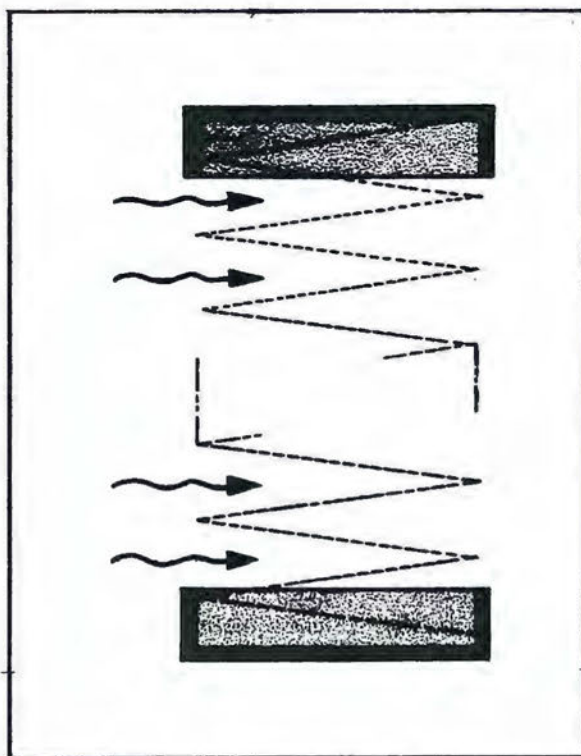
**Figure 3.—American Air Filter Pad for Coarse Dust Collection**



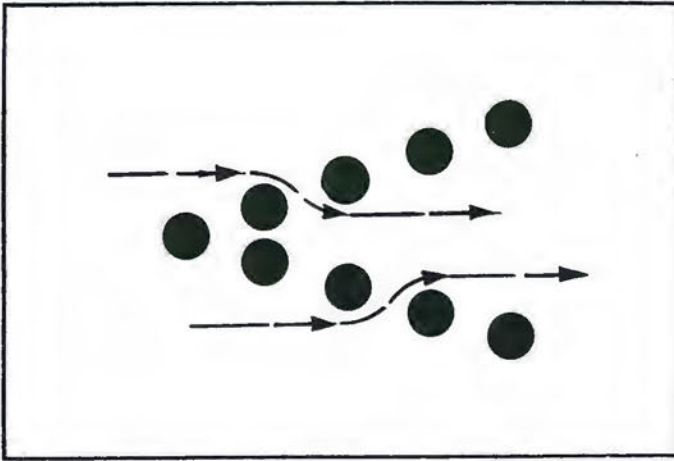
**Figure 4.—“Z”-Shaped Impingement Section**



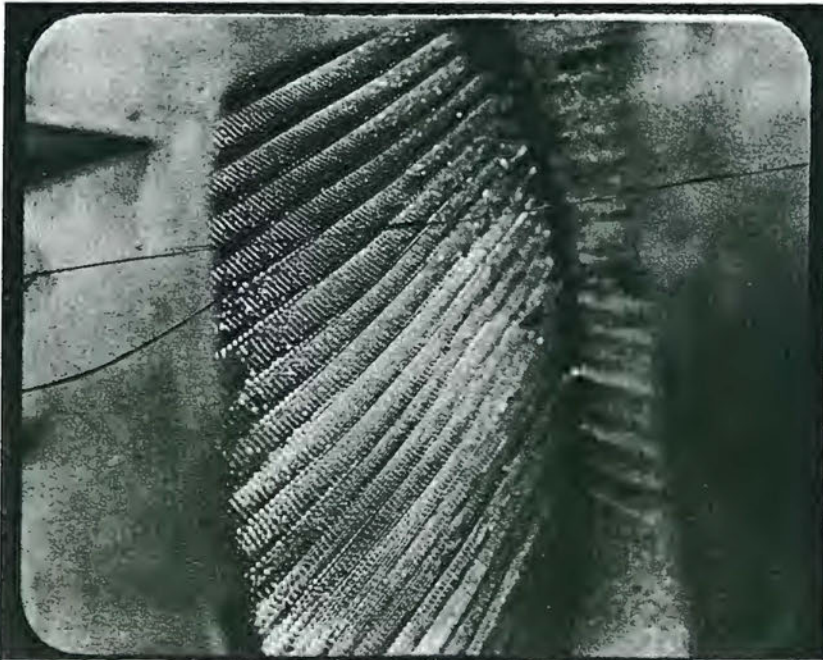
**Figure 5.—Adaptation of General Motors Radiator for Dust Collection**



**Figure 6.—Radial Section through Impingement Screen**



**Figure 7.—Magnified View of Wire Arrangement  
in Impingement Screen**



**Figure 8.—Impingement Section of  
Folded Mesh Material**

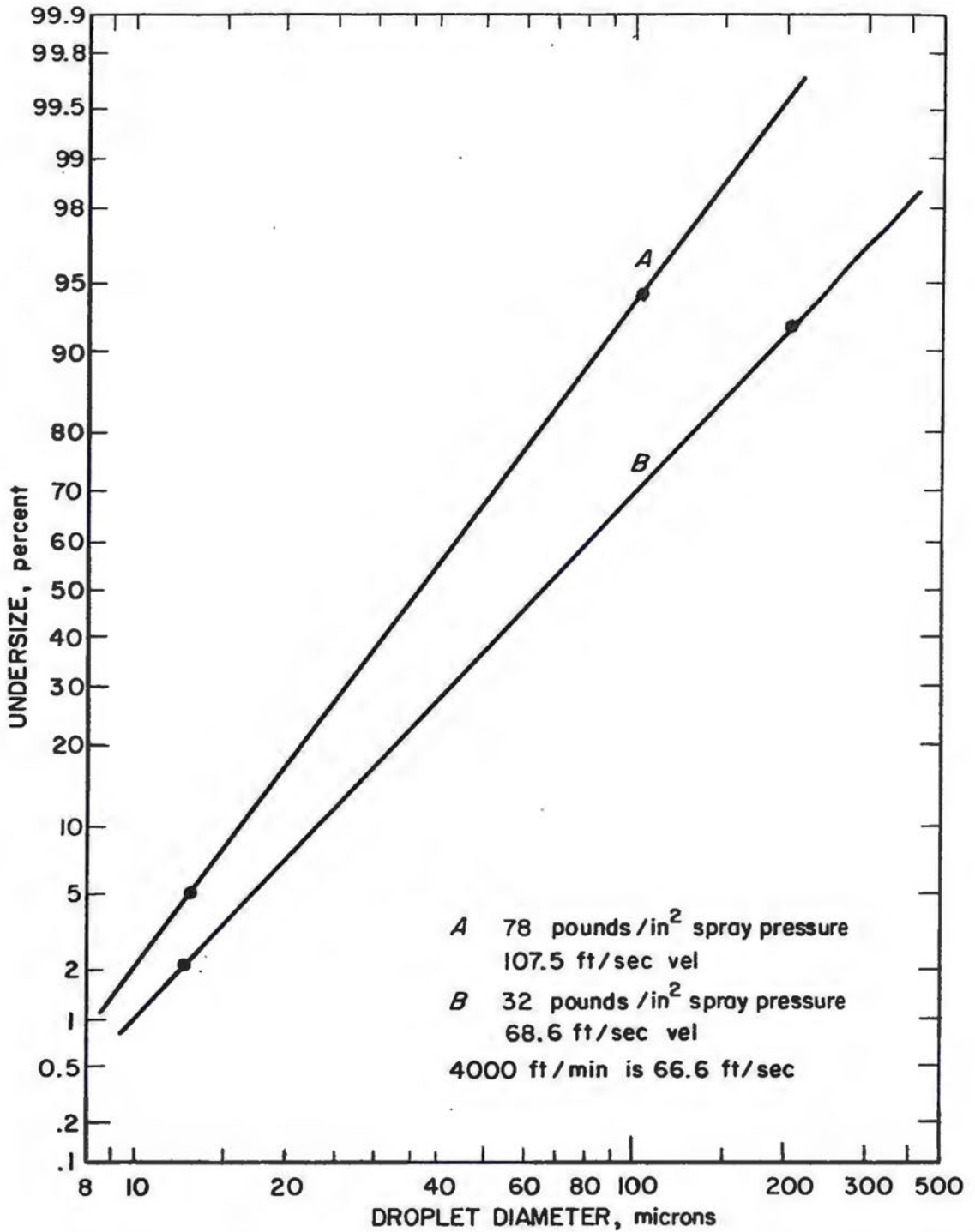
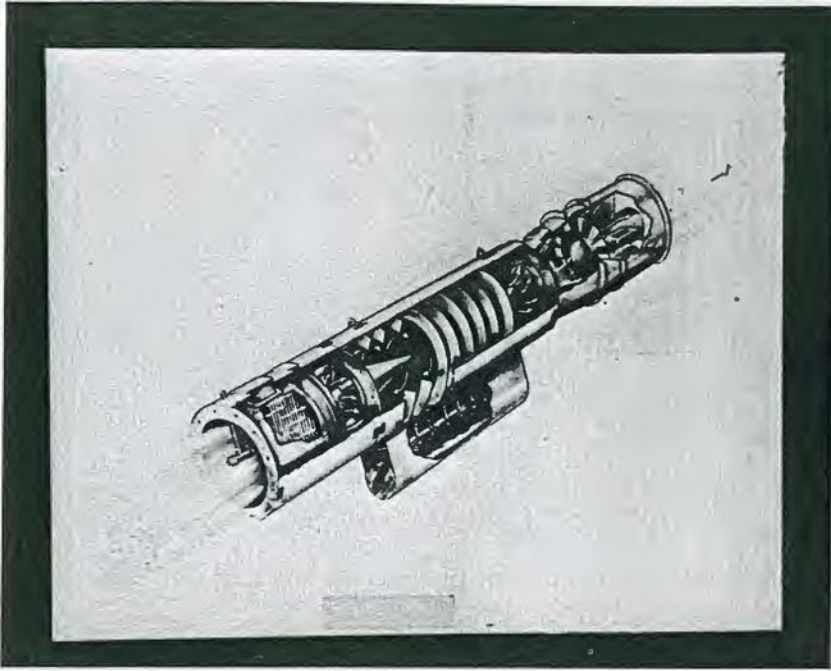
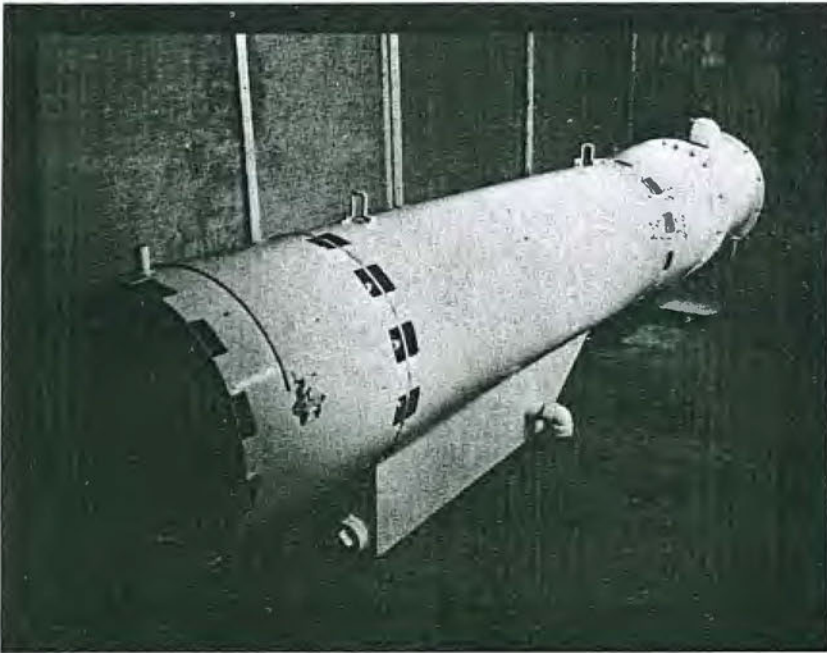


Figure 9. Effect of Pressure and Air Velocity on Atomization of Water (Chart - tube redrawn by USBM)



**Figure 10.—Axial Cyclone Water Collector (Cutaway)**



**Figure 11.—Axial Cyclone Water Collector**

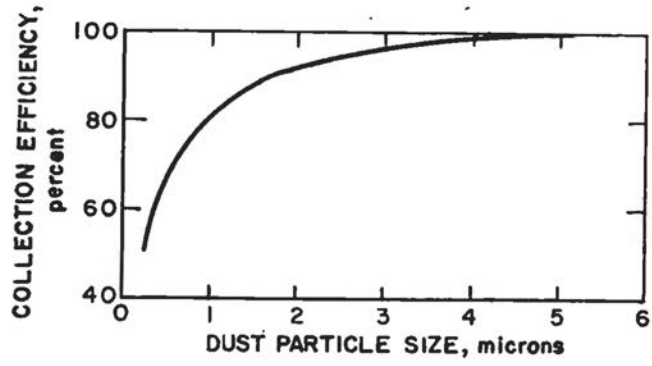


Figure 12.—Efficiency Collection Curve for Axial Cyclone Water Collector

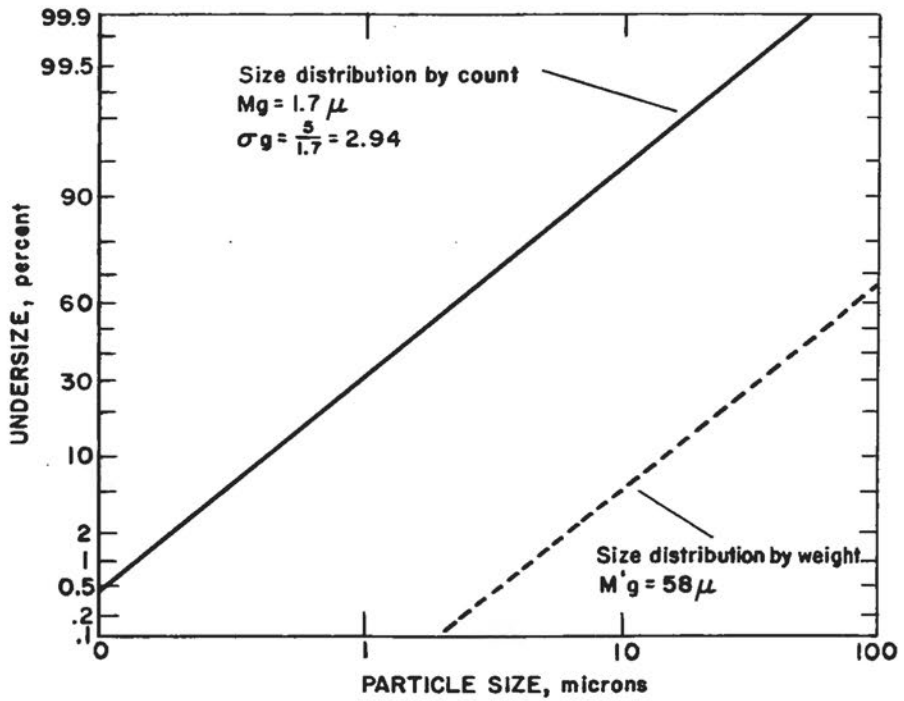
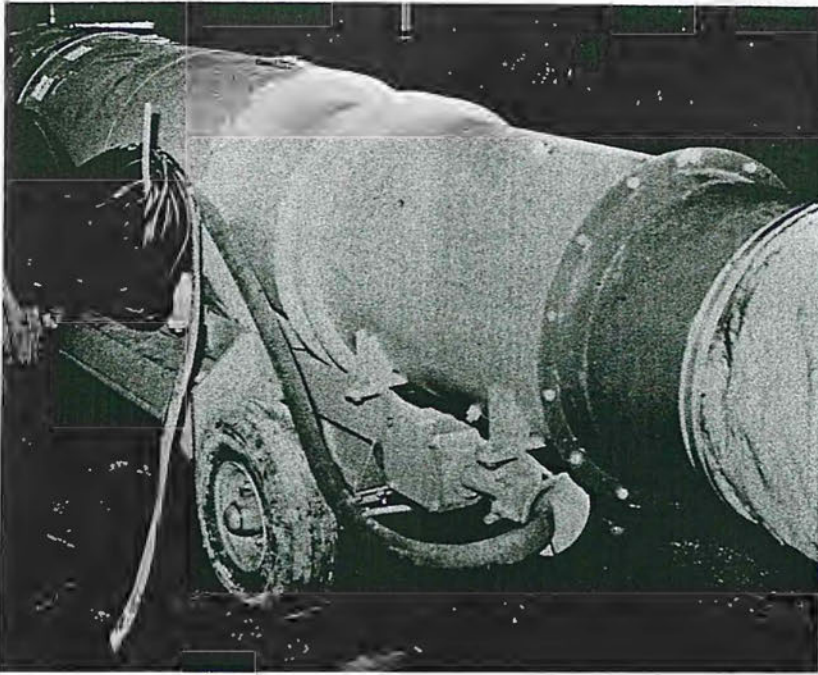
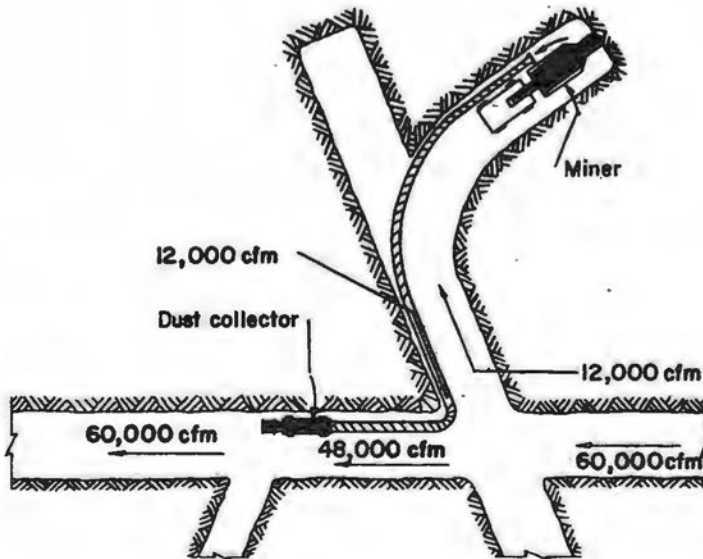


Figure 13.—Evaluation of Dust Collected



**Figure 14.—Portable, 30 Horsepower Model of Axial Cyclone Water Collector**



**Figure 15.—Dust Collector Tests**

DUST CONCENTRATION AT MACHINE OPERATOR				
REF.	DUST CONCENTRATION (MPPCF)	VENTILATION (CFM)		REMARKS
		TOTAL	COLLECTOR	
1.	256	--	--	Dust Collector not operating.
2.	16*	12,000	12,000	Dust Collector only.

RETURN DUST CONCENTRATION IN ENTRY				
REF.	DUST CONCENTRATION (MPPCF)	VENTILATION (CFM)		REMARKS
		TOTAL	COLLECTOR	
1.	6	12,000	12,000	

DUST COLLECTOR EFFICIENCY	
EFFICIENCY %	REMARKS
99.9*	By thimble weight method.
99.9**	By impinger count method.

\* - Average of three samples  
 \*\* - Average of six samples

Figure 16.—Dust Collector Efficiency

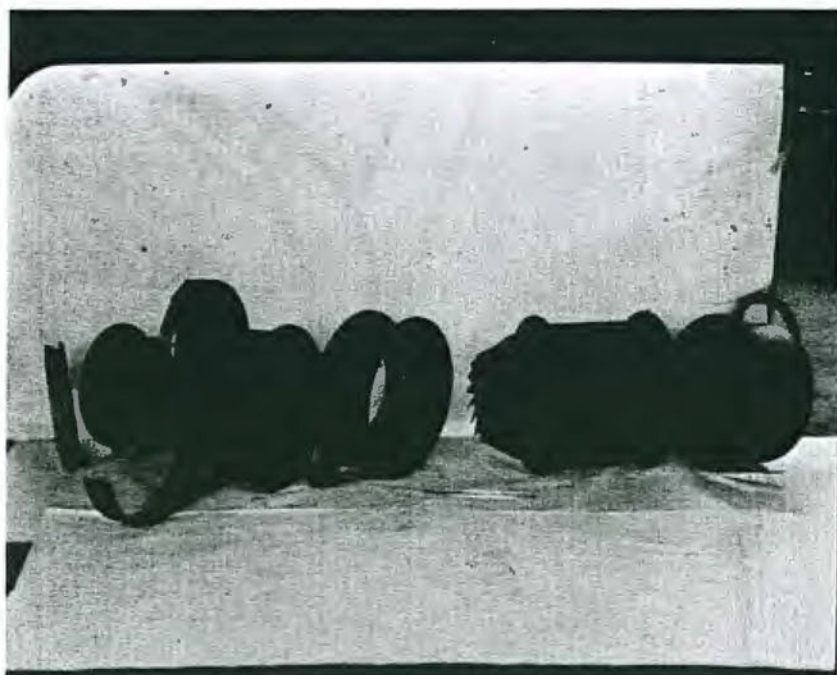
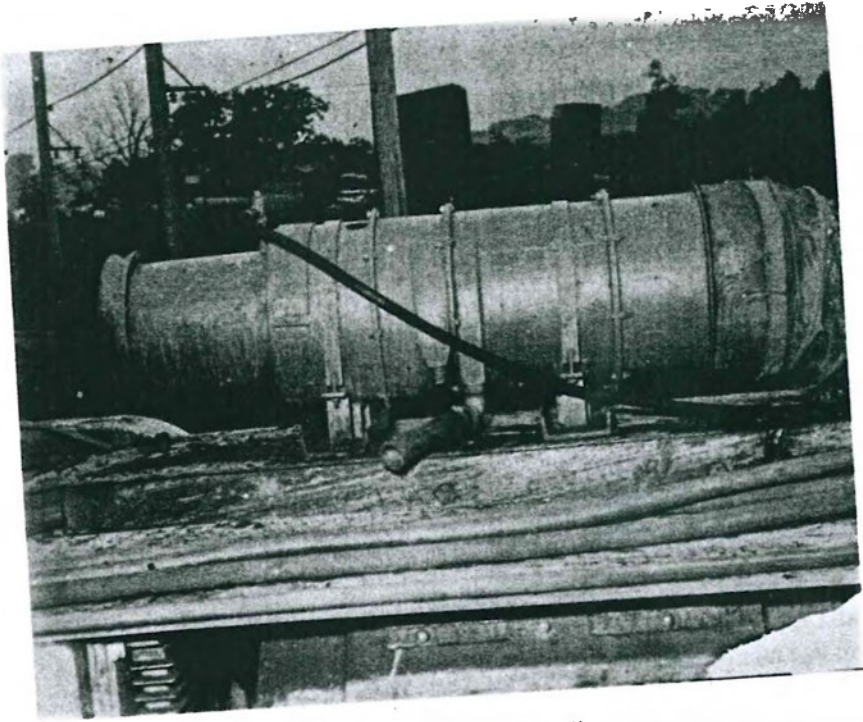


Figure 17.—Improved Dust Collector—Working Parts



**Figure 18.—Improved Dust Collector**

MR. CRENTZ: Under the general session of respirators and life support systems, we have the session entitled "Respirators -- Their Use and Limitations." It will be presented by Mr. Robert H. Schutz, Supervisory Research Chemist, Safety Research Center, Bureau of Mines.

