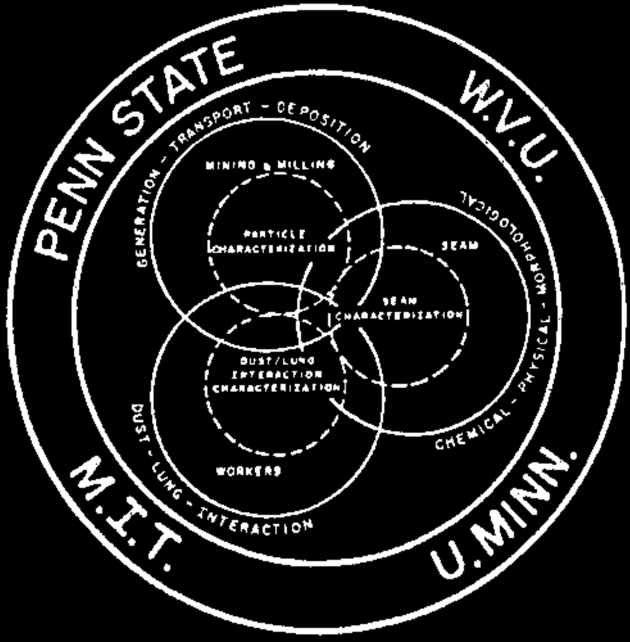
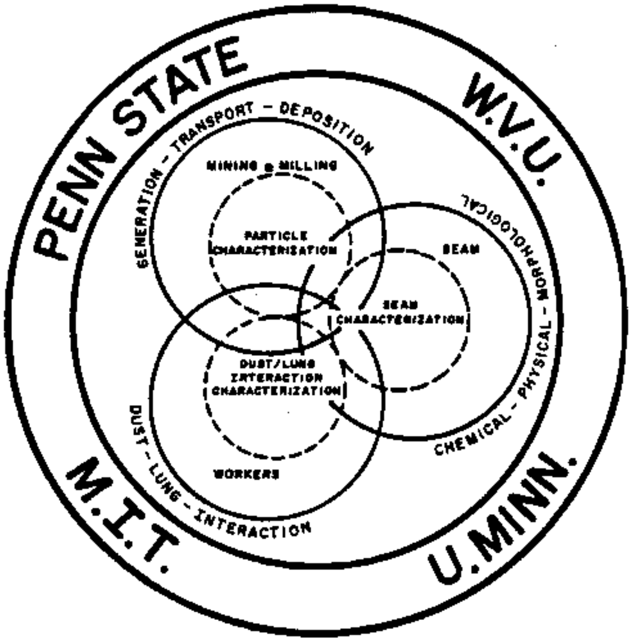
REPORT TO THE COMMITTEE ON MINING AND MINERAL RESOURCES RESEARCH 1987

Edited by
ROBERT L. FRANTZ
and
RAJA V. RAMANI



GENERIC MINERAL
TECHNOLOGY CENTER
FOR RESPIRABLE DUST

REPORT TO THE COMMITTEE ON MINING AND MINERAL RESOURCES RESEARCH
1987



GENERIC MINERAL TECHNOLOGY CENTER FOR RESPIRABLE DUST

The Pennsylvania State University
West Virginia University
University of Minnesota
Massachusetts Institute of Technology
Michigan Technological University

Submitted To
Office of Mineral Institutes
U.S. Bureau of Mines
Washington, D.C.

November 1988

REPORT TO THE COMMITTEE ON MINING AND MINERAL RESOURCES RESEARCH

BY

THE GENERIC MINERAL TECHNOLOGY CENTER FOR RESPIRABLE DUST

IN THE YEAR

1987

Edited by
Robert L. Frantz
and
Raja V. Ramani

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WEST VIRGINIA UNIVERSITY

Volumes of the Respirable Dust Center

VOLUME 1	Status Report, 1984-1988
VOLUME 2	Report to the Committee on Mining and Mineral Resources Research,1987
VOLUME 3	Publications, 1984
VOLUME 4	Publications, 1985
VOLUME 5	Publications, 1986
VOLUME 6	Publications, 1987
VOLUME 7	Respirable Dust Center Research Program Review
CONFERENCE PROCEEDINGS	Coal Mine Dust Conference West Virginia University Morgantown, West Virginia October 1984
CONFERENCE PROCEEDINGS	Respirable Dust in the Mineral Industries: Health Effects, Characterization and Control The Pennsylvania State University University Park, Pennsylvania October 1986

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FOREWORD

This publication has been prepared by the Generic Mineral Technology Center for Respirable Dust (GMTC), The Pennsylvania State University, University Park, Pennsylvania 16802. Mr. Robert Jankowski, Supervisory Physical Scientist for the U.S. Bureau of Mines (USBM) compiled the U.S. Bureau of Mines material for this report. His contribution and that of the USBM is gratefully acknowledged. The research conducted by the GMTC has been supported by the Department of the Interior's Mineral Institute program and administered by the Bureau of Mines through the Generic Mineral Technology Center for Respirable Dust under grant number G1135142. The assistance and co-operation of Dr. Ronald Munson, Chief, Office of Mineral Institutes, and the members of the Research Advisory Council for Respirable Dust is gratefully acknowledged. Also acknowledged and appreciated is the support and input from the U.S. Bureau of Mines (USBM), the National Institute of Safety and Health (NIOSH), and the Mining Safety and Health Association (MSHA).

This volume summarizes the research material presented by representatives of the USBM and the GMTC to the Committee on Mining and Mineral Resources Research, U.S. Department of the Interior on September 30, 1987 in Coraopolis, Pennsylvania. It highlights the cooperative efforts and extensive interaction of the USBM and the GMTC toward a mutual goal of reducing the incidence and severity of respirable dust disease in the mineral industry. The meeting, organized by Dr. Ronald Munson, was called to review the respirable dust activities of the U.S. Bureau of Mines (USBM) and the Generic Mineral Technology Center for Respirable Dust (GMTC). Dr. Orme Lewis, Jr. and Dr. James W. Ziglar served as co-chairmen of the meeting. Remarks by Dr. John Morgan, Chief Staff Officer, U.S. Bureau of Mines covered the history, scope, importance and congressional mandate of the Mineral Institutes program.

The committee heard presentations on the respirable dust programs of the Bureau of Mines and the Generic Mineral Technology Center for Respirable Dust. Dr. John Breslin, Senior Staff-Physical Scientist for the USBM reviewed the nature of lung problems resulting from respirable dust, current exposure limits, dose/response data, benefit payments, and currently used technology to reduce exposure and productivity. Mr. John Murphy, Research Director at the Pittsburgh Research Center, reviewed for the committee the internal Bureau of Mines respirable dust research program at the Pittsburgh and the Twin Cities Research Centers. Mr. Robert L. Frantz, Dr. Richard Bajura and Dr. Gerald Bartlett made presentations on the basic engineering studies and the biomedical research underway at the Generic Mineral Technology Center for Respirable dust (GMTC).

It is recognized that the strength and accomplishments of the Center are derived from the investigators and students who diligently work to achieve the research