## THE DUST RESPIRATOR PROBLEM

by

Robert H. Schutz

---

### ABSTRACT

Dust respirators have steadily improved as a result of user demands for better quality and the upgrading of approval requirements by the Bureau of Mines. Although dust respirators offer a positive degree of protection to the wearer, they have not gained wide acceptance in mines. Why not? What is their proper use in mining?

Suggested solutions to the nonacceptance problem include development of more comfortable respirators, their proper selection, use, and maintenance, and adequate training of respirator wearers. In addition to these solutions, this paper also describes Bureau plans to upgrade dust respirator approval requirements.

### INTRODUCTION

The U.S. Bureau of Mines first established performance requirements for dust respirators in 1934 with the publication of schedule 21. Since then, many improvements in respirator design, comfort, efficiency, and breathing resistance have been made. Much of the credit for improvements must be attributed to user demands for better respirators. The Bureau, in revising its schedule, has developed more severe tests to maintain and improve respirator quality. The present dust respirator schedule is 21B.

Although the subject of this paper is dust respirators, we should recognize that these devices are not and should not be regarded as a primary means of protecting miners from inhalation of airborne dust. Respirators are properly used until more suitable dust control methods can be installed, or when dust controls break down and where installation is impossible. Respirators are, of course, used when sudden release of dust temporarily overtasks dust control equipment. At times, the use of dust respirators may be necessary for several days; however, in their present form, they cannot be accepted as a permanent solution to the dust inhalation problem in coal mines.

When they are selected, used, and maintained according to accepted practice, approved dust respirators that are available today will protect workers against inhalation of many hazardous materials. The Bureau's tests make certain that more than 98 percent of respirable dust will be retained by filters of approved respirators. Usually, a comfortable and reasonably leak-tight facepiece fit can be obtained. This assures that the respirator will remove better than 95 percent of the atmospheric dust.

Information on respirator selection, use, and maintenance can be found in the new American Standard Practices for Respiratory Protection, Z88.2-1969, which is scheduled for publication late in 1969 by the American Standards Institute. Some of this information is summarized below.

Unfortunately, respirators may be used in high-dust concentrations where they plug quickly, making breathing difficult. The wearer may then discard the respirator rather than replace the filter. Also, many workers object to wearing what they regard as extra paraphernalia. This is particularly true when the adverse results of not wearing a respirator are not immediately apparent.

On one hand, respirators have been used successfully for many years in the lead, beryllium, and other metal industries, where a man who does not wear respiratory protectors in a toxic atmosphere will find positive proof of this neglect in a very short time. On the other hand, dust, such as silica, asbestos, and coal will incapacitate a worker only after years of exposure. Under these conditions, workers will object to and find reasons for not wearing protective equipment. This is particularly true if the respirator is more uncomfortable than exposure to the dust.

Hence, we have a twofold problem. First, how do we make good respirators even better, so they will be acceptable to more workers? Second, how do we convince workers that they should wear respirators, when conditions require that they be worn?

#### MAKING RESPIRATORS BETTER

Respirators approved under the latest schedule are almost always more comfortable and exhibit better performance than those approved under previous schedules. Materials and respirator knowledge are constantly improving, and the Bureau incorporates more severe test requirements in each schedule revision. Respirator manufacturers recognize this, and many have submitted their respirators for approval under schedule 21B. Unfortunately, respirators which were approved under older schedules do not fade away. Human nature, being resistant to change, tends to perpetuate use of respirators that manufacturers try to discontinue. While it must be recognized that dust respirators approved under Bureau schedules 21 and 21A are by no means unsafe to use, the user should know that better models approved under schedule 21B are available.

Studies of respirator design, performance, and ergonomics (that is, the effect of respirators on performance of work) have shown that several factors are important to respirator quality and wearer acceptance. Most important are breathing resistance, facepiece fit, comfort, and filter efficiency. Some factors, such as facepiece fit and comfort are personal requirements that depend principally on the facial features of the persons wearing the devices. Using information from these studies, manufacturers have developed and are continuing to develop new facepieces that are more acceptable to wearers.

The Bureau, in cooperation with other Federal agencies and respirator manufacturers, is currently developing new performance requirements and design criteria for dust respirators. Briefly, the following has been done or is underway at the Bureau.

On June 16, 1969, the Bureau issued amendments to schedule 21B, for approval of radon daughter respirators. Work done at Los Alamos Scientific Laboratory, under the direction of E. C. Hyatt, was the basis for new performance requirements for these devices. Tests at Los Alamos and at the Bureau showed (1) a correlation between radon daughter and lead fume penetration of filter media, (2) the usefulness of a quantitative facepiece-fit test using a coal dust test atmosphere, and (3) the satisfactory performance of certain filter media with unusually low breathing resistance.

Incorporation of the lead fume test and low breathing resistance requirements in the amended schedule should result in development and approval of more efficient respirators with lower breathing resistance, for use by uranium miners and others. The quantitative coal-dust facepiece-fit test has proven to be useful in evaluating respirator comfort. In this test, several subjects enter a chamber containing approximately 75 mg of coal dust per cubic meter and go through facial and body movements while wearing the respirator under test. Each subject is carefully instructed to put the respirator on comfortably (as it will be worn in use) even if this results in a loose fit. From comparison of the dust concentration taken from within the facepiece with the dust concentration in the chamber, the percentage of respirator leakage is determined. Most of the currently approved dust respirators show leakages of less than 1-2 percent on newer models and up to about 7 percent on older models. At least one manufacturer of an approved respirator has speeded up modifying an older facepiece to improve comfort and produce a better fit, after he was shown the results of this test.

Concurrently with work on these new performance requirements, the Bureau sponsored preparation of an American Standard, Z88.1-1969, on radon daughter respirators. This standard was written to assist users in proper selection, use, and maintenance of these devices.

Meanwhile, the Bureau and others are engaged in an accelerated program to develop new dust respirators with improved performance. One device being considered in this program is a disposable and valveless dust respirator that has high efficiency and low breathing resistance. Several models are being evaluated in field tests. The Bureau is working on high-humidity filter

penetration tests, since without an exhalation valve, moist exhaled air will have to pass through the filter.

Dust respirator designs of the air-supply type are also under development. These include an air-line respirator supplied with respirable air from a compressor located underground and an air-line respirator supplied from an underground liquid-air source. A filter-type respirator with attached blower is also being studied. Development of these respirators is being undertaken by several respirator manufacturers, a university laboratory, and companies and organizations in the coal industry. The Bureau is carefully observing their progress, while simultaneously developing new test requirements that may be necessary for approval of these devices.

The Bureau is also doing some basic research work on respirator filters. In one project, a sodium chloride aerosol for filter testing is being developed. In another, the basic mechanism of entrapment of dust particles by filters is under investigation. Novel instrumentation, including a scanning electron microscope, will be used in these and other Bureau studies on dust and dust respirators.

#### IMPROVING RESPIRATOR ACCEPTANCE

It may be assumed that wearers who object to presently available respirators will be at least partially satisfied with newer and improved models. However, considerable missionary work must be done before and after respirators are accepted by wearers.

Unfortunately, many people think that a respirator program consists of handing a new respirator to a worker and saying, "Here, wear this." You may be certain he'll wear it -- around his neck.

What is a minimal respirator acceptance program? The following brief guide has been adapted from the American Standard Practices for Respiratory Protection, Z88.2-1969:

1. When dust respirators are needed, the reason for their need and how long they may be needed should be explained to the workers.
2. A standard operating procedure should be established.
3. Respirators should be selected, first on the basis of the hazards present, and second, to fit the wearers comfortably.
4. Wearers should be instructed in proper respirator fitting procedures.
5. Respirators should be regularly cleaned and disinfected.
6. Respirators should be maintained with replacement parts to keep their protective capacity and retain their Bureau approval.

Field experience has shown conclusively that one respirator facepiece will not fit everyone comfortably. Faces come in a wide variety of sizes and shapes and, so far, respirator manufacturers have been unable to develop a universal half-mask facepiece. Some manufacturers provide two or more sizes which can be fitted with the same filters. Ideally, the respirator wearer should be allowed to select his respirator from at least two sizes. He should be trained from the manufacturer's instructions, how to perform a simple check of face fit. The model which fits satisfactorily and is most comfortable should be issued to him. Observing his face during the first few work periods will show if and where leakage may have occurred between the facepiece and face. If one size proves unsatisfactory after the initial trial, adjustment or issuance of a new facepiece, or a better job of selling respirator use, or all three, may be required.

The face-fit test made prior to each use is important; this procedure is carefully detailed in the manufacturer's instructions and in the American Standards. It is most important to impress the wearer with the need for performing this test each time the respirator is worn, and it is even more effective, if he checks his facepiece fit occasionally while wearing the respirator.

Another important factor governing respirator acceptance is making certain that a clean respirator is available when needed. Nothing will discourage its use more than having to put on a dirty respirator. All respirators should be gathered together at the end of a work shift for cleaning and disinfection. Several alternate methods of handling this are described in the American Standards and in the respirator manufacturer's instructions. Where respirators are issued without previous assignment to a particular person, they must be both cleaned and disinfected. Where each respirator is marked and issued to an individual, daily cleaning is important, but disinfection may be done on other than a daily basis.

During and after cleaning, respirators should be carefully inspected for worn and missing parts. These must be replaced. Identical replacement parts must be obtained from the manufacturer to insure maintenance of the approval status of the respirator.

### CONCLUSION

In conclusion, it must be recognized that dust respirators offer definite protection to the wearer when properly used in conjunction with and in addition to other controls. Probably the greatest factor in obtaining worker acceptance is the personal attention that must be paid to their selection, use, and maintenance. If management and workers are willing to approach the problem on an individual basis, select the correct respirator, fit it comfortably to the wearer's face, keep it clean and in good condition, and take time for proper training, the percentage of wearer acceptance will certainly improve, and the worker's hazards will be reduced.

QUESTION: Will you repeat the efficiency statement you made at the start of your discussion?

MR. SCHUTZ: We could expect for the filters alone probably better than 99 percent removal of respirable dust. This is the dust going to the filters. Facepiece fit is a limiting factor in respiratory protection, and if the facepiece is properly fitted, you should get better than 95 percent efficiency against respirable dust.

QUESTION: How long would you expect respirators to be usable under, shall we say, maximum dust conditions?

MR. SCHUTZ: Maximum, probably not more than a few minutes, from the maximum dust loading we have heard of. Of course, this is a very extreme condition. I would hesitate to give any definite figure. I would say that when breathing really becomes difficult, the filters should be replaced or should be disposed of.

MR. CRENTZ: Life support systems will be discussed by Dr. William A. Burgess, Associate Professor of Environmental Health and Safety Engineering, Harvard School of Public Health.

## LIFE SUPPORT SYSTEMS

by

William A. Burgess

---

### INTRODUCTION

The air-purifying respirator used for protection against dust can be considered a marginal life support system. Although simple and economical, this device suffers from serious performance limitations, including significant facial leakage, high seating pressures of the mask on the face, interference with speech and vision, increased thermal load, and interference with other personal protective devices. At the other extreme, the astronaut's space suit represents a sophisticated system which optimizes the oxygen supply, removes carbon dioxide, and provides protection from air contaminants, vacuum, meteorites, temperature, zero gravity, and acceleration.

In this paper I will explore the developments and potential of life support systems for extended wear which lie between the boundaries of conventional respiratory protective devices and the life support system of the astronaut. It is this equipment which may provide reasonable alternatives to present systems for personal protection for mine applications. I will attempt to identify broad protection concepts and show implementation of the concept with specific examples of devices now in use or in development. Some of these

examples are drawn directly from coal mines and others from industrial and military experience.

### LIFE SUPPORT SYSTEMS AND DEGREE OF ENCLOSURE

This discussion of life support systems is based on the mobility required by the wearer and the level of enclosure which is acceptable in a given application. Mobility is a major factor in determining the choice of system. Does the miner move from location to location and require complete flexibility, or does he have a fixed work station on large powered equipment where energy sources and a mounting platform are available?

#### The Mobile Worker

Let us first consider systems that are truly portable as shown in Figure 1. A series of three protective envelopes are shown: the mouth and nose, the head, and the complete body. These desired protection envelopes are identified by the dotted line on the set of figures in the first column. The types of device we use to implement these protection envelopes are shown in the second column, and specific examples of equipment are listed in the last column.

Minimum protection from the inhalation of airborne contaminants is provided by the first protective envelope. In practice this is usually provided by an oral nasal mask or occasionally by full face masks. In the simplest life support system this protection realm is implemented by delivering clean air to the mask under positive pressure using a system carried by the worker. Such devices which are identified as powered air-purifying respirators eliminate breathing resistance and minimize facial leakage (0.1 to 1.0 percent) without elaborate fitting procedures. They are usually designed to provide a minimum airflow of 4 cubic feet per minute, which slightly exceeds the peak inspiratory flow at a moderate work rate. Three systems of this type listed in Figure 1 -- the Fenzy Aerateur BQ, the Martindale, and a unit designed by the author for the American Iron and Steel Institute -- will be described in some detail.

The Aerateur BQ shown in Figure 2 was developed by the Center for Mining Medical Studies of the Nord Pas de Calais coal fields (1). It is produced by Fenzy & Cie, Paris, France, and distributed in the United States by Safety and Supply Company, Seattle, Wash. The unit consists of a dust filter and a simple fan element driven by a permanent magnet motor, all mounted directly on the rubber oral nasal facepiece. A power cable runs from the facepiece to a battery on the belt. The complete facepiece assembly weighs approximately 12 ounces. A standard dry cell battery is said to provide 60 to 70 hours of operation.

The cleanable filter, made of Amainte-Alfa paper, is pleated to obtain 464 square inches of media. The United States distributor states that the filter has an average efficiency of 98.5 percent, when tested with silica dust

with a median size of 0.8 micrometer at a dust loading of 160 to 200 milligrams per cubic meter (2).

Our tests show the unit will deliver 3.4 cubic feet per minute at a fan static pressure of 0.10 inch of water, when operated at 6 volts. At this operating point, the current drain on this unit is 110 milliamperes. Over a thousand of these units have been under evaluation in the French coal fields; however, the results of this evaluation study are not available (3).

Martindale Electric Ltd., London, United Kingdom, has developed a powered unit to be used with oral-nasal masks and plastic hoods. The motor-blower, a 6 volt silver-zinc battery, and a high efficiency filter are housed in the power unit which can be worn with either a front or back belt suspension. The unit, shown in Figure 3, will deliver 5.3 cubic feet per minute when used with a high efficiency filter. The current drain at this delivery is 500 milliamperes which permits an operating life of 8 hours. This unit, first described in the United States by Luxon, has been stated to have varied industrial application in England (4). The standard unit comes equipped with both a roughing filter and a high efficiency pad-type filter. The power unit weighs approximately 5 3/4 pounds and the associated delivery tubing and mask and belt another 2 1/2 pounds.

A powered unit, designed for this protective envelope by the author under a grant from the American Iron and Steel Institute, is shown in Figure 4. The power pack which is worn on a miner's lamp belt and consists of a simple radial blade blower, DC motor, and a rechargeable nickel cadmium battery system, provides a nominal delivery of 4.8 cubic feet per minute. The unit operates at 3.6 volts and has a current drain of 700 milliamperes at rated delivery. The unit was designed for coke-oven workers and based on particulate removal only. A deep wool batting filter media that had been impregnated with a resin was chosen after field studies of efficiency and loading characteristics. The power unit has a weight of approximately 2 1/2 pounds, and the breathing hose, mask, and belt weigh an additional 1 3/4 pounds. At the present time these units are being evaluated at a number of coke ovens in the United States.

Although the powered systems used with an oral-nasal mask eliminate inhalation resistance and minimizes leakage, one must still accept interference with speech, discomfort from the wearing of the mask, and difficulties in using the device with head and eye and ear protection.

The next obvious protective envelope shown on Figure 1 is that of the head envelope. The neck seal in this system can usually be designed to be more comfortable than the facepiece seal. A major advantage of the head envelope is a reduction in leakage to the range of 0.1 to 0.01 percent. One can also integrate head and eye and ear protection into a single system, and if communications are required, this too can be accomplished. (Anyone who has worn a hard hat, safety glasses, ear muff protectors, and a respirator for an extended period will acknowledge this advantage.) A significant disadvantage is that this system requires a minimum supply rate of 6 cubic feet per minute.

The Whitecapsul shown in Figure 5 presents the integrated protection concept which is characteristic of this level of enclosure (5). The helmet is used in conjunction with a 15-pound backpack which supplies 6 cubic feet per minute through a particulate filter and activated charcoal bed. This delivery is obtained at a power consumption which limits the operating time between battery recharging to 2 hours. I understand this manufacturer is developing a smaller unit for dust applications only.

The third envelope shown in Figure 1 approaches that of the astronaut, but it can be provided with relaxed requirements to meet the simpler protection needs of industry and the mine.

In addition to respiratory, head, and eye and ear protection, this type of enclosure obviously provides skin protection, and when used with proper overgarments, it can provide protection against flash fires. There are several examples of this enclosure developed for operational and rescue needs. The one I will describe is a suit system developed by the Clothing and Personal Life Support Equipment Laboratory, U.S. Army Natick Laboratory for Explosive Ordnance Disposal personnel (EOD) (6). This system has a unique clothing design feature which should make it attractive for a number of applications.

If a worker is encapsulated in a complete garment, one can reduce leakages to 0.01 -- 0.001 percent; however, a number of significant design problems arise which must be solved. One problem is that of thermal comfort, especially if the garment is impervious to water vapor. The Natick clothing system is based on their thermal equilibrium concept which provides an effective solution to this problem.

The suit system shown in Figure 6 consists of a helmet with an integrated voice and electronic communication system, body clothing with gloves and boots, and a powered air cleaning unit with a distribution system. A battery-powered fan operating at a static pressure of 4 inches of water delivers 18 cubic feet per minute to the system. Six cubic feet per minute is directed to the helmet and the balance to the suit. The suit consists of a double void as shown in Figure 7. The suit supply is directed to the ventilation layer and distributed to the torso, arms, and legs. It then flows to the extremities, where the air flow is reversed into the exhaust layer. The exhaust layer is provided with a series of conventional respirator exhalation valves which permit the exhaust to dump to the atmosphere. This air distribution system and its countercurrent flow technique permit the suit to be used in the temperature range of  $-40^{\circ}$  to  $110^{\circ}$  F.

The air supply system is carried on a backpack as shown in Figure 8 and consists of a battery-powered fan delivering 18 cubic feet per minute through a filter and activated charcoal air cleaning component. The system operates at 12 volts at a current drain of approximately 3 amperes for a total operating time of 2 hours. The present system has a suit weight of 23 pounds and a life support component weight of 19 pounds. The investigators state that they anticipate an 8-hour operating time with an advanced power supply system.

### Fixed Work Stations

If we now consider systems which can be used by men working at fixed machine stations, we find that a number of other protection devices may be considered. These possibilities are described in Figure 9, using the same envelope classification of Figure 1. The first envelope, an oral-nasal mask for protection of the respiratory tract only, can be satisfied in a number of ways, since weight and energy requirements are not of great importance. One attractive approach presently in use on continuous miners in Gary, W. Va., is shown on Figure 10. This system, fabricated for Mine Ventilating Systems by Essex Cryogenics, Inc., is a liquified air system (7)(8). The main components of the system consist of a 10 liter Dewar with evaporator which is picked up by the miner at the lamphouse, carried to the continuous miner, and placed in its holder. A simple delivery tube with demand regulator supplies respirable air to the half-mask piece worn by the miner. Tare weight of the Dewar is 17 pounds and when full, 35 pounds. The mine must provide an air liquifier to service this equipment.

This system appears to have received good acceptance by the individual miner, based on its simplicity and the quality of the respirable supply. It does seem to be an attractive solution to full-shift protection of an individual working from a fixed work station.

The second enclosure classification in Figure 9 could also be serviced by a cryogenic system; however, a continuous flow of 6 cubic feet per minute would be required which would demand a rather large system. Since adequate power is available, a small air cleaning system, using a dry filter seems feasible. Such a system would require significant maintenance, due to the very high dust loadings, unless it were equipped with an automatic filter change system. Another interesting approach which has been actively pursued by the Mine Safety Appliances Company is the use of the Nash Clean Air Blower shown in Figure 11. This unit is a low pressure air compressor which has been used with success on airline respirator supply systems for a number of years. The compressor action is generated by a rotating water ring. The blower supplies 8 to 10 cubic feet per minute at 20 psig with a power requirement of 2 horsepower. This device is also a good air cleaner and has demonstrated efficiencies greater than 99 percent against coal dust. If a dry filter is used downstream of the Nash unit, efficiencies of 99.9 percent can be achieved (9). Wetting agents will cause foaming in the pump chamber and carry over into the helmet or facepiece. Therefore, the 3/4-gallon per minute water supply should not contain such additives. At the present time Mine Safety Appliances Company is conducting a field study on such a system.

If one is working from a fixed work station with normal services, the suit envelope shown in Figure 9 becomes especially attractive. A number of simple suit systems have been described by various authors, principally those in atomic energy laboratories. One recent system is the Douglas Point Air-Supplied Vault Suit (10) shown in Figure 12. This is a two-piece garment consisting of a cotton coverall with an overgarment of plastic. The suit is provided a total compressed air supply of 20 cubic feet per minute with approximately one-third of the supply directed to the helmet by means of a vortex

tube. The helmet shell is custom molded; however, the visor and other components are fabricated from standard units. A major difficulty was encountered in providing suitable communications with this system. However, total enclosed ear pieces and a noise-cancelling microphone resolved this difficulty. A number of other suit systems with umbilical service lines have also been described (11)(12).

The ultimate protection envelope shown in Figure 9 is a completely enclosed work station with a controlled environment. This concept has already been applied to industrial crane cabs and construction equipment cabs with a high level of protection, greater acceptance by the worker, and possibly some favorable impact on work efficiency.

#### SUMMARY

This review of life support systems has revealed the advantages of extending our protective envelope to the entire man. The development of the hardware which may be assembled for such systems is well on its way; however, the impact of such systems on the worker has not been investigated.

In closing I would like to quote C. N. Davies (13) at the joint meeting of the Ergonomics Research Society and the British Occupational Hygiene Society in 1961 on the Design and Use of Respirators:

"One is left wondering what is the future of the personal respirator; always, probably, they will be needed for special maintenance tasks, but machines, now, are often better protected against dust than the men who work them and the feeling remains that, if this is necessitated by the delicacy of inert mechanism, the time will soon come when the only irreplaceable component will be enclosed along with all the rest."

This very valid observation opens the door for life support systems in many of our work environments including the coal mine.

#### REFERENCES

1. Anon. LaMasque Aerateur, Individuel, Travail et Securite, February 1965.
2. Kusian, R. Personal Communication, October 1969.
3. The Prevention and Suppression of Dust in Mining, Tunnelling, and Quarrying, Third International Report, 1958-1962. ILO, 1966.
4. Luxon, S. G. Recent Development of Dust Respirators in the United Kingdom. AIHA, March-April 1968.
5. Whitecapsul, Rite Hardware, Glendale, Calif.

6. D'Iacono, V. Protective Clothing and Life Support Equipment for Explosive Ordnance Disposal Personnel, Technical Report 69-48-CE. Clothing and Personal Life Support Equipment Laboratory, U.S. Army Natick Lab., November 1968.
7. Burgess, J., Mine Ventilation Systems Co., Personal Communication, October 1969.
8. Morse, K. Sampling and Control of Airborne Dust in Bituminous Coal Mining in the U.S.A., Proceedings of the First Australian Pneumoconiosis Conference, Sidney, February 1968.
9. Merkle, R. E. Mine Safety Appliances Co., Personal Communication, October 1969.
10. Simmons, R. B. The Douglas Point Air-Supplied Vault Suit. Am. Ind. Hyg. Assoc. J., v. 29, No. 605, 1968.
11. Croley, J. J. Protective Clothing -- Responsibilities of the Industrial Hygienist. Am. Ind. Hyg. Assoc. J., v. 27, No. 140, 1966.
12. Crockford, G. W. Industrial Pressurized Suits. Ann. Occup. Hyg., v. 11, 1968, pp. 357-365.
13. Davies, C. N. (Ed.). Design and Use of Respirators: Proceedings of a Joint Meeting of the Ergonomics Research Society and the British Occupational Hygiene Society, Porton, July 1961. Pergamon, London, 1962.

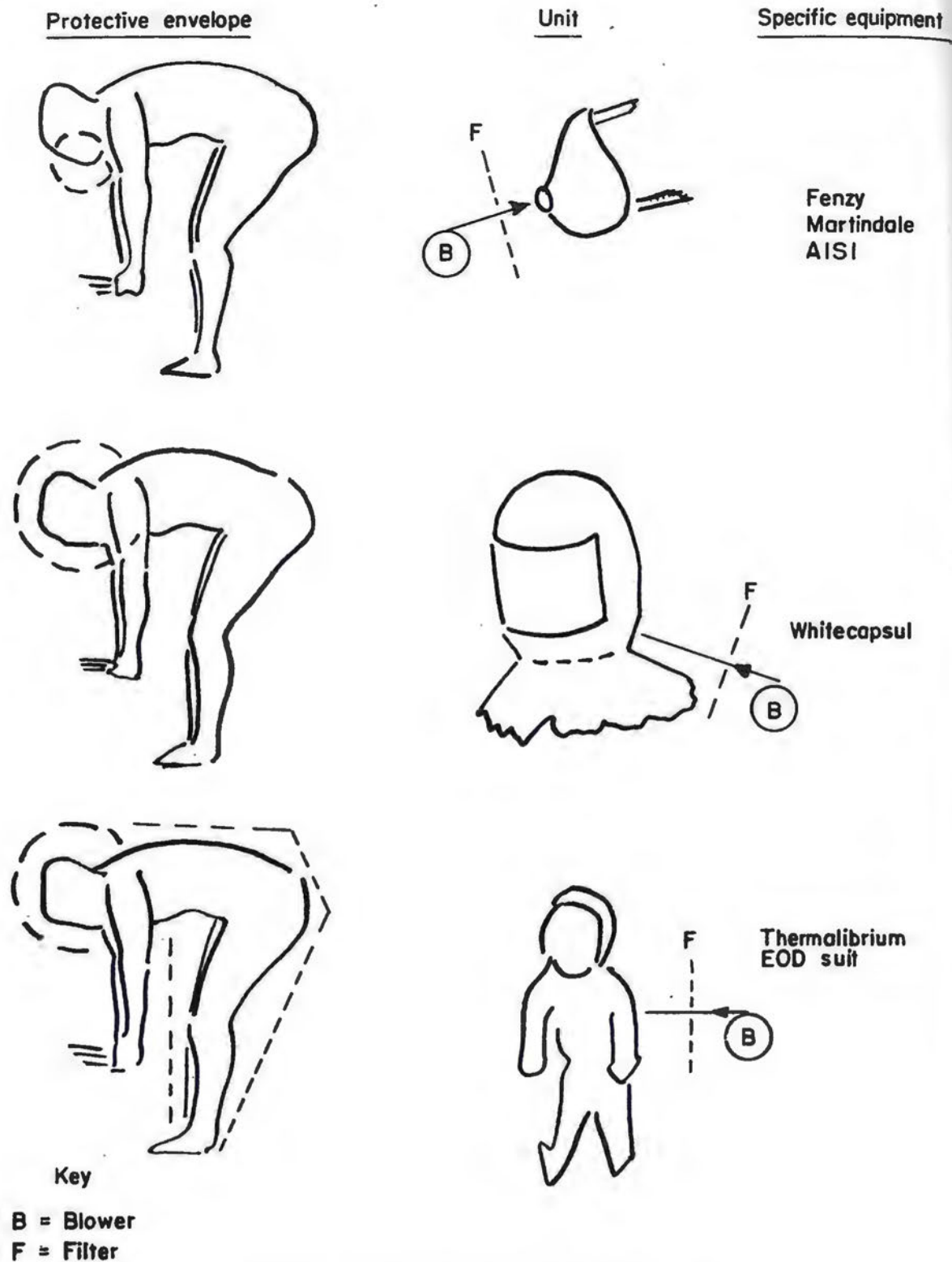


Figure 1.—Protective Envelopes for Mobile Worker.



**Figure 2.—Fenzy Aerateur BQ.**



Figure 3.—Martindale Powered Unit.



**Figure 4.—American Iron and Steel Institute (AISI)  
Powered Air-Purifying Respirator.**



Figure 5.—Whitecapsul Unit.



**Figure 6.—Thermalibrium EOD Suit.**

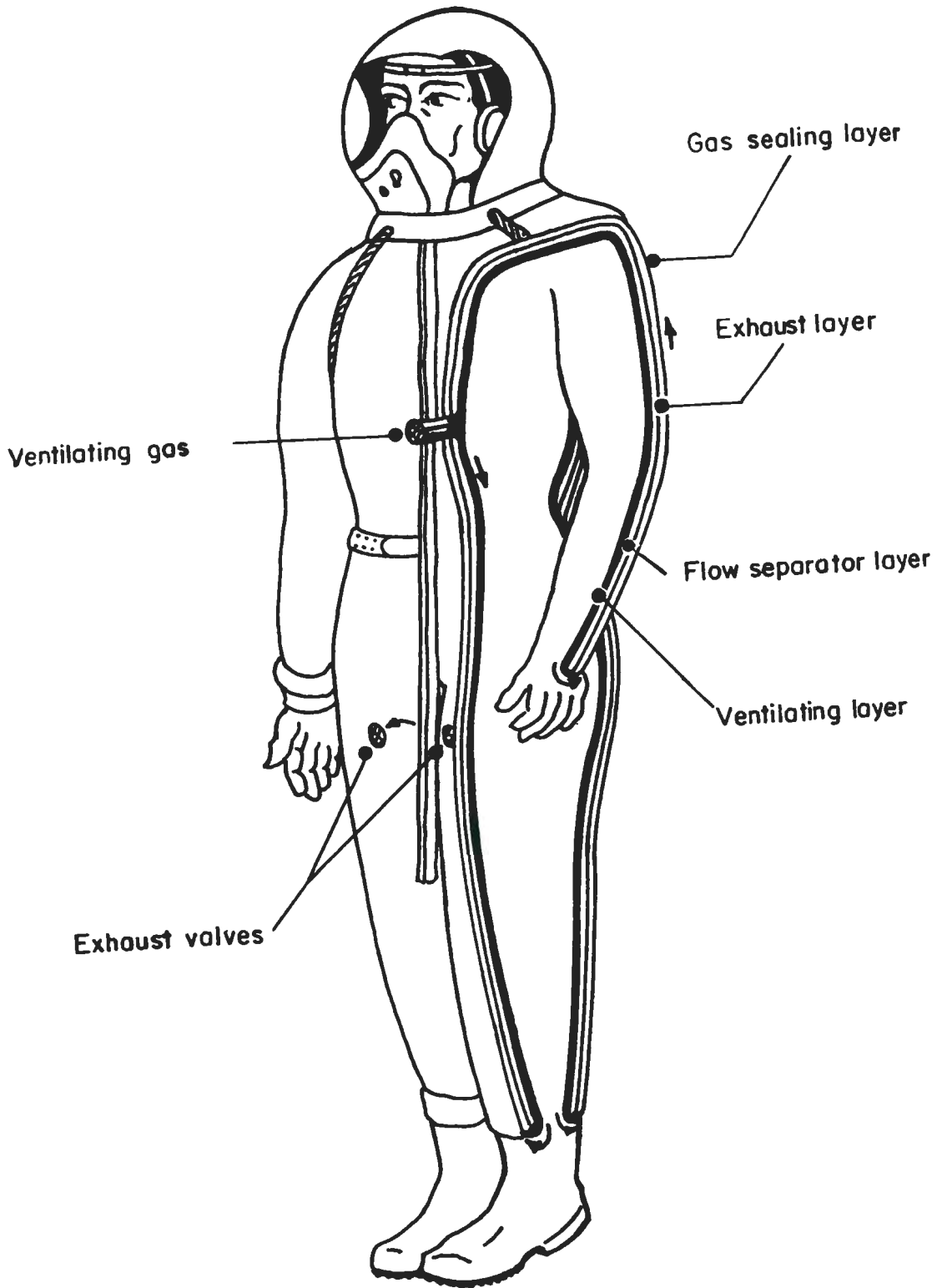


Figure 7.—Air Distribution for Thermal Equilibrium EOD Suit.



Figure 8.—Air Supply System for Thermalbarium EOD Suit.

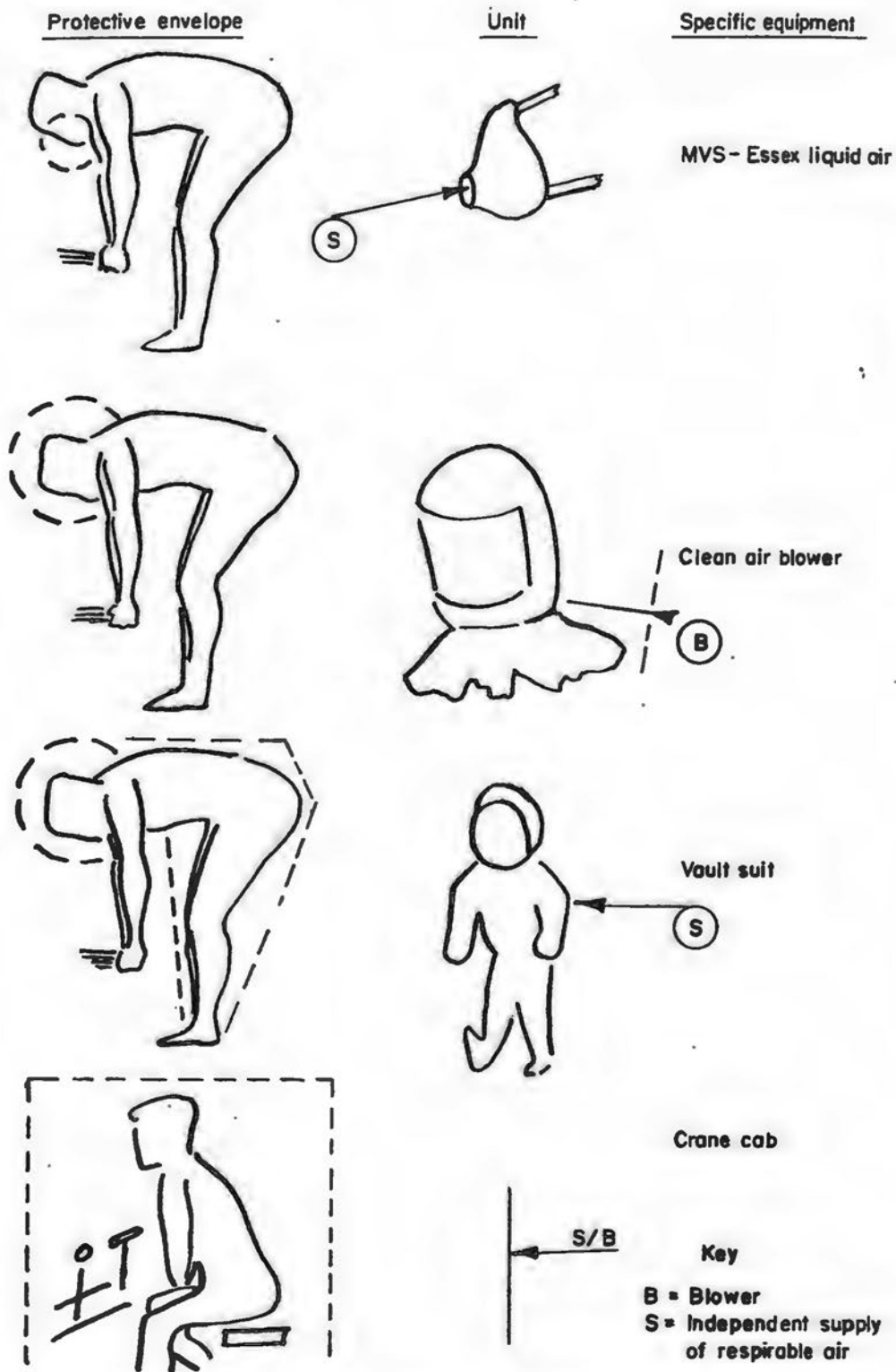


Figure 9.—Protective Envelopes for Worker With Fixed Work Station.

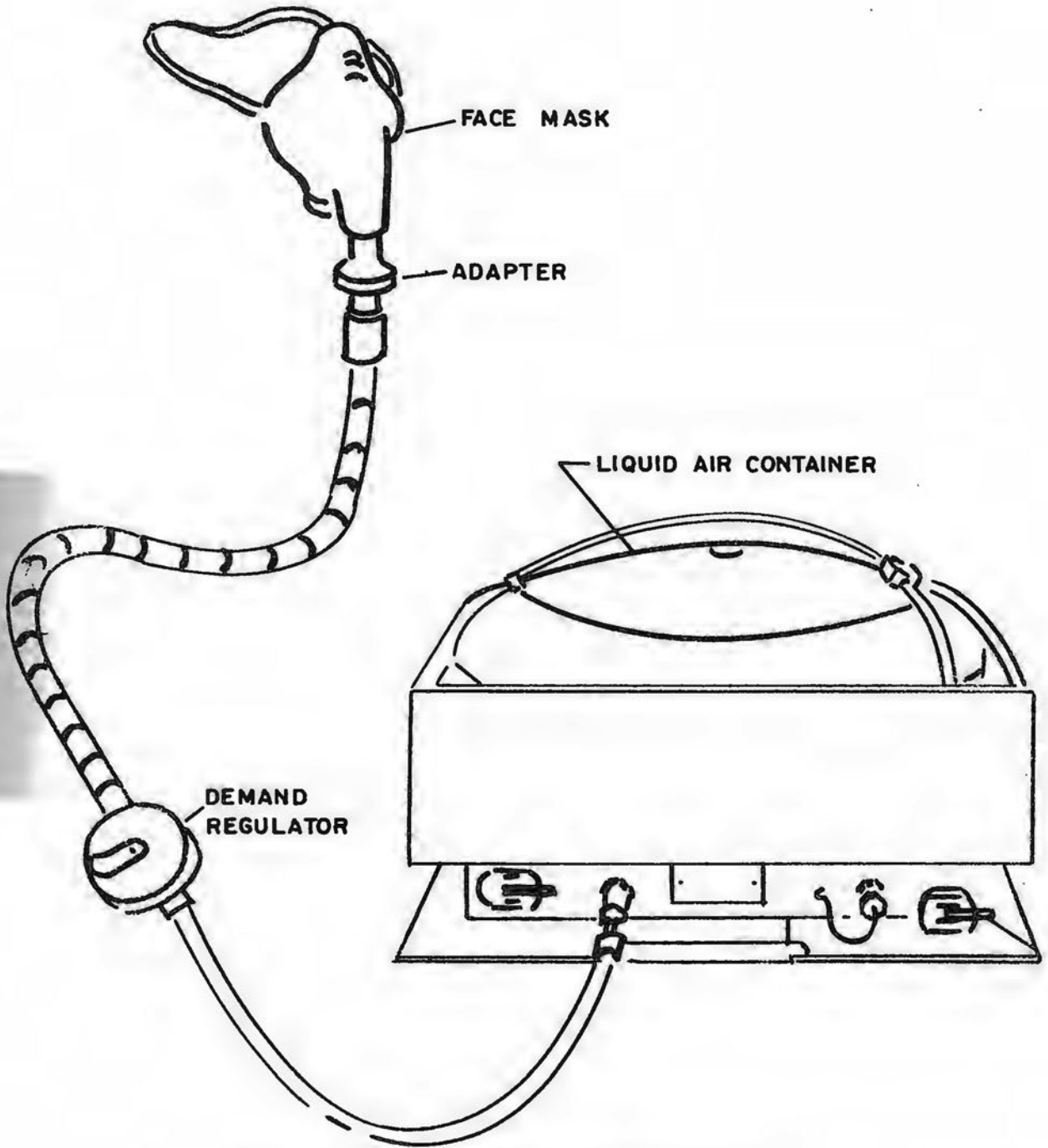
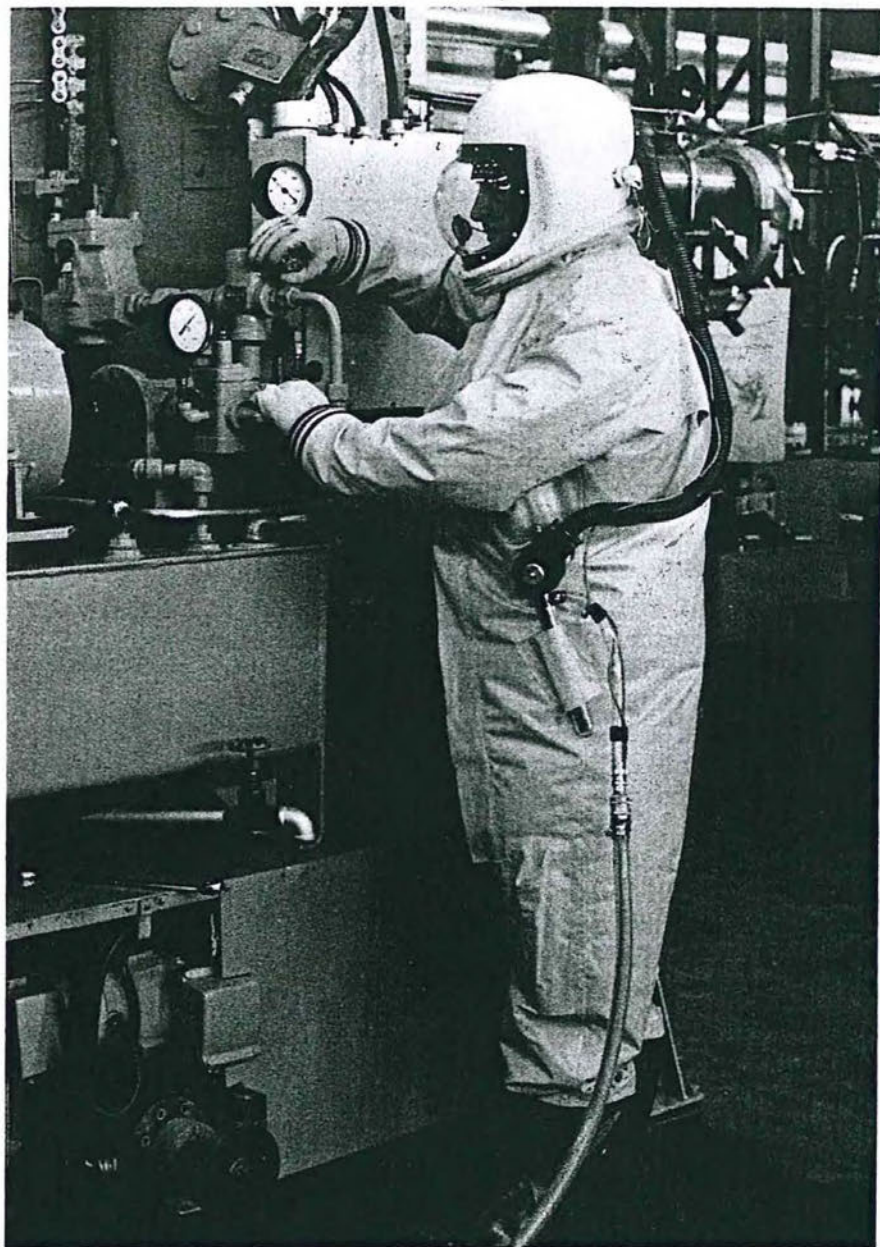


Figure 10.—Liquid Air Unit Fabricated for Mine Ventilating Systems by Essex Cryogenics Inc.



Figure 11.—Nash Clean Air Blower Under Test.



**Figure 12.—Douglas Point Air-Supplied Vault Suit.**

MR. CRENTZ: Our final paper this morning will be on some experiences with respirators in an underground coal mine, and will be presented by D. K. Flanagan, General Superintendent of Putnam Coal Mines, Union Carbide Corporation.

## EXPERIENCE WITH RESPIRATORS IN AN UNDERGROUND COAL MINE

By

D. K. Flanagan

---

### INTRODUCTION

The interest of Union Carbide Corporation and its employees in accident prevention is well demonstrated by the fact that last year the three Bell Creek-Blue Creek underground coal mines in West Virginia, working the No. 5 Block Seam, experienced no disabling injuries. Site Safety experience for 1968 for Union Carbide's Coal Department was D.I. -- 2.1, S.I. -- 19.2, SEV. 35. Throughout the years, accident prevention activities have been increased with excellent results, and in the last 12 months there has been intensity in the Coal Department program to prevent respiratory complications. For years the use of personal respirators has been a part of the Union Carbide Corporation's safety program, and individuals have been provided with their individual respirators. The point was frequently made that the wearing of the respirator was a good practice, but the wearing was left on an optional basis, and safety activities were not keynoted on this area.

### POLICY

The policy of the Union Carbide Corporation is to protect the miner's health by reducing or eliminating exposure to respirable dust.

### Procedure

The use of a respirator is necessary in dusty conditions, and our OBJECTIVE is to work with our program and in unison with our local United Mine Workers of America members, to eventually make it mandatory for men to wear a respirator in areas where our testing and sampling activities indicate the necessity.

We do not consider respirators as a substitute for the best technology available in reducing, suppressing, or controlling dust. However, we do feel that 100 percent use of the respirators is necessary among our employees in

situations where dust concentrations are high enough to be injurious to health, and respirator use is the only known and sure way to positively reduce this hazard and protect the miner.

### Our Program

Our program is personalized in every way possible. What are we doing to attain our objective?

1. Furnish the equipment. We chose a respirator with a throw-away or replaceable filter. This allows the worker to replace the filter, if it should limit his breathing due to contamination during his working hours in the mine.

The filters are available in the Lamp House, Mine Foreman's Office, and Safety Supervisor's Office, and the Section Foremen carry extra ones in the mine. Any repairs that are requested are done by the Safety Supervisor.

2. Hold 15 to 20 minute Safety Meetings with employees which include:
  - A. Facts on dust and its effect,
  - B. Pictures of lungs affected by dust,
  - C. Demonstrations on the proper way to wear the personal respirator,
  - D. Programs to emphasize the correlation between dust control and proper application of ventilation standards.
3. Specifically include dust hazards in the half-day orientation program for new employees and furnish the personalized respirator the first day on the job.
4. Individually counsel those with complaints concerning the respirator and even to vary the type of respirator to the individual preference, provided, of course, the requested substitute meets specifications and is USBM approved.
5. Constantly refer to respirators as "personal protective equipment" which warrants good care and maintenance by the person it is protecting.
6. Constantly check the percentage of program acceptance in order to make improvements and keep our program alive.
7. Have suppliers (primarily MSA, since we use MSA equipment) address the group safety meetings.

8. Share information on spot dust samples to emphasize "areas and jobs" which should be considered as needing "additional respiratory protection" -- a respirator.

#### EXPERIENCE

We have not yet hit upon a final method of evaluating our Program's effectiveness. Our present objective is to instill in all employees a desire to protect their health by avoiding exposure to respiratory problems. It is not easy for some workers consider the choice of wearing or not wearing a respirator a matter of human rights. Does a company have the right to tell a man he must stop smoking, or that he must wear a respirator? From medical and government reports we know that coal dust causes lung damage. Who is to say what an individual must do to protect himself? Some feel that the individual has the right to choose. We are giving him the facts and the protection he needs. We are doing our best to educate and to get him to wear his respirator for his own protection. We don't feel we will be successful, if we merely give him the alternative to "wear the respirator" or "be released from his job".

Our success, then can be best measured by the percentage of men wearing respirator protection. By observing specific job conditions and areas plus our dust sampling efforts, we have decided upon four areas of importance: (1) the Cutting Machine and Continuous Miner Operators, (2) the Loading Machine and Shuttle Car Operators, (3) the Roof Bolters, and (4) the Coal Drill. In the first area, our sampling has indicated that to be on the safe side, respirators should be worn during the operation of the machines. In the second area, our sampling thus far has not indicated the necessity of wearing respirators while operating the machines. Because of our dust collecting system on Roof Bolters, our sampling indicates that respirator protection is not needed. In the fourth classification, our current sampling does not indicate a need for respirators. We are using these four classifications for determining percentages of our ultimate goal of a 100 percent for the respirator program in dusty conditions.

A year ago, less than 40 percent of our miners wore respirators. Recent surveys show an increase to 85 percent. This, we feel, is due to our educational program, recent publicity on coal dust effects, and better respiratory equipment. The original respirator used was cumbersome, difficult to maintain, and often self-defeating. The respirator most popular among employees today is the Dustfoe 77 Respirator, which has passed the new USBM approved Schedule 21B. This newly designed respirator is comfortable, and the filters are easily changed for added convenience.

Also, we are trying to use involvement in our over-all dust control efforts to foster acceptance of respirators. Tests to define and evaluate dust problem areas are currently being carried out. They will be done with different ventilation systems, with water addition, on the basis of exhaust fans vs. line brattice, etc., to obtain the best environmental conditions possible. All these activities will be communicated to the work force, and always the point

concerning "use of personal protective equipment" will be made to get the individual involved in matters of dust control which would lead him to the use of the respirator.

#### SUMMARY

The program lists my part as being "Experience with Respirators in an Underground Coal Mine" -- not all underground coal mines, and I have tried to limit my remarks to the experienced angle.

IT IS NOT AN EASY TASK -- BUT IT IS A NECESSARY ONE IN THE OPINION OF UNION CARBIDE CORPORATION.

Will we achieve 100 percent participation? There are those in our organization who think so -- but we have not achieved it yet. Under the "involvement program" most of the younger men to the mine and many of the older ones have REDUCED THEIR EXPOSURE TO RESPIRATORY DUST BY THE WEARING OF A RESPIRATOR. THIS IS OUR GOAL.

It is our intention at some future date, possibly in 1970, to make the program MANDATORY.

#### AFTERNOON SESSION

2:00 p.m.

MR. GARVEY: I am James R. Garvey, moderator for this afternoon session of the Symposium on Respirable Coal Mine Dust.

The format for this, the fourth and final session of the symposium, will be different from that of the prior three sessions. At those you spent your time listening -- now you will spend this session talking; questioning those you have heard and expressing your own experiences and views.

I hope you will all participate, because as pointed out in the printed program and stated by Mr. O'Leary yesterday, one of the purposes of this symposium is to develop "a textbook of available technology on dust suppression." Your questions and the answers will be a part of the record.

But before we start with that part of the program I would like to take a few minutes to summarize what we have heard. Perhaps this will stimulate more questions from you, which can be directed at the total panel of speakers.

The health standards prescribed by the Coal Mine Health and Safety Act of 1969 will present unique problems for the coal miner, the coal-mine operator, and for the Bureau of Mines. Unfortunately, the law, instead of, as we had hoped, establishing a sound base for the development of a health protection program, as the British did, will probably prescribe specific levels of

respirable dust which must not be exceeded and severe penalties for failure to meet those levels.

Numerous times during the Congressional hearings prior to the enactment of the law, it was pointed out that the United States is the only coal mining country in the world which does not have a national standard for respirable coal mine dust. That statement was not entirely accurate, but we certainly now have the most restrictive coal mine dust standard in the world. Whether the severity of the standard is necessary to protect the miners' health is largely unknown, but further discussion along this line would be only academic.

We will soon have a law which we must meet if we are to continue to mine coal. It is apparent from the limited information we have available that meeting the respirable dust standards as they will be prescribed in the law will present some difficult problems. But the United States coal mining industry has overcome difficult problems before, and I am certain that given sufficient time, it will overcome this one. But cooperation by all parties involved will be essential.

During the past day and a half you have heard how and why the standards were developed, how dust levels are measured, what the current levels in U.S. coal mines are, and what might be done to reduce them. From listening to the presentations, I conclude that many of the proponents of the new health standards have (1) misunderstood the basic health versus dust level information available, (2) failed to recognize that the instruments and techniques for dust measurement are far from precise, and (3) failed to give due credit to the coal industry for the work it has already done on dust suppression -- and done long before the date of a year ago, when everyone became an expert.

Our colleagues from Great Britain have told you of their work. The carefully conceived and well-executed program which they have pursued is deserving of compliment. How our Government officials could select a standard of  $3.0 \text{ mg/m}^3$  as a result of their review of the British work is as much a mystery to them, I am sure, as it is to those of us who have been in close contact with the British work for many years.

But, as I said earlier, this is merely history. On the other hand, we do hope that since so much guidance has been attributed to the British, our legislators will go the full route and also copy the British system of multiple-shift averaging in determining compliance. We believe this is essential, if we are to have any hope for compliance.

You have listened to a description of the possible sampling instruments which will be used in our mines. And most importantly, the precision inadequacies of the sampling and measurement methods have been brought out.

Following Mr. Jacobson's presentation, he agreed with a member of the audience that a one-shift reading of  $3.5 \text{ mg/m}^3$  could mean compliance with a  $3.0 \text{ mg/m}^3$  standard because of built-in instrument errors. The fact is that a single shift  $3.8$  or  $3.9 \text{ mg/m}^3$  reading could also be in compliance. I believe Murray would also agree to that.

And finally you have heard of the various methods of control of respirable dust -- ventilation, water sprays, water infusion, foams, wetting agents, machine design, and dust collection. All have their place in this program to reduce dust levels. But, as Bill Kegel so clearly pointed out, -- as did several other speakers -- coal mines and coal mining methods are so variable that anyone who concludes that any one method will be the answer demonstrates his ignorance of both.

As I said, the coal miner, the coal mine operator, and the Bureau will all play significant roles in the solution of this problem. The miner must be trained to operate the coal mining machinery so as to minimize respirable dust production, but despite all control efforts, he will still produce dust.

The only really effective way in which compliance with the standards can be achieved is by controlling the exposure of the miner. He must learn how to do his job with a minimum of exposure to high dust levels, and he must know how to take full advantage of whatever means are available, such as water sprays, ventilation, etc., to keep the dust away from his breathing zone. This will not be easy, because the respirable dust with which we are concerned is invisible. The miner must learn how to avoid it without being able to see it or otherwise detect it.

The coal mine operator, for his part, must incorporate on his machines and in his mining methods, the latest available technology for (1) minimizing the production of respirable dust and (2) preventing exposure of the miner to that dust which is produced. Examples of the former would be the use of adequate and effective water sprays and frequent bit changes.

An example of the latter would be adequate ventilation, including quantity, direction, and quality. The quality of the air coming to the face is most important because providing, say 10,000 cubic feet of air per minute, to insure that a velocity of 100 feet per minute is directed past the machine operator, will be of little help if that air has already become dust laden in passing the belt transfer points, shuttle-car dumps, and other dust-making operations in the mine. The air reaching the miner must be essentially dust-free. And this we may not yet know how to accomplish in existing mines.

And finally, the Bureau of Mines will have a heavy responsibility. The new law will charge the Bureau with the responsibility for specifying how dust sampling will be done and how compliance will be determined. We understand that advisory committees with industry members will be appointed by the Bureau to assist them in this regard. Perhaps in our discussions here this afternoon we will hear more about this from the Bureau representatives who are with us.

Further, the Bureau has the only personnel trained in the dust sampling and measurement techniques which probably will be used. Industry will need the help of this nucleus in becoming equipped to do the required sampling.

The Bureau, through the dust sampling program which they have had underway since April 1968, has learned a great deal not only about coal dust sampling but also about the effectiveness of available measures for dust control. Consequently, industry must look to them for initial guidance on the application of effective measures for minimizing coal miner exposures to respirable dust.

Some of the work which they have done along this line was described in Technical Progress Report No. 19 which was distributed yesterday. That report describes work carried out in seven mines wherein, by the use of axial flow fans to increase the ventilation rate and control the air-flow patterns at the face, substantial reductions in dust levels were achieved in the mines. But it is unfortunate that the report did not point out the possible limitations of this technique in existing mines. It will not be the total answer to the problem in all mines, although it does indicate the potential of change in ventilation practices. Many such studies in other mines will be necessary if we are to gain sufficient knowledge to enable both health protection and the production of coal. I believe a well-planned and well-executed cooperative program involving both Bureau and industry personnel should be developed promptly to accomplish this.

The ultimate answer to the respirable dust problem probably lies in the development of better means for minimizing production of dust. This will require an accelerated program of research, hopefully stimulated by the Bureau of Mines with the funds which may be authorized for such research under the new Coal Mine Health and Safety Act. But the Bureau cannot do this job itself. It must have the full cooperation of the coal mine operators and the manufacturers of not only coal mining equipment, but of other auxiliary equipment which might be used. This will be a big job and, as is so well stated in the Bureau's report to Congress on their auxiliary fan study: "It is evident that before the results summarized herein can be generally applied, it will be necessary to develop equipment not now available to the industry, permit industry time to set up production facilities to manufacture this equipment, and to assure its distribution throughout the industry."

I presume this statement applies primarily to the axial flow fans mentioned in the report. But it will be equally applicable to all new developments resulting from research. The task which lies ahead is indeed a formidable one. But we must succeed -- not because of the new legislation -- but in the interest of maintaining health and needed coal production.

Gentlemen, the title of this session is "Applying the State of the Art." If some of my comments do not seem to fit that concept, let me remind you that as a researcher, I interpret the phrase "state of the art" to include knowledge of what cannot be done as well as what can. The tendency to oversimplify the solution of the problem has been appalling.

We have heard from various experts regarding the state of the art of respirable coal dust measurement and control. Most of these experts are assembled before you now, and this provides you with a final opportunity to question them regarding their experience on the various subject areas.

Other than the few minutes I have taken here with some introductory remarks, there are no planned presentations. The program is yours.

At the start of the symposium we had asked you to fill out your questions on these blue cards, which were passed around, and we got quite a few of them back. We will start this session by going over these cards. I will read the questions directly to the appropriate people, and we have until about 4:30 to discuss this subject.

If at the end of the reading and discussion of these questions there is opportunity for further discussion, I will call for questions from the floor. I intend to go through this group of questions generally in the order in which the presentations were made, except that we have one man from West Virginia, Mr. Flanagan, who was last on the program, but who has a transportation problem.

The questions for Mr. Flanagan concern the sampling which has been done at the Union Carbide Corporation's mines and their respirators. I will read both questions.

It was indicated in your talk that there was a 25 percent difference in sampling results of the sampling devices. Were the devices alike or different. You also stated in your talk that you used only 21B approved devices and that you used the Dustfoe 66 respirator. Is this contradictory?

MR. FLANAGAN: The testing devices were both of the same type. One device was attached on one side of the man, nearer the face, and the other device was on his other side, nearer the rib. Possibly the first device accumulated moisture, and the second one did not. Whether this is true or not, I could not say, but they were the same type of testing devices.

As far as the 66 is concerned, the Dustfoe 66 respirator is on Schedule 21A. It is approved by the Bureau. If I said it was approved on 21B, I was wrong. The most popular respirator with our employees today is the Dustfoe 77, which is approved on Schedule 21B.

MR. GARVEY: We have a number of questions directed to Mr. Walton. He told us about the dust control procedure sampling methods, standards and so on in Great Britain. The first question reads as follows: Is there any way to determine ahead of time an individual who may be more sensitive to dust? Could pre-employment physical and special examinations determine this?

I would answer that question this way. Neither Mr. Walton nor I are medical men, But we have talked to many doctors and, unfortunately, I think the consensus of the British, German, and the United States medical experts is that you cannot predetermine this. You can tell, of course, if the man does have some disease already, but you cannot predetermine susceptibility.

On the other hand, periodic X-rays during the time of employment, while he is exposed to dust, will indicate that he is developing symptoms faster -- if he is susceptible -- and this is about the only indication from a medical standpoint you have.

Mr. Walton, would you say that that answers the question?

MR. WALTON: Yes, I agree. Pre-employment examinations of young people entering the British coal mining industry have been given for some 25 years, but there is no evidence whether or not the selection has any bearing on susceptibility to dust.

Further analyses of the results of the Pneumoconiosis Field Research will be concerned with individual dust exposures rather than average concentration. These should indicate the extent of differences in the response of individuals to equal dust exposures and perhaps whether the response is affected by the type of work. For example, differences might arise because men engaged in heavy work breathe more air (and hence more dust) than those employed in light activities.

Our Physiology Branch, under Dr. David Muir, are studying the lung deposition of aerosols inhaled by men of differing respiratory function with and without X-ray signs of pneumoconiosis. It is hoped that this work will throw some light on the question of differing susceptibilities to dust, but it is unlikely to reveal the whole story, because men may also differ in their ability to eliminate dust from the respiratory spaces after deposition and in their tissue reaction to the relatively small fraction of material that is permanently retained in the lung.

MR. GARVEY: We have several questions for Mr. Walton regarding the British standards. I will read them. The first asks about the new dust standards which are going to be announced or have been set in Great Britain. I believe these were covered earlier, but we will go over them again.

First of all, what are the standards? Are they going to be statutory? How do you arrive at the 4.3 milligrams per cubic meter figure versus the 8 milligram per cubic meter in the return?

MR. WALTON: The new standards are given in my paper: 3 milligrams per cubic meter in stone drivages and 8 milligrams elsewhere. These refer to respirable dust, as measured with the MRE Gravimetric Sampler Type 113A operated continuously from the time that men reach the work place at the beginning of the shift to the time of leaving, averaged over a number of shifts.

The 8 mg/m<sup>3</sup> figure was derived from the interim results of the Pneumoconiosis Field Research specifically for longwall coal faces (from which most British coal is got). The normal sampling point is in the return roadway, 70 from the coal face, so that the concentration is measured after the ventilation air has acquired its maximum dust burden. This distance, which has been increased from the previous figure of 25 yards, allows instruments to be left

in position during shot firing at the face or ripping lip. The fallout of respirable dust between the face and the sampling point is small.

No corresponding research data for stone work are yet available, and until they are, it was thought prudent to maintain the previously existing differential between the standards for coal and stone. Hence the new gravimetric standard of  $3 \text{ mg/m}^3$  for stone drivages.

The British standards are not statutory; they are agreed by the National Joint Pneumoconiosis Committee which meets under the aegis of the Ministry of Power (now the Ministry of Technology) with representatives from that Ministry, the Ministry of Social Security, the National Coal Board, the Trade Unions, and other interested parties. The National Coal Board aims to meet the standards. Dust concentrations at all working places are measured and regularly reported to Dust Suppression Committees at both local and national levels. In 1968 about 80 percent of coal faces had approved dust conditions.

The relationship between the 4.3 and 8 milligram figures needs to be clearly understood. The interim results of the Pneumoconiosis Field Research established relationships between the colliery mean coal face concentrations of dust, measured portal-to-portal and averaged over all face workers (on longwall faces) in each colliery and the probabilities of contracting Category 1 or Category 2 pneumoconiosis after 35 years' work in such conditions. After consideration of these probabilities, a limiting colliery mean coal face concentration of  $4.3 \text{ mg/m}^3$  was decided upon.

From a study of the relationship between mean coal face concentrations, as measured in the Pneumoconiosis Field Research and the results of sampling in the return roadways, it was concluded that if the concentrations were not permitted to exceed  $8 \text{ mg/m}^3$  (averaged over a number of shifts) in the return roadway from any coal face, then the overall colliery mean coal face concentration would not exceed the  $4.3 \text{ mg/m}^3$  limit. Thus  $8 \text{ mg/m}^3$  was chosen as the working standard. Steps will be taken to check the continuing validity of the factors by which this was derived from the basic figure of  $4.3 \text{ mg/m}^3$ .

We have not yet studied the corresponding problem in the very few British collieries worked by other than longwall methods, but this will receive further attention.

MR. GARVEY: Thank you. We have several questions directed at the Bureau of Mines. Mr. Doyle, that are followups on this British standard. "Since most of the testimony relating to the need for a dust standard was based on English data, why is it that their current recommended standard of  $8.0 \text{ mg/m}^3$  is not now being considered and presented as part of our proposed standards?"

MR. DOYLE: I think it was evident from Mr. Walton's discussion that the British standard is not  $8 \text{ mg/m}^3$ , but  $4.3 \text{ mg/m}^3$ . When you compare the two figures, you must compare the American proposed standard of 3.0 against 4.3 which is the British proposal in terms of what the individual should be exposed to.

When the Public Health Service team, along with the Bureau of Mines team, went to England last October to review the British data, you must remember that what was available to them at that time was a lot less than what is available at the present time. At that time, our British colleagues had not finished their last round of X-ray examinations in the mines. They had not compiled much of the data which is available today, nor had they constructed the pneumoconiosis probability charts that were available to us at a later date.

So that the Public Health Service team really had to take some rather inadequate data that existed at that time and interpret this in terms of a standard.

It seems to me that they came out pretty close; the Public Health Service said 3.0, and the British said 4.3.

MR. GARVEY: I have to have a rebuttal here.

MR. DOYLE: You did not let me finish, Jim.

I said they came out pretty close in terms of data that was available at that particular time. Now, since that time, there has been a great deal more data that has become available.

MR. GARVEY: One thing that could mislead you a little bit here is that the British standard of 8.0, as described by Mr. Walton, means 4.3 for the face worker, but remember that the 4.3 is an average of all for the face workers. It is not the maximum of any individual. Our 3.0 refers to the maximum any individual would be exposed to. If we were allowed to average the faces and all of the people at them in a mine. I am sure the 3.0 standard would have a different meaning. It would be more nearly related to the 4.3. But we are comparing eggs and oranges. You cannot compare the British longwall with our pillar system.

Let us get on to the next question. What sampling scheme is going to be used under the new legislation?

Now, I don't know how far Mr. Doyle can go in answering a lot of this, because I think it will depend on how the final legislation comes out.

Henry, could you comment on your views? The question also asks who collects the samples?

MR. DOYLE: I rather think it is premature to try to comment on this. There are two bills now, as you know. Both of these bills agree in one respect in that the operator shall take a dust sample and forward this sample to the Bureau of Mines. It remains up to the Bureau to advise the operator of what the reference point is, the frequency of samples, and so forth.

The Senate bill sets the concentration as a maximum exposure which shall not be exceeded on any single shift. The House bill at this time specifies this to be an average of a certain number of shifts. We are not in a position to indicate what our sampling procedures will be until we know definitely which procedures the Congress will approve. I can tell you at this time that we do have a group of alternative procedures which are designed to meet either one of these requirements.

We will doubtlessly give you a reference point, if you are required to take your own samples, provide you with a sampling scheme, and request that these samples be sent to the Pittsburgh Health Group where they will be weighed and the data put in an automatic data processing system.

This system requires our receiving a great number of samples from the industry. To handle this volume, we are designing an automated laboratory that will handle these samples on an automated basis, in the system. We are working with the filter companies, so that they can give you a preweighed, encapsulated filter to fit into the personal sampler. This will have stamped on it the weight of the capsule in computer language.

The automatic data processing system that we are thinking of is one that would accumulate all of the necessary data, such as the difference in weight, the concentration in milligrams per cubic meter, the location of the sample, its number, and other identifying data. The system will select a certain number of samples with a yet to be determined percentage for a chemical and physical analysis which will include particle-size distribution, quartz, volatile and non-volatile matter, and trace elements.

I am reluctant to discuss these in detail at this time, because we have not yet finalized a plan within our own organization.

As Jim pointed out to you earlier, we do plan to consult both with industry and the labor unions on this matter and formulate an advisory committee once the legislation has been passed when we have authority to formulate advisory committees.

MR. GARVEY: Another question along this line of enforcing the legislation: have the provisions been made in the pending legislation which will allow the States to, one, carry out the respirable dust testing and, two, be responsible for enforcement of regulations based on the new standards?

MR. DOYLE: I think the legislation clearly puts this responsibility on the Bureau of the Mines rather than the States.

MR. GARVEY: We have heard about some of the work. What research or suggestions does the Bureau of Mines have to reduce dust created from caving behind the chocks on a longwall face, other than water infusion?

MR. DOYLE: I know of no research we have underway at this time in response to that particular problem.

MR. GARVEY: We have another health question. Again I want to point out that no one on this panel is a medical doctor. Henry was with the Public Health Service. What effect does cigarette smoking, if any, contribute to the susceptibility of respirable dust disease?

MR. DOYLE: That is a very difficult question. There was a symposium in Kentucky 2 or 3 weeks ago which considered this very question. I do not think that they were able to resolve it, so I seriously doubt that I can resolve it. Let us recognize the fact that cigarette smoking is an insult to the respiratory system. As a result of smoking, many of us are going to have certain respiratory problems. This might lead to emphysema, shortness of breath, and other kinds of symptoms which are very similar to those that one develops as a result of long term exposure to coal dust or any other kind of dust. Smoking also destroys certain mechanism the body has to remove dust from the respiratory system. Doubtlessly long term smoking increases the susceptibility of an individual to develop pneumoconiosis. Thus, we have additional insults to the body, both affecting the cardio-respiratory system.

MR. GARVEY: Thank you, Henry.

We have a number of questions on this method of sampling and other things which Murray Jacobson talked about. Since we are interested in sampling coal dust concentrations, how will corrections be made for rock dust which may be in the air and ultimately reach the coal dust sample?

MR. JACOBSON: At present the concentration is for coal mine dust which includes the coal, the rock, and the rock dust with no allowance for the correction for the rock dust which is in the sample.

MR. GARVEY: In other words, no correction for rock dust will be made.

MR. JACOBSON: I said at the present time, Jim.

MR. GARVEY: How was 2.0 liters per minute established or determined to be the optimum flow rate for respirable dust using the AEC system of dust separation?

MR. JACOBSON: Four years ago we started evaluating the elutriator for sampling of respirable dust. Last May, a paper by Mr. Tomb and Mr. Raymond was presented at the Denver meeting of the AIHA at which we covered the calibration of both the horizontal plate and the cyclone type elutriator. As a result of our investigations, we found that at a flow rate of 2.0 liters per minute, our penetration curves for the cyclone matched or matched as closely to the AEC-recommended respirable curve as we could get.

We did run tests at the other flow rates, 1.3, 1.7, 2.5, and 2.8 liters per minute.

MR. GARVEY: There seems to be some question again regarding why you get two different weights from the MRE and the AEC samplers, and why this should be, when you are actually measuring theoretically the same dust level.

MR. JACOBSON: As both instruments operate according to different collection efficiency curves, there is a theoretical difference of about 20 percent. When we calibrate them and run them in a laboratory, we come up with this ratio of difference of 20 percent. When we go into coal mines in which we have multi-component dust system which we do not know the density of, and we do not know the particle sizes, we find we get almost a 50 percent difference. However, the relationship between both methods has a linear correlation coefficient of better than 90 percent.

We do not feel too badly about the actual differences between them as long as we can relate one to the other. This relationship may change according to the composition of the material, the change in density, and also in the change of the particle size distribution, but on the average we have a very good correlation.

MR. GARVEY: We have a question on sampling which I believe has been answered in part by Mr. Doyle. It asks to elaborate on method of sampling to meet the new law requirements, that is, volume, weight, et cetera. A sample will be taken by the operator and submitted to the Bureau for weighing and analysis.

Is that it?

MR. DOYLE: That is essentially correct, Jim. The sampling program that the operator has to undertake will be supplemented by some kind of an inspection program by the Bureau of Mines. It might be twice a year or more frequent than that. The inspection program of the Bureau of Mines is envisioned as being much more complete than the taking of one sample at an operating section, as is proposed at this time for the operator's sampling program.

MR. GARVEY: Murray, another question is what percentage of respirable dust drops out between the face and last open crosscut, when the face is in 50 feet of minimum ventilation? It says here that his limited experience is that from 75 to 50 percent drops out in 50 feet.

MR. JACOBSON: Fifty or 70 percent might drop out, but I would envision less than 10 percent dropping out in the first 1,000 feet of respirable dust.

MR. BARRETT: I happen to have some tables here that give the exact figures. We have an air velocity of 86 feet per minute. At the end of 60 feet, 99.8 percent of the 5 micron dust is still airborne. At the end of 6,000 feet, 84 percent of the 5-micron dust is still airborne.

Let's go to 20-micron particles. At the end of 60 feet, 97 percent is airborne. At the end of 6,000 feet, 7 percent is airborne.

For 100-micron particles, at the end of 60 feet, 57 percent is still airborne, and at the end of 300 feet, 6 percent is still airborne.

MR. GARVEY: I think that should give you a good illustration of the dust that we are talking about, and how the respirable dust does stay in the air.

Murray, another question: What would be the average portal-to-portal dust concentration, averaged over all face men, corresponding to the proposed standard of 3 milligrams?

MR. JACOBSON: The average exposure of the dust-producing people, such as the operators of continuous miners, cutting machines, coal drills, and loading machines, runs fairly close on the average. This exposure lessens as the men, such as your shuttle car operators, supply men, foremen, mechanics, and utility men, get away from the dust producing areas. It depends upon the operation. If you actually average them, you would have to give me a specific operation, and I would have to look at it.

I cannot generalize and say what kind of concentration you will have. There are some places that would meet it, and there would be other almost identical places which would not meet the proposed standard.

MR. GARVEY: We have another question that relates to the rock dust question. Is it technically and economically possible to remove the respirable portion of the rock dust before entering the mine?

Tests that we and others have conducted were mentioned during the program, and rock dust does run from 20 percent up to as much as 45 percent in respirable dust.

QUESTION: Is there any sense in trying to take it out?

MR. JACOBSON: It could be. What do you want to pay for it?

MR. GARVEY: Mr. Hamilton would like to comment on this.

MR. HAMILTON: This is a worry to us in Great Britain, because there is no doubt that the miners are kicking up an enormous amount of this fine dust. I do not think that we have ever seen 45 percent of it being respirable, but it is a notable proportion, -- and this is a bit off the cuff; it may be different in this country -- but there is a crushing process to produce the rock dust. There are cyclones that are put over the crushers to stop a lot of these fines from becoming airborne, and then these particles are put back into the crushed product.

We would like to see a cyclone used to remove this respirable dust completely. This approach also has the advantage that if you take out the respirable dust, the rest of the stone dust might be more easily dispersed and be a safer quenching agent. We might, in fact, kill two birds with one stone.

MR. GARVEY: We have a slight change. As this session was originally scheduled, the Director of the Bureau of Mines was going to close this session. Unfortunately, as it often happens, when you are working for a Government agency, you get a call from the Hill, and you have to go. Such is the

case in this particular instance. We are going to have Director O'Leary speak to us now, and then following that we will resume these questions.

Mr. O'Leary.

First of all, let me congratulate you on these sessions that you have had. I think that the sustained attendance has been really remarkable; it shows a tremendous interest in your program. It is a tribute to the superb quality of the papers that have been presented here.

I want to single out Henry Doyle, particularly. About 3 months ago, I said, "Henry, let's have a symposium," and that was about the sum of my instructions. All of this has arisen from that one small injunction. He has done a marvelous job.

I think it is pertinent to note that this sort of a meeting represents a bridging of the dilemma in which the Bureau of Mines frequently finds itself because of the dual role that history has assigned to it. We are on the one hand -- and have been since the Bureau was created -- charged with a degree of responsibility for the protection of the people who work in the nation's mines. On the other hand, over the years we have been called on by the Congress to assume a share of responsibility for assuring an adequate and continuing supply of minerals and fuels.

In the particular legislative situation in which we now find ourselves, the Bureau's dilemma becomes apparent. If we were so determined to eliminate entirely the hazards to health and safety associated with mining that we could ignore our other responsibility, why then we could simply recommend that mining itself be eliminated. Similarly, if use of the nation's highways were forbidden, the highway death toll would drop to zero overnight. Of course, neither action is practicable.

The products of the nation's mines are necessary. Probably never before in our history have we been at a point so close to crisis from the standpoint of our mineral supplies. For example, I noticed, this morning that Canadian nickel is selling in 60-pound bags for \$4.90, as a result of a mineral supply shortage. Copper also is in a tight supply, has been for years, and so far as we can see, will continue to be in that same situation.

Only recently has sulphur, another major commodity, emerged from a period of very tight supply, and we find that on the fuel side, right now we are in the midst of a coal shortage, and an even more serious shortage on natural gas.

As a Federal Agency dedicated to the public interest, we must be concerned with these shortages. We must bend every effort to find ways to assist the private sector to produce these commodities efficiently -- in all the senses of the word "efficient." That is to say, efficient in dollar terms, and that first, because the dollars pay for the rest of it. But also efficient in social terms; that is to say, in environmental terms, because more and more the public is demanding as a price for your remaining in business.

that you be efficient and not destroy the landscape, or foul the water or the air. And, finally, but just as important, efficient in human terms . . . not wasteful of the lives and health of those whose skills give us access to essential minerals and fuels.

This, then, is our dilemma. The responsibilities of the Bureau are heavy in all three of these areas . . . the economic, the human, and, increasingly, the environmental. In each area the public pressures can be expected to keep growing. It is up to us, working effectively with you in industry, to find ways to respond to those pressures. Only in this way can we fully discharge all of our responsibilities.

I look upon this sort of a meeting as a response in the best tradition of this country and of your industry.

Thank you.

(Applause.)

MR. GARVEY: Thank you, Mr. O'Leary

We have a number of questions on water infusion, the use of water, and also a number of questions on the use of auxiliary ventilation. Some of the questions on ventilation are best directed to Mr. Kingery and his group.

Has the Bureau any recommendations or suggestions to help reduce coal dust, in the Western coal fields, due to mine "bouncing", a prevalent problem out West?

You might start out by explaining what "bouncing" is.

MR. KINGERY: This, of course, is an interesting question. I have never considered this problem one of dust control. Usually it is a problem of roof control. We have bouncers and bumps in Utah and bumps in West Virginia. They are caused by a complex relationship of overburden, mining practices, stress distribution, and other factors.

The only answer I have is the possibility of water infusion, and I believe that this was tried in Utah several years ago. The U.S. Steel Corporation has developed methods to trigger bumps under controlled conditions. However, this was not to reduce dust generation.

MR. GARVEY: The gentleman asks, was not the great danger of methane buildup and the explosion hazard that results from recirculation, a main cause for discouraging auxiliary fans for many years? Doesn't the addition of another piece of equipment increase this potential?

MR. KINGERY: This matter of recirculation came into being a number of years ago, when the Bureau of Mines determined that several disasters were caused by auxiliary fans operating in a manner considered unsafe. Some 20 years ago with the first of the continuous mining machines and related complex

problems of face ventilation, a number of us felt that auxiliary ventilation was a possible solution for improving ventilation for methane control. At the time we met with resistance principally because throughout the years it has always been thought that auxiliary fans are basically and inherently dangerous. This may be true under certain conditions; however, an auxiliary fan operating in a face area, immediately establishes a state of equilibrium. The amount of intaking air, the amount of return air, combined with the percent recirculation and the volume of methane liberated at the face establishes this state of equilibrium, and without a change of factors there cannot be a methane buildup.

The concept apparently developed that recirculation could continue until explosive methane occurred.

There is a basic formula pertaining to recirculation effects with auxiliary ventilation installations. As examples, a mine face, liberating 20 cfm and air volume delivered at 3,000 cfm without recirculation; the percent of methane in the face return is 0.67 percent.

With 10 percent recirculation; and if conditions have not changed from 3,000 cfm intake and methane liberation 20 cfm, the percent of methane in the return will increase to 0.74 percent. With 25 percent recirculation. Under these same conditions, the percent of methane in the return would then only be 0.89.

These figures show that recirculation is not the great hazard that people believe, recognizing that as professionals, we are going to install and maintain this equipment properly.

MR. GARVEY: What do you suggest should be done with the dust discharged into return from auxiliary fan? This is in violation of the Federal Law concerning explosive dust in back air courses. Could you comment on that, Mr. Kingery?

MR. KINGERY: This serious problem of fine float dust discharged into return airways was responsible for research conducted a number of years ago, and it brought about the recommendation that 65 percent incombustible was not sufficient to inert such dust. With auxiliary fans and tubing, we will not discharge any more float dust than under other ventilating systems. The amount of dust generated is usually in direct proportion to rate of mining, the condition of the mining machine, different coal beds, and other factors. With an auxiliary system -- and I am not recommending auxiliary systems per se -- I believe that we have a possibility to better control coal dust.

There is no ideal solution to safely reduce this dust problem. The most successful I suppose has been the trickle rock duster. We would like to see a dust collector put in series with the auxiliary fan. There is a wide range for research effort in this direction.

MR. GARVEY: What is the recommended amount of ventilation on a section, when a face ventilating fan is exhausting 10,000 cubic feet per minute?

MR. KINGERY: This goes back to history again, and unfortunately our mining industry has been saddled by some archaic concepts. Some of our State laws, recommend 2-1/2 times the volume of air delivered by the fan be available to the working face. In my opinion, this is not realistic in view of the tremendous air volumes required. With modern fan installation properly installed and handled by competent people, I do not think that more than 1-1/2 times rated fan capacity is required for adequate safety.

MR. GARVEY: Doesn't a Bureau study similar to Report 19 show that any given quantity of air, delivered to the face with the line brattice, sweep the face more efficiently, if delivered to the face in a blowing fashion rather than an exhausting fashion? Can it not be concluded that blowing face ventilation has a greater safety factor in controlling methane content?

MR. KINGERY: By the law of air physics, the answer is definitely "yes," provided we are dealing with methane alone. The kinetic energy of air being discharged from a blowing system will extend some 20 to 25 diameters in advance of the discharge. It will be at a relatively high velocity and will sweep across the face to reach the more difficult to ventilate corners. We have found from our work and other work that for methane control, it is the better system.

MR. GARVEY: You did mention dust collectors, and here is a question in light of that. What is the best type of dust collector available now for removal of dust from exhaust ventilation from working face?

MR. KINGERY: I don't know of any dust collector available at the present time that is capable of being integrated into the mining cycle and is of sufficient size and capacity to perform effectively. There may be certain types, such as cyclones or other units, such as the microdyne which could be altered and become practicable in a reasonably short time. I fully expect this to happen.

MR. GARVEY: One more question on this ventilation: What attitude is to be assumed for compliance with the increased primary ventilation in old low coal mines, plagued with continually occurring pressure falls, which place extreme restrictions on the system, when many years of research, including Bureau research, has not solved the problem?

MR. KINGERY: Unfortunately, no research will solve this problem, unless someone comes up with an instant air shaft. The mine resistance of such mines, especially older mines with extensive areas and long distance for air travel make it virtually impossible, without complete ventilation modifications to effectively reduce this high mine resistance. It will be possible to clean up return entries, increase air splits, and increase the number of air courses. This, however, is very expensive and effectiveness is usually small. This may become a tragic problem to many operating coal mines today. I do not see how

many mines will be able to deliver enough air at the working face to accomplish the job that is expected.

MR. GARVEY: We have a couple of more questions which refer to Technical Progress Report No. 19, but I believe Mr. Schlick might be in a better position to answer them. What type of continuous miner -- ripper, milling, borer -- what bit design -- flat shank, plumb bob, pencil -- and how much machine horsepower were used in tests for TPR-19?

MR. SCHLICK: Technical Progress Report 19 was concerned with an oscillating-type continuous miner, using 440 ac power. We have no information at this time on bit design under other parameters that you have discussed.

MR. GARVEY: This says, studies made apparently have been on continuous miner sections or development. How will the problems be solved on conventional sections?

MR. SCHLICK: Yes. First let me answer that question by saying that I think some of our colleagues in the audience have constructively criticized Report 19 for only presenting information on seven mines, but first let me say that in order to give you a report on seven mines, we have collected roughly 500 eight-hour respirable dust samples and at least 400 other dust samples. We want to continue this work. We have one more fan on order, making a total of two fans that we want to do this work with. We have not tackled conventional mining. Hopefully, by using split ventilation, bringing air in the center entry and down the two sides, wetting agents, foam, water sprays, and perhaps water stemming we will be able to reduce the amount of dust on a conventional section. The Bureau of Mines desires to initiate tests on conventional mining, to answer both of these questions on continuous mining and conventional mining, but in order for us to get at this problem, we need mines where we can send our teams into -- our dust survey teams as well as the technical teams -- in order to report and try out new methods.

So, for this reason from time to time we are asking other mines to loan their sections to us. That is about the best I can say for that one.

MR. GARVEY: In regard to deposition of coal dust in the exhaust tubing -- is it due to the moisture in the dust collected?

MR. SCHLICK: I do not think in the tests we have run we have had a problem in dust collecting inside the tubing. It has fallen out, when we move the tubing, but I would think if it cakes on there, you have to wait until it dries, and perhaps a little bump will send it on its way out.

MR. GARVEY: I have a couple of questions for Mr. Jacobson. Why can't we have a personal dust sampler that gives us the same readings as the MRE sampler?

MR. JACOBSON: One of the problems with the two types of samplers, we have two respirable curves. We can adjust the personal sampler to give us the same cut of curve as the MRE, and it will do that under certain conditions,

but it is not going to meet the AEC curve, which has been proposed in the United States. If you change your particle-size distribution, you change the relationship between the instruments, and that is as simple as you can make it.

MR. GARVEY: One final question on this: assuming dust can contain moisture, should the samples be dried before their final weighing?

MR. JACOBSON: In the areas we have covered -- 90 mines in which we have conducted from one-shift to 20-shift surveys -- we have found very little effect from the moisture. We have also done this in the laboratory. Because of the selection of the type of filter, and the fact we are drawing the air through the filter for the eight-hour period, the nominal change of weight would be well within the experimental error that we have in the instruments themselves.

MR. GARVEY: We have several questions here for Dr. Breuer. The first one says that the Bureau Report No. 19 recommends an air velocity of 70 to 100 fpm. Dr. Breuer states the optimum velocity as 2.5 meters per second, approximately 490 fpm. How can these figures be reconciled?

DR. BREUER: The two figures concern air velocities at different places and under different conditions. Mr. Doyle recommends an optimum air velocity between 70 and 100 feet per minute in room and pillar operations. We found this figure, too, as an optimum in our headings where air conditions are comparable to your room and pillar workings. The figure of 490 feet per minute mentioned in my paper is the optimum air velocity in longwall faces that are not comparable to headings or room and pillar workings. For this value of 490 fpm, we found an optimum effect for dilution.

MR. GARVEY: You are also asked to elaborate on the water infusion technique, length of borehole, pressure, and quantity of water from gateroads on a retreating longwall face.

DR. BREUER: I have given the data in my paper. The length of the borehole varies between 20 and 40 meters. The quantity of water is between 4 to 8 liters per minute, and the pressure applied is from 80 to 20 kilograms per square centimeter.

MR. GARVEY: How is the dust suppression efficiency affected by water particle size? Some literature indicates that there is a lower limit for waterdrop size beyond which there is no improvement in suppression efficiency. Do you agree?

DR. BREUER: The capture efficiency of water droplets depends above all upon the impact effect. For dust particles from 1 to 5 microns, the size of droplets must be about 50 to 100 times larger than the particle size. Droplets in the form of mists have no efficiency, because their relative speed is very, very low. The influence of the size of the water droplets on the capture efficiency of particles has been calculated by Professor Barth in West Germany. These calculations were published in the Journal "Strub" in 1959, if I remember correctly.

MR. GARVEY: Thank you.

One question for Tom Kobrick: What improvement in the state of the art would you like to see in the use of wetting agents?

MR. KOBRIK: Studies should be made which would include environmental studies to determine what effect wetting agents have, both on the respirable-size dust and the float dust. These studies should eliminate all other variables other than the effects of the wetting agents.

MR. GARVEY: Dr. Hamilton would like to comment on this.

DR. HAMILTON: We did a lot of work some years ago on wetting agents. We used these in high concentrations with a variety of coals, both on coal transport systems and in direct cutting from the face, and without exception, our results were most disappointing. We have come to the conclusion that it is much more profitable to look at methods of applying water properly than to bother with wetting agents at all.

Much the same goes for foam. We tried this exhaustively in a coal mine, and it was really most ineffective.

MR. GARVEY: Lee, do you want to comment on that, too?

MR. BARRETT: Yes. In our study, this was one of the first things we attacked with considerable vigor. As you saw yesterday in some of those slides, if you put some wetting agent in water, and put it on a piece of coal, it does spread more readily. If, however, you put the wetting agent in the water stream and caused it to be sprayed, it takes time for the wetting agent to come to the surface of the water where it apparently must go to have its effect. We noticed in low pressure and low velocity systems, wetting agents did have some effect, but as the pressure went up, and we got up to 800 pounds per square inch, there was no ascertainable effect of any kind, and it does seem to be related to this time factor. The wetting agent is not uniformly distributed apparently within the drop. It must have time to move to the surface, and if we use high velocity, it does not get there in time to do any work.

MR. GARVEY: Kenneth Morse and Henry Doyle mentioned volume relationships between diffuser air volume and exhaust auxiliary fan volume, a 4 to 1 ratio was mentioned. They further discussed the basis of the statements and the effect of the exhaust tubing entrance and the diffuser fan entrance.

MR. MORSE: The figure I utilized was about 25 percent. I don't remember what Henry utilized. Mine was based on the original Bureau of Mines studies and our applications. The U.S. Bureau of Mines published data indicated a diffuser fan with a capacity of about 1,000 or 1,500 cfm, with the exhaust tubing handling about 5,000. This would make about 20 to 30 percent, based on whether you take 1,000 or 1,500.

MR. KINGERY: Could I add something to this?

MR. GARVEY: Yes.

MR. KINGERY: I am volunteering to stick my neck out. This is a small blower working in combination with an exhaust system. The mechanical advantage of this blower is simply this: By its injection principle, it will entrain the air as it passes, and the amount of entrainment will be in direct proportion to the distance from the face. In this way you can provide an air sweep at that corner that we cannot reach today with most of our auxiliary systems operating exhaust.

The point that Ken made about the problem of high velocity is true; but because of the momentum theory, and the fact that this is operating on top of the machine, and there is not a great deal of open space, kinetic energy is rapidly dissipated.

MR. GARVEY: Thank you.

We have a couple of questions on the machine design discussion. I want to hear from Mr. Hamilton.

American experience indicates a plus-15 rake angle dulls much more rapidly than a plus-5 degree. If dust make is increased by dull tools, it would appear that smaller rake angles would be preferable. Any comment?

MR. HAMILTON: This question is always difficult. When we first did this work, we decided that we wanted a pretty steep rake angle of about 30°. Unfortunately, this causes fracturing of the tungsten carbide tools -- so that we set on a 15° as a reasonable compromise between the strength of the bit and wear. I do not think this is necessarily very important. It is more important to have a genuine clearance angle on top of the bits. If you have a negative clearance angle or one with no clearance, you can have a considerable amount of rubbing and grinding of fine coal.

MR. GARVEY: We have one for Mr. Arentzen. Would you care to comment on the machine made for Texas Gulf Sulfur with water sprays incorporated in the disk from the standpoint of dust suppression?

MR. ARENTZEN: I think this question refers to that 3 years ago we had a machine at Texas Gulf Sulphur, and with this machine we attempted to use some extremely large tools. These tools were about 2 1/2 pounds apiece. They had shanks on them on the order of one inch wide and 2 1/2 inches in the horizontal. They had carbide which was 3/4-inch diameter, 1 1/2 inches long in the tip, and from the cutter wheel to the top of the tool was about 9 inches. The sprays were similar to the ones that you saw in the photograph that Tom Kobrick had where the sprays were placed between the tools so that they would try to flush each of these large tools. Unfortunately, these experiments were not concluded. They have never been tried in coal. It has

always been our intention to continue this experiment, because in our opinion the use of large tools that last a long time on the machine is one of the things that will produce the coarser cuttings I talked about before.

MR. GARVEY: Thank you.

One gentleman wants to know, do you consider noise reduction in the design and manufacture of mining machines? In what way?

MR. ARENTZEN: I think any manufacturer's design engineer would like to eliminate that noise, because it is an example of inefficiency.

MR. GARVEY: You do not have any specific examples, though. The audience is aware that the new legislation sets up machinery for establishing limits, noise levels, in coal mining -- I think this is a pertinent question. It is a problem we are going to have to face.

MR. ARENTZEN: I did not want to bring that question up at this symposium, because we are aware that noise is going to be one of the factors that we are going to be involved with. Everybody is studying, I am sure. We have some specific problems in fans, electric motors, eliminating the sound of the fans. We would like to get closed hydraulic systems so that we get positive suction and don't get all of the rattle from the screeches. These are the things that we are really concerned with.

There will be problems in driving dust collecting devices, using blowers that are very, very noisy. The silence we try to apply to them are not effective yet. We have no solution to any of those problems, but every manufacturer of a blower is trying to discover how to silence them.

MR. GARVEY: This question is directed to Mr. Barrett: What is the purpose in designing and building equipment, going to the trouble of evaluating it, when it is obvious at the start that its size, or method of operation, is totally unsuitable for mine use?

I presume the gentleman is referring to the work you have done on collectors. The question has often been asked of me as it has of any research man, and all I can say in answer to it is that my hindsight improves greatly with my age.

MR. BARRETT: It sounds like the main problem is stupidity on the researcher's part, but I hardly believe this to be the case. Babies always crawl before they walk and so researchers. So you start doing what you can do and then try to proceed to what at first you could not do. I think this explains the fact that you have to work your way into a real answer to your problem. We do have a difficult-sized problem, and it is being improved. I think it will continue to be improved step-by-step.

MR. GARVEY: We have a number of questions on respirators. The first is, I want a high efficiency dust respirator of the disposable type approved under schedule 21B. When can I get one?

MR. SCHUTZ: We are currently establishing performance requirements for the dust respirators and, hopefully, these standards will be available by mid-1970, and an approved model will be available by the end of 1970.

MR. GARVEY: Maybe this next question ties into it. Is the 3-M dust mask adequate for respiratory protection of coal miners to prevent pneumoconiosis? If not, what is wrong with this popular mask?

MR. SCHUTZ: The Bureau does not test respirators unless they are submitted for us for approval. It is a disposable 3-M mask that was never sent to us for approval. Judging from the manufacturer's test data, the filter media is not suitable for removing respirable coal dust. We have some more information from other laboratories on face fit, and if you will take my second-hand word for it, we do not believe that the face fit is suitable for use in coal mines.

MR. GARVEY: I believe you answered this question this morning. At least it was raised this morning. What is the protection factor for dust respirators on a shift-long basis in a coal mine?

MR. BURGESS: I am not aware of any sampling in coal mines demonstrating the protection factors of dust respirators. Many of us have been looking at facial leakage of this type of respirator under varied industrial conditions. My own experience in the field has been that one can expect leakages in the range of 5 to 10 percent for half-mask dust respirators. I believe that Los Alamos has found that if a complete respirator program, including individual fitting, is provided that facial leakage can be reduced below 5 percent.

The above figures refer to leakages encountered during the actual wearing of the mask. If one considers the complete shift, including those periods when the mask is not worn or is raised from the face, the effective protection factor may be as low as 5 to 10, corresponding to effective leakages of 10 to 20 percent.

MR. GARVEY: We have had a number of questions on the mandatory wearing of face masks. One question asked, why does the Bureau downgrade the use of respirators for protection of the coal miners; and another is, should they be required to wear? I believe Henry Doyle can comment on the Bureau's position on this particular subject.

MR. DOYLE: I don't know that the Bureau has downgraded the use of respirators. I think every biologist and industrial hygienist would agree that the use of respirators is not a primary method of prevention, and in any good manual on respirators, you will find very clear concise statements that respirators are not intended to be a primary method of control, but their use is recommended for emergency situations or for short-term exposure where it is not economical to provide necessary environmental protection. This is certainly in conformance with the Bureau's attitudes on the use of respirators.

Experience has indicated that it is very difficult to get a worker to wear a respirator for any length of time. He may wear it 5, 10, 15, or 20 minutes, but to get him to wear it for a full eight-hour shift is a very different problem.

I was very interested in what Mr. Flanagan said in terms of the success of his company, but you must remember that Mr. Flanagan also made the statement that it was a policy of his company to reduce dust concentrations by the use of engineering methods and to use respirators as a supplement to this.

I think also any biologist would agree that the best standard for any kind of dust or contaminant is zero exposure. This is impossible in most industrial situations. I see no reason why, if you have the dust controlled to what is presumed to be a safe level and if then you want to superimpose the use of respirators, this would be quite acceptable to most everybody.

I would like Ken Morse to comment on this, since he has had industrial experience and a similar technical background to mine, to see if he agrees with this concept.

MR. MORSE: I concur essentially with Henry. For years respiratory protection was a recognized means of control for those types of exposures that Henry indicated; emergency, temporary, and short-term exposures. I think that in some cases, both inside and outside of coal, we have had some pretty good success in the use of respirators where we have gone into a carefully planned educational program. If you simply hand out respirators and expect a man to wear them without any guidance on telling him why, we have not had good success.

Also, to assure that the respirators are going to be worn with some degree of success, the respirators must be made a personal respirator of that particular miner, with his clock number or other means of identification, so that when you clean it and sterilize it, he is going to get it back.

It is a rather peculiar thing, but it is very difficult, after a respirator has been worn by somebody else, although cleaned and sterilized, to have it accepted by another worker. You have to assure him that he is getting back the same respirator that he turned in for cleaning or sterilizing. There are places that respirators can be utilized and utilized very effectively, and I am sure that you heard today of some of the life supporting devices, the sort of air supply to a respirator which has worked very effectively. These can be of the filter type or of the cryogenic type.

I think we cannot pass off the effective role that respiratory protection has in the protection against air contaminants, whether they be gaseous or otherwise.

MR. DOYLE: One other thing. Until such time as we are able to get the dust concentrations down, I certainly think it is wise to encourage the use of respirators until our environmental control systems can go into effect.

Even if the worker wears it only half of the time, he is getting a certain amount of personal protection.

MR. WALTON: The position in the United Kingdom is very similar to that described by Mr. Doyle and Mr. Morse. The policy is that the air should be fit to breathe without the necessity to wear a respirator for protection. There can be no disagreement with that in principle; but it remains a fact that a respirator, if worn, can reduce a man's dust exposure by around 90 per cent, and it is difficult if not impossible to achieve an equal degree of dust control in any other way.

I think there is a real dilemma as to what to do about this; but the course adopted by the National Coal Board is surely sound as far as it goes: respirators are made available to any miner who wishes to have one. Only types that have been tested and approved for efficiency and wearability are purchased, and there are continuing attempts to improve these qualities. For example, underground wearer trials showed that the clogging of the filters by dust within a single shift was a more serious problem than previously thought, particularly in very humid conditions, and an appropriate test specification was devised. The Board's laboratory test requirements for dust respirators are covered by the revised British Standard BS 2091: 1969.

MR. DOYLE: I don't like to belabor this subject, but I think I should point out that neither the Senate nor the House bill accept respirators as a primary method of control.

MR. GARVEY: Thank you.

I have three questions left which I have saved for the end. The first one is a question which has been raised by many and has been brought to my attention several times. It also has had publicity in the newspapers, and the papers generally have gotten the information wrong. The question is, what is the dust count in an industrial urban atmosphere such as Los Angeles, Pittsburgh, or New York City? How does a dusty city compare with a mine atmosphere of, say, 3.0 milligrams of dust per cubic meter in air?

I happen to be involved in air pollution control work, too, and in such work dust levels are measured in micrograms, not milligrams. A milligram is equal to 1,000 micrograms. Therefore, 3.0 mg/m<sup>3</sup>, as proposed for the coal-mine dust standard, is equal to 3,000 micrograms. A very dirty city could have a dust level of 1,000 micrograms, one-third of what a coal mine under the proposed standard would be. A clean city would have an airborne dust level of about 100 micrograms, although some public health officials have proposed that the air quality standard for cities should be 60 micrograms. The levels for cities refer to 24-hour averages.

But comparison of city air and mine air must take into consideration some important differences. For example, the miner is only exposed to his dust level 5 days a week, at most 6, for 8 hours a day. So you need a factor to bring these and other differences out. If you develop a factor on 5 days a

week, 8 hours a day, and include vacations, holidays, etc., you find that the mine air at 3 milligrams is three or four times as dusty as an average industrial city. But it is not thirty or forty times, as some of our friends from West Virginia have been saying in the press. It is not as bad as they say it is, but it is still not good when you compare the two. One other point must be kept in mind when comparing the two. City air also contains a number of other pollutants such as sulfur oxides, nitrogen oxides, carbon monoxide, etc. The presence of these other pollutants requires that the air quality standard for airborne dust in a city should be much lower than that of a coal mine.

MR. CORN: You are a little high on the urban estimate. Pittsburgh averages about 180 micrograms. The dirtiest area will reach a few times a year, 500, on a 24-hour average.

MR. GARVEY: You are quite correct. I don't want anybody to misunderstand what I said. I think what I said was you can get 1,000 in a city. -- I believe New York and London, if I recall (laughter) have recorded levels this high. I think there are some industrial areas in the United States which get above 500.

MR. WALTON: You are measuring the fog, too (laughter).

MR. GARVEY: The next question is, what do you think applying the state of the art to control respirable dust will do to the cost of coal and its competitive position with other energy sources, particularly oil, and the position of small mine operations and equipment outlay? We all got together and decided Bill Kegel is going to answer this one.

MR. KEGEL: Don Kingery touched on this, when he talked about small mine compliance. There are many variables involved, which therefore makes this a rather loaded question.

Assume someone is presently operating a mine profitably and with what is now regarded as safe procedures. He is producing a certain tonnage with specific machines and ventilating equipment. I will limit the example to dust provisions only.

The operator could be forced into redesigning his primary ventilation system. He quite possibly could require a new shaft or slope or at least be required to laboriously drive additional airways to better his shaft bottom ventilation to meet with requirements indicated at this meeting.

If we then assume that auxiliary fans are the answer, he would have to purchase one or two for each unit. He would have to take on a supply of tubing which are both expensive and easily destroyed.

He quite possibly would now have to add more people to his payroll to handle this equipment and particularly to conduct the sampling program. Along with this will be the sampling equipment cost. If the mining equipment he is using doesn't easily lend itself to the ventilation method decided upon, he

could be forced into more spending in this area. At the very least, he has a major increase in cost.

When you consider, however, our present situation which has only recently had us meeting pollution and subsidence rulings and when you look at the contractual obligations under the new contract and how all these other facts interrelate, there can be no doubt that competitive fuels have been given a tremendous boost.

MR. GARVEY: Thank you very much.

The last card I have here asks a question which I think the whole conference has been all about, and that is directed to Mr. Walton. In his view, what are the most important fields for research in dust technology? Do you want to add to what has been said over the last few days?

MR. WALTON: That is a big question, even when confined to the area covered by this symposium.

Let me say right away that the most important field is dust control; research into dust sampling and medical aspects of pneumoconiosis, although necessary, will not eliminate the disease. One of the main outstanding problems is to find how the hazard varies with the mineral composition of the dust, from almost 100 per cent coal to 100 per cent incombustible mineral, and particularly with the silica content so that the standards can be 'weighted' appropriately. On the medical side, I suggest that much pneumoconiosis might be avoided if predisposing factors were understood, and if means could be found to identify susceptible individuals before exposure to dust and before recruitment to the industry; improved means of early diagnosis of pneumoconiosis, to indicate those who are more susceptible, would also be of help.

MR. GARVEY: Does anybody else on the panel care to comment on this particular subject?

We are now going to throw the whole meeting open to questions from the audience, and we have one from the panel.

MR. KEGEL: I would like to ask Mr. Hamilton about the amount of rock dust used per ton of coal mined, used in England.

MR. HAMILTON: I cannot give that figure. The requirement is, of course, like yours, that we must dilute any coal dust in the airways three to one with rock dust. I cannot tell you the exact amount in tons of rock dust per ton of coal mined that we use.

MR. GARVEY: I am sorry. I didn't mean to cut you short.

Do you have some other areas of research to talk about?

MR. WALTON: Research on the control side is the important one, and, obviously, the job here is to keep the dust away from the man or the man away from the dust.

In the field of dust control, much research has been done, as we have heard at this symposium, into the principles which should be followed in cutting rock or coal by mechanical tools, and in applying water, in order to minimize dust production. This has not yet been fully exploited in machine designs, and, indeed, there are difficulties to overcome; more work is needed here. I doubt whether dust can be completely controlled by such means, and, in my view, further research might profitably be directed towards the problem of separating the environments of the men and the machines. In surface industry dusty processes are commonly enclosed, or carried out in booths or under ventilation hoods from which the contaminated air is exhausted; or the workman is enclosed in a cabin or suit or helmet supplied with clean air.

These approaches are more difficult in the restricted space and arduous conditions of a mine where usually both men and machines are in the same air stream. One might envisage 'clean' intake and 'dusty' return airways, any dust-producing operations in the intake being provided with exhaust ventilation which is either filtered or discharged into the return, while any workers who are unavoidably situated in the return wear respirators or are otherwise supplied with clean air. Research is required into exhaust systems which are perhaps integral with the machine and permit the dust to be entrained in a minimum volume of air; into filtration systems of small size, high capacity, and high efficiency; and into air supply systems which will add to rather than detract from the comfort of the mineworker. The requirements of dust control should be considered when mine layouts and systems of working are planned.

MR. MORSE: I think there is a need for some real extensive work as far as ventilation is concerned. I think the study of air flow patterns is of interest. This means, of course, you cannot be cutting coal at the time, but it should be done when moving the cutters and the bits and simulating water sprays by air jets. We did a limited amount of this work a number of years ago. I think this kind of work has got to be done under as close to actual mining conditions as we can get, and also to study the various types of ventilation systems in more detail than has been done up to the present time.

MR. GARVEY: Does anyone else care to comment on this subject on the panel?

MR. HAMILTON: We have to get together and design integral dust extraction and filtration equipment for the mining machines. The next thing, there is not really enough understood about the loading of broken material by cutter drums which could result in a lower dust make.

I am not entirely happy that a lot of effort should go into problems of dust sampling. The most important thing is to stop dust, but I think we need a lightweight self-contained monitoring instrument working over fairly short periods of time for the dust control engineer to use.

There is a need for better dust collectors, and we want ones which are flexible: ideally a type which could be used at a flow rate ranging from 4,000 cubic feet a minute to 12,000 cubic feet a minute. We cannot use a lot of water, and it will be necessary to incorporate effective and compact water recirculation systems for dust collectors.

MR. GARVEY: Thank you.

Yesterday there was a question raised, which I do not feel was completely answered. I would like to call now on Ed Onuscheck from the Rochester and Pittsburgh Coal Company, which has done a great deal of sampling using the personal samplers.

The question is, do you have problems in getting the men to wear these samplers, and what are the problems associated with a coal mining company operating a sampling system? Perhaps Mr. Onuscheck can briefly tell us what his company is doing.

MR. ONUSCHECK: As Jim has stated, we have done extensive studies on sampling. When we first started our program on sampling, we called in union representatives, the safety and mine committees. We went over the program and discussed it with them in its entirety. When we first started the program, we had about 1 to 2 percent rejection of men refusing to wear the sampling devices.

After the program progressed for 4 or 5 months, the progression rate of rejection, if you want to call it that, kept increasing. It is now to the point where we have a refusal rate from anywhere from 10 percent to 15 percent. My question to either Mr. Doyle or Mr. Jacobson is this: what do we do when this happens? What is the Bureau going to do? What do we all do? I don't know.

MR. DOYLE: Ed, I don't think I am in any better position to answer that question right now.

MR. ONUSCHECK: This is what faces us, Henry.

MR. DOYLE: I do not think this is an experience of ours. Mr. Jacobson can comment on this. In the 29 mines studied and in subsequent studies, we have had almost 100 percent cooperation among the men.

MR. ONUSCHECK: Just within our little family, I would say with our ratio on sampling that we have more samples than anyone. This is prorating it, and we are running into some difficulty with refusals. I would suspicion that some individuals were very forceful in their refusal -- I don't see how you could even do it, Henry.

MR. DOYLE: Let me add one thing; in the enforcement of the regulations, we are certainly hopeful it will not be necessary to require the workers to wear the personal sampler for a high percentage of the time. We hope that we can work this out so that we can give you a reference point which would not

an individual but a location in the mine. I am unable to tell you at this particular time that this is going to be possible, but certainly this is what are working for.

Both Congressional bills require the Bureau to conduct frequent dust inspections, a minimum of two per year. On these occasions, of course, we will expect to sample all of the men in the sections being studied, so here we would require a high degree of participation on the part of the men.

I think that this is a problem in which we need to involve the labor union. Certainly, they are interested in seeing these regulations enforced, and to do so we are going to have to depend on a high degree of cooperation from the men in the mines to do this adequately.

MR. ONUSCHECK: All of our union representatives, district, and the mine and safety committees, were behind this program 100 percent. We had no quarrel with all with them. They were very cooperative, and they wanted to see the program completed. Still you get some individuals that just won't cooperate. For the benefit of the audience here, in our program on sampling, these were complete eight-hour shift samples. We put the samplers on the men in the lamp-house, and we did not take them off until they came out. This included mantrip time, everything for the full 8 hours.

MR. DOYLE: I think the Bureau has a great responsibility in carrying out an educational program, which we have to extend to the men in the mines to demonstrate to them their responsibilities in meeting these standards, and also their responsibilities in providing the kind of assistance that is needed in making the necessary determinations. Although we have thought in terms of such a program, this has not been definitely planned at this time, but I can assure you that we will do whatever educational work is necessary in this respect.

MR. GARVEY: Thank you, Ed.

Gentlemen, the questions that were submitted to us have been exhausted, and we are now open for any additional questions from the floor.

QUESTION: I would like to know if there will be a copy of the transcript of this particular symposium made available.

MR. GARVEY: Yes, there will be. It will be part of the transactions.

MR. ONUSCHECK: I have a question that has been plaguing me for quite some time, particularly in an all-belt mine where you are limited to the use of water on reducing dust on your belt systems due to quality of your product.

There have been statements made here on controlling respirable dust. Everybody comes up with pretty good answers, but they also have stated that in order to have good effective face control, we must have uncontaminated air. In an all-belt mine, in order to have uncontaminated air, you are going to have to reduce your velocity on the belts, which we are doing to a certain

degree in our all-belt mines, but you have got to reduce these velocities to the extent where you need additional stoppings, overcasts, air bridges, and air locks, and what have you.

Is there a possibility of creating an explosion hazard, due to confining all of this float dust and coal regardless of how well your belt entries are rock dusted? Also in a high production mine where your belts are completely full of coal, and you have your loading points up near the face area, you have the possibility of an explosion jumping on the belt, going down this corridor that we are going to have to create. Has there been any research done on confining these belt entries with limited velocities and creating a situation that we might not be able to control, if we ever get a blow at the face, and it jumps on this belt line?

MR. GARVEY: Does anybody on the panel wish to comment on that from the Bureau people? Don, do you have any ideas?

MR. KINGERY: I don't think I can help you. There has been little research. We have recommended, of course, that belt entries be in a sense neutral or the air velocity passing over them be reduced to prevent pickup of airborne dust.

This specter of a coal dust explosion on a belt entry is something that has disturbed many of us for a long, long time. I think we have been very fortunate that we have not been exposed to such a disaster. Regardless of what we do in our working faces, regardless of how well we rock dust our back entries, we know from experience in Germany, and other places that if an explosion gets started down a belt entry, even though rock dust has been placed on the floor a foot high, the shock wave will pick up fuel, and we will have a serious explosion probably reaching outside.

We recognize that this is a serious hazard and are concerned. We have not developed a rock dust barrier like that used in Europe, since we recognize with our mining system that this is not the most practical solution. Our only effort so far is to develop individual cans of inert material to be niched into the rib along the belt entry. These inerting devices can then be activated by flame sensing and pressure devices to scatter inerting material in sufficient volume to quench the explosion flame.

MR. ONUSCHECK: Do you think there will be any research on this in the near future?

MR. KINGERY: Yes. There would be accelerated research in this direction, if I understand the picture developing in the Bureau today.

MR. ONUSCHECK: Thank you.

MR. GARVEY: Does anyone care to comment either from the panel or the audience on this problem?

MR. HALEY: I would like some clarification on this supplementary statement made a little while ago. This meeting is sort of like the story of Alice in Wonderland meeting the Mad Hatter, as to what the objective is.

The objective is, as I understand it, to eliminate black lung. If I were a coal miner, I would wear a respirator. My father was a coal miner from 1920. He was a cutter from 1934. He wore his respirator voluntarily all of the time. He died of cancer, but not of black lung, and he had no problems in the lung area.

I am rather new to the coal business, and when I first came into this, I felt we had a management deficiency in respirator wearing. Putting safety glasses or hard-toe shoes on a person is not easy either. Now, the respirators were put on our men to keep them from having black lung. We really have to do all of these things that the new legislation says, but I don't believe that these will eliminate black lung. I think your Department of Health, Education, and Welfare will tell you that 3.0 will not eliminate that black lung, particularly if it is an average. So, don't look on respirators as supplementary to the problem, that is, eliminating the black lung and doing everything else to cut the dust in the air. Respirators should be worn in dust-producing stations. I would like to make that point clear.

MR. CORN: My name is Morton Corn. I am a member of the Faculty of the University of Pittsburgh.

I think that the new legislation will combine medical data, through the responsibilities of the operators, with monitoring data relative to the environment, and if extra effort is made it will give us the opportunity, to associate dust exposures with the health of the individual miner to obtain a valid dosage-response relationship. I agree that there is little assurance that the exposure guidelines we are aiming for will eliminate risk to lung disease, but there is now an opportunity to gather that data. My question is directed to Dr. Breuer. Will he elaborate on efforts made in his country to relate measured dust exposures on a day-to-day and year-to-year basis to incidence of this disease?

DR. BREUER (through Interpreter): First, of course, is to try to prevent the dust concentration in the area where the miner actually works from day-to-day. Secondly, we pay great attention to removing a man who has the first indications of damage to his lungs. We remove him to an area where he is exposed to a less dense dust concentration, and there is a Government provision, legal provision, according to which a miner who already shows signs of pneumoconiosis, or some kind of damage, that he has to be put in a working place where there is less dust concentration in order to prevent development of silicosis.

MR. GARVEY: Thank you.

MR. MORSE: I'd like to take this opportunity to say that such a study is proposed with the Public Health Service doing periodic chest X-rays which will be correlated with the environmental data that the Bureau will collect, and

there is provision for moving miners who show early evidence of pneumoconiosis into less dusty areas.

MR. GARVEY: That is correct. We will collect this type of data.

Are there any further questions?

MR. CHELERA: One of the minor problems, but immediate ones, based upon a small amount of work that we have done and some conversations with other people is the unreliability of the cyclone personal sampler. I would like to see if someone, perhaps Mr. Doyle, could comment on this experience. If some people undertake a program of sampling with this device, I would think the result could be pretty chaotic.

MR. DOYLE: What do you mean by unreliability?

MR. CHELERA: Just that. I don't mean accuracy, and I don't mean the precision. If you go down with six of these things, maybe four of them will work and two of them will be working sort of in a half-baked way.

MR. JACOBSON: There is some question of what you mean by unreliability. We have about 160 or 170 personal sampling pumps, and when we started off, had a good bit of difficulty working with them until we learned how to handle them and keep them clean.

There is still a certain degree of failure rate where you are taking a small instrument into a coal mine, and you are banging it around, not the way it was designed, but the way it is being used. They must be checked, and they must be kept clean. If they are kept clean, and they are charged correctly and used correctly, the "unreliability" is more of a factor of the variation in conditions of the environment that you are working in, not of the instrument.

We have sampled more than 300,000 manshifts in the past, and the failure rate is down to 5 percent. I don't know what you mean by the "unreliability factor."

MR. GARVEY: There was one more question in the back there.

MR. MENSEY: My name is Bill Mensey, National Mine Service Company.

I would like to ask Ed Oruscheck why the men refused to wear the respirators?

MR. ONUSCHECK: Bill, I can't answer that.

MR. GARVEY: There does not seem to be any more questions.

I hope you have benefited from this afternoon's general session.

I want to express my appreciation to the panel for sitting in and the audience for staying with us. We are surprised so many of you came back.

I will now turn the meeting over to Henry Doyle for adjournment.

Thank you.

MR. DOYLE: I would like to express my appreciation to the National Coal Association, to the American Mining Congress, and to the National Independent Coal Operator's Association for their cosponsorship of this Symposium. I would also like to extend my thanks to the speakers and the members of the panel and the audience.

Three months ago the Director told me "to put on this conference." You know I have a sizable family. In my family I have frequently given an order my oldest child, only to see it being carried out by the youngest some time later. I would like to pay tribute to my own staff for the great effort and any long hours they have devoted to the arrangements of the symposium.

I wish that I could point them out individually. However, I would be amiss in not identifying a young lady whom you have seen moving very unobtrusively about this audience. She had been of very great help to me and to you, too, in getting these details arranged. I would like Mrs. Lynn Harris to stand up, please.

I would also like to pay tribute to Pat McMurrer, who so wonderfully handled all of the details, the social arrangements, the registration, and all of the minor details that are involved in an endeavor of this kind. Thank you.

The proceedings of the symposium will be out hopefully within 4 to 6 weeks. Everyone registered at the symposium will receive a copy of the proceedings.

As the Director has told you, we hope that this will be a textbook, and I hope that in about 2 years from now, this textbook will be so out of date that another symposium of this kind will be necessary.

Thank you very much for attending.

## APPENDIX

## LIST OF ATTENDEES

Mr. H. William Ahrenholz  
University of Alabama  
University, Alabama

Mr. Robert G. Aldrich  
Syracuse University Research Corp.  
Syracuse, New York

Mr. Ralph E. Allan  
Kaiser Steel Corp.  
Fontana, California

Mr. Andy Allen  
Peabody Coal Company  
St. Louis, Missouri

Mr. G. L. Alston  
Mine Safety Appliance Company  
Pittsburgh, Pennsylvania

Mr. Michael Amoroso  
Lee-Norse Company  
Charleroi, Pennsylvania

Dr. David M. Anderson  
Bethlehem Steel Corporation  
Bethlehem, Pennsylvania

Mr. Floyd G. Anderson  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Bob Andrews  
Alabama Power Company  
Birmingham, Alabama

Mr. Rolf F. Arentzen  
Lee-Norse Company  
Charleroi, Pennsylvania

Mr. Howard Ayer  
U.S. Public Health Service  
Cincinnati, Ohio

Mr. John M. Badovinac  
Christopher Coal Company  
Osage, West Virginia

Mr. E. J. Baier  
Pennsylvania Dept. of Health  
Harrisburg, Pennsylvania

Mr. Rufus J. Bailey  
Harlan County Coal Operators'  
Association  
Harlan, Kentucky

Mr. W. O. Barnard  
National Mine Service Company  
Pittsburgh, Pennsylvania

Mr. Virgil L. Barr  
U.S. Bureau of Mines  
Washington, D.C.

Mr. A. Lee Barrett  
Joy Manufacturing Company  
Michigan City, Indiana

Mr. S. R. Barrett  
Peabody Coal Company  
Evansville, Indiana

Mr. Robert C. Benashski  
The Travelers Insurance Co.  
Hartford, Connecticut

Mr. Otes Bennett, Jr.  
The North American Coal Corp.  
Cleveland, Ohio

Mr. Arnold L. Biscontinini  
Glen Han Coal Company  
Wilkes-Barre, Pennsylvania

Mr. Leslie G. Black  
Pittsburgh Coal Company  
Library, Pennsylvania

Mr. Clarence B. Blair  
Black Diamond Coal Mining Co.  
Birmingham, Alabama

Mr. J. M. Blair  
Jones & Laughlin Steel Corp.  
California, Pennsylvania

Mr. D. R. Bomberger  
Consolidation Coal Company  
Library, Pennsylvania

Mr. Donald M. Bondurant  
West Virginia University  
Morgantown, West Virginia

Mr. R. B. Booth  
American Cyanamid Company  
Stanford, Connecticut

Mr. J. A. Bottomley  
Sahara Coal Company, Inc.  
Harrisburg, Illinois

Mr. Arnold Bower  
General Electric Company  
Detroit, Michigan

Mr. C. E. Brackett  
Southern Electric Generating Co.  
Birmingham, Alabama

Mr. John W. Brantner  
Jeffrey Mining Machinery Co.  
Columbus, Ohio

Mr. George C. Breidenbach  
T. J. Gundlach Machine Company  
Belleville, Illinois

Dr. Ing. Hans Breuer  
Chief of Central Office for Dust  
Control and Silicosis  
Steinkohlengerbauverein  
Essen Federal Republic of Germany

Mr. J. Allan Brookes  
Pickands Mather & Co.  
Carmichaels, Pennsylvania

Mr. H. B. Brown, Jr.  
Keystone Bituminous Coal Assn.  
Harrisburg, Pennsylvania

Mr. P. M. Budzak  
Freeman Coal Mining Corporation  
West Frankfort, Illinois

Mr. Howard E. Bumsted  
United States Steel Corporation  
Pittsburgh, Pennsylvania

Mr. James V. Burgess, Jr.  
Mine Ventilation Systems, Inc.  
Madison, West Virginia

Mr. William A. Burgess  
Harvard School of Public Health  
Boston, Massachusetts

Dr. William M. Busey  
Hazleton Laboratories  
Falls Church, Virginia

Mr. R. I. Bush  
Eastern Associated Coal Corp.  
Pittsburgh, Pennsylvania

Mr. Harry M. Callaway  
U.S. Dept. of Commerce  
Washington, D.C.

Dr. Seymour Calvert  
Garrett Research and Development  
Co., Inc.  
LaVerne, California

Mr. Michael Cimba, Jr.  
Associated Drilling, Inc.  
Johnstown, Pennsylvania

Mr. C. Thomas Clagett, Jr.  
Zeigler Coal and Coke Company  
Washington, D.C.

Mr. James A. Clem  
Peabody Coal Company  
St. Louis, Missouri

Mr. John Cline  
Wolf Creek Collieries, Inc.  
Lovely, Kentucky

Mr. U. A. Cobb  
The Carbon Fuel Company  
Decota, West Virginia

Mr. Thomas S. Cochrane  
Mining Research Centre - Mines  
Research  
Ottawa, Ontario, Canada

Mr. E. L. Coe, Jr.  
Joy Manufacturing Company  
Los Angeles, California

Dr. William C. Cooley  
Terraspace Inc.  
Bethesda, Maryland

Mr. H. W. Cooper  
Allied Chemical  
Morristown, New Jersey

Dr. Morton Corn  
Monterey Coal Company  
Pittsburgh, Pennsylvania

Mr. R. M. Cornforth  
Hewitt-Robins  
Passaic, New Jersey

Mr. Jasper K. Cornett  
Blue Diamond Coal Company  
Knoxville, Tennessee

Mr. H. N. Cotabish  
Mine Safety Appliances Company  
Pittsburgh, Pennsylvania

Mr. Welby G. Courtney  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. David W. Coy  
Resources Research, Inc.  
Reston, Virginia

Mr. Joe Craggs  
Peabody Coal Company  
Taylorville, Illinois

Mr. William L. Crentz  
U.S. Bureau of Mines  
Washington, D.C.

Mr. A. B. Crichton, Jr.  
Dept. of the Interior  
Washington, D.C.

Mr. T. J. Crocker Jr.  
Bethlehem Mines Corp.  
Bethlehem, Pennsylvania

Mr. Frank Cronin  
American Mining Congress  
Washington, D.C.

Mr. Robert W. Dalzell  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Dr. Glenn H. Damon  
U.S. Bureau of Mines  
Washington, D.C.

Mr. D. V. d'Arbeloff  
Millipore Corporation  
Bedford, Massachusetts

Mr. R. A. Daugherty  
American Cyanamid Company  
Wayne, New Jersey

Mr. G. E. DeRusha  
Republic Steel Corporation  
Uniontown, Pennsylvania

Mr. Maurice Deul  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Wallace DeYarman  
Youngstown Sheet and Tube  
Youngstown, Ohio

Mr. William F. Diamond  
Island Creek Coal Company  
Cleveland, Ohio

Mr. Henry N. Doyle  
U.S. Bureau of Mines  
Washington, D.C.

Mr. B. E. Duke  
Bethlehem Mines Corp.  
Bethlehem, Pennsylvania

Mr. Walter Dummer  
Chilean Mutual Insurance Co.  
Santiago, Chile

Mr. James L. Dwyer  
Millipore Corporation  
Bedford, Massachusetts

Mr. M. H. Evans  
Acme Machinery Company  
Huntington, West Virginia

Dr. Walter N. Ezekiel  
U.S. Bureau of Mines  
College Park, Maryland

Mr. Thomas J. Fitzmorris  
National Coal Association  
Washington, D.C.

Mr. M. M. Fitzwater, Jr.  
The Buckeye Coal Company  
Nemacolin, Pennsylvania

Mr. Donald K. Flanagan  
Union Carbide Corporation  
Leon, West Virginia

Mr. J. W. Fleming  
Clinch Field Coal  
Dante, Virginia

Mr. Alfred E. Flowers  
Coal Age  
New York, New York

Dr. William Foreman  
Virginia Polytechnic Institute  
Blacksburg, Virginia

Mr. D. T. Foust  
Woodward Company  
Woodward, Alabama

Mr. D. F. Frailey  
Old Ben Coal Corporation  
Benton, Illinois

Mr. Eustace Frederick  
Pocahontas Fuel Company  
Pocahontas, Virginia

Mr. James R. Garvey  
Bituminous Coal Research, Inc.  
Monroeville, Pennsylvania

Mr. Larry Gentile  
Petrolite Corporation  
St. Louis, Missouri

B. G. Giel, M.D.  
U.S. Public Health Service  
Washington, D.C.

Mr. John S. Glass  
Millipore Corporation  
Bedford, Massachusetts

Mr. A. R. Goepfert  
The Valley Camp Coal Company  
Triadelphia, West Virginia

Mr. Claude A. Goode  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. John S. Graham  
Millipore Corporation  
Washington, D.C.

Dr. Rudolf E. Greuer  
Michigan Technological University  
Houghton, Michigan

Mr. J. M. Griffin  
Appalachian Stone  
Harrisburg, Pennsylvania

Mr. John M. Hackett  
American Electric Power Service  
Corporation  
Lower Burrell, Pennsylvania

Mr. C. Hager  
U.S. Pipe and Foundry Co.  
Birmingham, Alabama

Mr. H. J. Hager  
Alabama By-Products Corporation  
Birmingham, Alabama

Mr. B. J. Haley  
Union Carbide Corporation  
Marietta, Ohio

Mr. Ted D. Haley  
University of Kentucky  
Lexington, Kentucky

Mr. Robert G. Hagstrom  
Peabody Coal Company  
Columbia, Tennessee

Mr. J. R. Hamilton The Aro Corporation Bryan, Ohio	Mr. R. Paul Hightower International Harvester Company Benham, Kentucky
Mr. R. J. Hamilton National Coal Board Isleworth, England	Mr. Ralph Hiltz MSA Research Evans City, Pennsylvania
Mr. L. J. Hammel, Jr. Blue Diamond Coal Company Knoxville, Tennessee	Mr. Warren H. Hinks, Jr. Rushton Mining Company Johnstown, Pennsylvania
Mr. James W. Hammond Humble Oil & Refining Co. Houston, Texas	Mr. Emil J. Hlinsky WABCO-MED Chicago, Illinois
Mr. S. L. Hanton The Aro Corporation Bryan, Ohio	Mr. E. J. Hohos MSA Research Evans City, Pennsylvania
Mr. M. V. Harrell Freeman Coal Mining Corporation West Frankfort, Illinois	Mr. Charles T. Holland West Virginia University Morgantown, West Virginia
Mr. E. J. Harris U.S. Bureau of Mines Pittsburgh, Pennsylvania	Mr. Clyde Holvenstot Lee-Norse Company Charleroi, Pennsylvania
Mrs. Lynn M. Harris U.S. Bureau of Mines Washington, D.C.	Mr. A. R. Hood Duquesne Light Company Greensboro, Pennsylvania
Mr. D. H. Harrold Red Bird Mining Company Tazewell, Virginia	Mr. M. L. Hoover Joy Manufacturing Company Franklin, Pennsylvania
Mr. Ralph W. Hatch Consolidation Coal Co., Div. Cadiz, Ohio	Mr. Glenn M. Hostetter Pickands Mather & Company Cleveland, Ohio
Mr. Arthur Hawthorne Div. of Consolidation Coal Co. Cadiz, Ohio	Mr. D. C. Howe The Valley Camp Coal Company Shrewsbury, West Virginia
Mr. W. E. Haynie Old Ben Coal Corporation Benton, Illinois	Mr. Gary E. Hughes Standard Oil Company Cleveland, Ohio
Mr. C. Heft National Coal Association Washington, D.C.	Mr. Louis Hunter National Independent Coal Operator's Association, Inc. Richlands, Virginia

Mr. James H. Hurley  
The Florence Mining Company  
Seward, Pennsylvania

Mr. Tracy W. Hylton  
Whitesville A & S Coal Company  
Beckley, West Virginia

Mr. Andrew Hyslop, Jr.  
Hanna Coal Division  
Cadiz, Ohio

Mr. R. L. Ireland  
100 Erieview Plaza - 36th Floor  
Cleveland, Ohio

Mr. Ralph M. Jacobs  
Syracuse University Research Corp.  
Syracuse, New York

Mr. Murray Jacobson  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. John A. Janous  
Jones & Laughlin Steel Corp.  
Pittsburgh, Pennsylvania

Mr. S. M. Jarret  
U.S. Bureau of Mines  
Washington, D.C.

Mr. Lewis Jesalosky  
Hanna Coal Company  
Cadiz, Ohio

Mr. Clarence E. Jessee  
Allied Chemical Corporation  
Bluefield, West Virginia

Mr. C. R. Jesse  
Health Department  
Richmond, Virginia

Mr. Elmer P. Johnson  
Ayshire Collieries Corp  
Farmersburg, Indiana

Mr. H. Bradley Johnson  
American Mining Congress  
Washington, D.C.

Mr. T. A. Jonas  
Garrett Research & Development Co.,  
Incorporated  
Washington, D.C.

Mr. Donald C. Jones  
Coal Mining and Processing  
Chicago, Illinois

Mr. George W. Jones  
Amherst Coal Company  
Lundale, West Virginia

Mr. Robert Kirk Jones  
State Department of Health  
Frankfort, Kentucky

Mr. George L. Judy  
George L. Judy Associates  
Washington, D.C.

Mr. John A. Jurgiel  
Industrial Hygiene Foundation  
Pittsburgh, Pennsylvania

Dr. Lawrence L. Kavich  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Albert M. Keenan  
Colorado School of Mines  
Golden, Colorado

Mr. W. G. Kegel  
Jones & Laughlin Steel Corp.  
California, Pennsylvania

Mr. Alex Kelemen  
Armco Steel Corporation  
Montcoal, West Virginia

Dr. Jay Hilary Kelley  
Urdata Associates, Inc.  
Philadelphia, Pennsylvania

Dr. Victor Kevorkian  
Ingersoll-Rand Research Inc.  
Princeton, New Jersey

Mr. John L. Kilcullen  
National Independent Coal Operators'  
Association  
Washington, D.C.

Mr. William Kilgore  
Kentucky Carbon Corporation  
Phelps, Kentucky

Mr. Donald S. Kingery  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. W. A. Kiser  
Department of Labor  
Big Stone Gap, Virginia

Mr. E. F. Knapp  
The Aro Corporation  
Bryan, Ohio

Mr. Geoffrey Knight  
Energy Mines and Resources  
Elliot Lake Ontario, Canada

Mr. Jeffrey C. Knight  
Rochester & Pittsburgh Coal Co.  
Indiana, Pennsylvania

Mr. T. E. Kobrick  
Bethlehem Mines Corporation  
Bethlehem, Pennsylvania

Mr. Robert J. Kohn  
Unico Environmental Instruments  
Fall River, Massachusetts

Mr. T. O. Kroehle  
Jeffrey Mining Machinery Co.  
Columbus, Ohio

Mr. Louis S. Kovash  
The Travelers Insurance Co.  
Louisville, Kentucky

Mr. Stephen Krickovic  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Joseph Kuti  
Mining Progress, Inc.  
Charleston, West Virginia

Mr. Joseph A. Lamonica  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Lester E. Langan  
The Pittston Company  
Washington, D.C.

Miss Lucille M. Langlois  
U.S. Bureau of Mines  
Washington, D.C.

Mr. W. H. Leckie  
Leckie Smokeless Coal Co.  
Rupert, West Virginia

Mr. R. H. Leske  
Bethlehem Steel Corporation  
Bethlehem, Pennsylvania

Mr. Nicholas Levo, Jr.  
Duquesne Light Company  
Pittsburgh, Pennsylvania

Mr. H. S. Lewis  
Duquesne Light Company  
Greensboro, Pennsylvania

Mr. T. J. Liddle  
Westmoreland Coal Company  
Big Stone Gap, Virginia

Mr. Paul C. Lingo  
Monterey Coal Company  
Carlinville, Illinois

Mr. C. E. Linkous  
Island Creek Coal Company  
Holden, West Virginia

Mr. John B. Long  
Long Airdox  
Oak Hill, West Virginia

Mr. Charles E. Lopple  
Stanford Research Institute  
Menlo Park, California

Mr. L. M. Lototzky  
Pickands Mather & Company  
Indianapolis, Indiana

Mr. W. S. Lucas  
Sahara Coal Company, Inc.  
Harrisburg, Illinois

Mr. Gordon MacVean  
National Mine Service Co.  
Pittsburgh, Pennsylvania

Mr. Clarence Maggard  
Clarence Maggard Coal Co., Inc.  
Hazard, Kentucky

Mrs. Clarence Maggard  
Clarence Maggard Coal Co., Inc.  
Hazard, Kentucky

Mr. Gerald Manning  
Armco Steel Corporation  
Middletown, Ohio

Mr. M. Marchich  
U.S. Pipe and Foundry Co.  
Birmingham, Alabama

Mr. James O. McArdle  
Central Appalachian Coal  
Montgomery, West Virginia

Mr. A. H. McBane  
The Valley Camp Coal Company  
Cleveland, Ohio

Mr. E. E. McBurney  
Island Creek Coal Co.  
Cleveland, Ohio

Mr. Stephen McCann  
Western Pennsylvania Coal Operator's  
Association  
Pittsburgh, Pennsylvania

Mrs. Kathryn S. McCarthy  
American Mining Congress  
Washington, D.C.

Mr. W. W. McClanahan, Jr.  
National Coal Policy Conference, Inc.  
Washington, D.C.

Mr. J. D. McClung  
West Virginia University  
Morgantown, West Virginia

Mr. C. R. McClure  
Bureau of Labor Standards  
Washington, D.C.

Mr. W. T. McCormick  
Inland Steel Company  
E. Chicago, Indiana

Mr. C. D. McDowell  
Harlan County Coal Operator's  
Association  
Harlan, Kentucky

Mr. P. D. McMurrer  
American Mining Congress  
Washington, D.C.

Mr. Joseph R. McVicker  
Republic Steel Corporation  
Cleveland, Ohio

Mr. H. W. Meador, Jr.  
Westmoreland Coal Company  
Big Stone Gap, Virginia

Mr. Phillip G. Meikle  
National Ash Association  
Washington, D.C.

Dr. T. P. Meloy  
Melpar  
Falls Church, Virginia

Mr. W. D. Menzie  
National Mine Service Company  
Pittsburgh, Pennsylvania

Mr. C. R. E. Merkle Jr.  
Mine Safety Appliances Company  
Pittsburgh, Pennsylvania

Mr. E. W. Merry  
Mine Safety Appliances Company  
Pittsburgh, Pennsylvania

Mr. D. Blaine Mikesell  
American Brattice Cloth Corp.  
Warsaw, Indiana

Mr. Herman Mills  
Peter Cave Coal Company  
Lovely, Kentucky

Mr. Hugh B. Montgomery  
Hugh B. Montgomery & Associates  
Irwin, Pennsylvania

Mr. Joseph E. Moody  
National Coal Policy Conference, Inc.  
Washington, D.C.

Dr. Kenneth R. More  
U.S. Bureau of Mines  
Washington, D.C.

Mr. E. T. Moroni  
Old Ben Coal Corporation  
Benton, Illinois

Mr. Robert N. Morris  
Southern Railway System  
Washington, D.C.

Mr. Kenneth M. Morse  
United States Steel Corp.  
Pittsburgh, Pennsylvania

Mr. Paul Morton  
Cannelton Coal Company  
Cannelton, West Virginia

Mr. Quin Morton, III  
Kanawha Coal Operator's Assn.  
Charleston, West Virginia

Mr. J. H. Mosgrove  
Department of Mines & Minerals  
Lexington, Kentucky

Mr. Donald J. Motz  
NUS Corporation  
Pittsburgh, Pennsylvania

Mr. Walter Mueller, Jr.  
Kaiser Steel  
Sunnyside, Utah

Mr. W. Foster Mullins  
U.S. Department of Labor  
Big Stone Gap, Virginia

Mr. H. K. Najarian  
St. Joseph Lead Company  
Monaca, Pennsylvania

Mr. Frank M. Noonan  
West Virginia University  
Morgantown, West Virginia

Mr. John F. O'Leary  
U.S. Bureau of Mines  
Washington, D.C.

Mr. Jerry Omer  
Pittsburgh & Midway Coal Mining  
Company  
Madisonville, Kentucky

Mr. Edward J. Onuscheck  
Rochester & Pittsburgh Coal Company  
Indiana, Pennsylvania

Mr. Joseph Orlandi  
Orlandi Coal Company  
Charleston, West Virginia

Mr. J. Allen Overton, Jr.  
American Mining Congress  
Washington, D.C.

Mr. Arno M. S. Paas  
Mining Progress, Inc.  
Charleston, West Virginia

Mr. E. M. Pace  
Inland Steel Company  
Sesser, Illinois

Mr. Eugene R. Palowitch  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. John H. Paul  
Bethlehem Steel Corporation  
Bethlehem, Pennsylvania

Mr. Robert G. Peluso  
U.S. Bureau of Mines  
Washington, D.C.

Mr. Keith D. Pfoor  
Oglebay Norton Company  
St. Clairville, Ohio

Mr. Claude E. Phillips  
U.S. Bureau of Mines  
Mount Hope, West Virginia

Mr. George Pickios  
The Flexaust Company  
New York, New York

Mr. David W. Pinkard Mining Congress Journal Washington, D.C.	Mr. J. Robbins U.S. Pipe and Foundry Company Birmingham, Alabama
Mr. C. J. Potter Rochester and Pittsburgh Coal Company Indiana, Pennsylvania	Mr. W. Homer Robbins R. M. Wilson Company, Inc. Wheeling, West Virginia
Mr. William N. Poundstone Consolidation Coal Company Pittsburgh, Pennsylvania	Mr. John Robertson, Jr. CF&I Steel Corporation Weston, Colorado
Mr. C. W. (Bill) Powell General Electric Company Detroit, Michigan	Mr. Adam Robinett North American Coal Corp. Powhattan Point, Ohio
Mr. L. B. Powers Blue Diamond Coal Company Knoxville, Tennessee	Mr. Ernest R. Rodriguez U.S. Bureau of Mines Washington, D.C.
Mr. George Pudlo West Virginia University Morgantown, West Virginia	Mr. Thomas E. Rosendahl Donaldson Company Minneapolis, Minnesota
Mr. Patrick M. Quinlan Petrolite Corporation Webster Groves, Maryland	Mr. C. R. Ross Department of National Health and Welfare Ottawa, Canada
Mr. George Radomsky Barnes and Tucker Company Barnesboro, Pennsylvania	Mr. Robert D. Saltsman Bituminous Coal Research, Inc. Monroeville, Pennsylvania
Mr. John J. Raves National Mines Corporation Isabella, Pennsylvania	Mr. E. J. Sandy West Virginia University Morgantown, West Virginia
Mr. William H. Revoir American Optical Corporation Southbridge, Massachusetts	Dr. Eric B. Sansone University of Pittsburgh Pittsburgh, Pennsylvania
Mr. Fred Rice Peabody Coal Company St. Louis, Missouri	Mr. Robert Saxton Imperial Colliery Company Burnwell, West Virginia
Mr. Raymond R. Richards Koehler Manufacturing Company Marlboro, Massachusetts	Mr. Donald P. Schlick U.S. Bureau of Mine Washington, D.C.
Mr. Dewey Rife Black Diamond Fuel Company Conaway, Virginia	Mr. Darwin W. Schmitt Joy Manufacturing Company Pittsburgh, Pennsylvania

Mr. B. P. Schofield  
Health Department  
Richmond, Virginia

Mr. William E. Schroeder  
Schroeder Brothers  
McKess Rock, Pennsylvania

Mr. Charles W. Schulties  
Peabody Coal Company  
St. Louis, Missouri

Mr. Robert H. Schultz  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Bill Scott  
Dowell Div. of the Dow Chemical Co.  
Marietta, Ohio

Mr. Franklin L. Scott  
The North American Coal Corp.  
Seward, Pennsylvania

Mr. James J. Scott  
Mining & Petroleum Dept.  
Rolla, Missouri

Mr. William E. Sebesta  
Republic Steel Corporation  
Independence, Ohio

Mr. Hymin Shapiro  
Ethyl Corporation  
Baton Rouge, Louisiana

Mr. E. H. Shaw  
Eastern Associated Coal Corporation  
Beckley, West Virginia

Professor T. C. Shelton, Jr.  
Virginia Polytechnic Institute  
Blacksburg, Virginia

Mr. Earle P. Shoub  
U.S. Bureau of Mines  
Washington, D.C.

Mr. Paul Shrechengost  
Solar Fuel Company, Inc.  
Hooversville, Pennsylvania

Dr. James D. Shreve  
Kerr-McGee Company  
Oklahoma City, Oklahoma

Mr. Mack H. Shumate  
Bell & Zoller Coal Company  
Chicago, Illinois

Mr. John B. Shutack  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Wilbur T. Simon  
Christopher Coal Company  
Osage, West Virginia

Mr. C. W. Simpson  
Armco Steel Corporation  
Middletown, Ohio

Mr. Jack Sims  
Alabama Power Company  
Birmingham, Alabama

Dr. A. K. Sinha  
Pennsylvania State University  
State College, Pennsylvania

Mr. J. Richard Skuse  
U.S. Information Agency  
Washington, D.C.

Mr. E. D. Slone  
Howe Coal Company  
Heavener, Oklahoma

Mr. F. W. Smith  
Mine Safety Appliances Company  
Pittsburgh, Pennsylvania

Mr. John W. Smith  
Atlantic Richfield Company  
Denver, Colorado

Mr. William M. Smith  
National Steel Corporation  
Weirton, West Virginia

Mr. William S. Smith  
Peabody Coal Company  
Taylorville, Illinois

Mr. J. Roy Snyder  
Bacharach Instrument Company  
Pittsburgh, Pennsylvania

Mr. Henning E. Soderberg  
American Air Filter Company  
Louisville, Kentucky

Mr. Thomas E. Somers  
Hewitt-Robins  
Passaic, New Jersey

Mr. Coy L. South  
Bell & Zoller Coal Company  
Johnston City, Illinois

Mr. Don Spilker  
Medill News Service  
Washington, D.C.

Mr. F. Steven Spoerle  
Nalco Chemical Company  
Chicago, Illinois

Mr. Robert Stefanko  
The Pennsylvania State University  
University Park, Pennsylvania

Mr. Richard Stein  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. A. J. Steinhauser  
U.S. Department of Commerce  
Washington, D.C.

Mr. Robert H. Stevenson  
American Brattice Cloth Corporation  
Warsaw, Indiana

Mr. John W. Straton  
Gates Engineering Company  
Beckley, West Virginia

Mr. Phil Stone  
American Mining Congress  
Washington, D.C.

Mr. G. E. Stuart  
Garland Coal Company  
Knoxville, Tennessee

Mr. Harold Suter  
Consolidation Coal Company  
Morgantown, West Virginia

Mr. Kenneth Suter  
Johnson-March Corporation  
Philadelphia, Pennsylvania

Mr. Glen W. Sutton  
Public Health Service  
Cincinnati, Ohio

Mr. G. R. Swanson  
Armco Steel Corporation  
Montcoal, West Virginia

Dr. Jon R. Swanson  
George D. Clayton & Associates, Inc.  
Southfield, Michigan

Mr. R. O. Swenarton  
U.S. Bureau of Mines  
Washington, D.C.

Mr. Woods G. Talman  
U.S. Steel Corporation  
Pittsburgh, Pennsylvania

Mr. Bert Teasdale  
Schroeder Brothers  
McKees Rock, Pennsylvania

Mr. James L. Tenley  
Pickands Mather & Co.  
Phelps, Kentucky

Mr. Pramod C. Thakur  
Pennsylvania State University  
State College, Pennsylvania

Mr. L. N. Thomas  
The Carbon Fuel Company  
Charleston, West Virginia

Mr. Jack E. Tisdale  
U.S. Bureau of Mines  
Vincennes, Indiana

Mr. Thomas F. Tomb  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Leonard J. Timms  
United Pocahontas Coal Co.  
Crumpler, West Virginia

Mr. James G. Topper  
Martin Marietta Corporation  
Harrisburg, Pennsylvania

Mr. Melvin Triolo  
Logan Coal Operators' Assn.  
Logan, West Virginia

Mr. Chester N. Truax, Jr.  
American Mining Congress  
Washington, D.C.

Mr. Charles E. Ulrich  
Hazelton Laboratories  
Falls Church, Virginia

Dr. Robert W. Van Dolah  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Robert W. Van Evera  
American Mining Congress  
Washington, D.C.

Mr. Russell Van Houten  
Liberty Mutual Insurance Company  
Hopkinton, Massachusetts

Mr. Wayne E. Veneman  
U.S. Bureau of Mines  
Washington, D.C.

Mr. Robert L. Vines  
Bituminous Coal Operators' Assn.  
Washington, D.C.

Mr. George F. Walker  
Sovereign Coal Corporation  
Bluefield, West Virginia

Mr. David P. Walkey  
U.S. Dept. of the Interior  
Washington, D.C.

Mr. G. W. Wallwork  
Bethlehem Mines Corporation  
Bethlehem, Pennsylvania

Mr. W. R. Walton  
National Coal Board  
Edinburg, Scotland

Colonel V. W. Wark  
Spindletope Research  
Lexington, Kentucky

Mr. E. M. Warner  
Joy Manufacturing Company  
Franklin, Pennsylvania

Mr. A. J. Webster  
Old Ben Coal Corporation  
Benton, Illinois

Mr. Jerry Weil  
Cahn Division, Ventron Instruments,  
Corporation  
Somerville, New Jersey

Mr. C. L. Wendroff  
Dowell Div., Dowell Chemical Co.  
Tulsa, Oklahoma

Mr. E. M. White  
Mine Safety Appliances Co.  
Pittsburgh, Pennsylvania

Mr. William E. Will  
Peabody Coal Company  
St. Louis, Missouri

Dr. John E. Willson  
University of Utah  
Salt Lake City, Utah

Mr. Richard M. Wilson  
R. M. Wilson Company, Inc.  
Wheeling, West Virginia

Mr. R. Wingo  
U.S. Pipe and Foundry Co.  
Birmingham, Alabama

Mr. James M. Winston  
U.S. Bureau of Mines  
Pittsburgh, Pennsylvania

Mr. Jace Wisely  
Bell & Zoller Coal Company  
Johnston City, Illinois

Mr. Ronald L. Witman  
Willson Products Division  
Reading, Pennsylvania

Mr. Jack L. Workman  
Preiser Chemicals  
St. Albans, West Virginia

Mr. Lincous E. Yates  
Black Diamond Fuel Company  
Conaway, Virginia

Mr. Stephen G. Young  
West Virginia Coal Assn.  
Charleston, West Virginia

Mr. S. W. Zanolli  
B.C.O.A.  
Washington, D.C.

Mr. J. E. Zatek  
Mine Safety Appliances Co.  
Pittsburgh, Pennsylvania

Mr. Raymond D. Zinn  
Environmental Control Administration  
Morgantown, West Virginia

Mr. Phil Zullo  
Department of Health  
Harrisburg, Pennsylvania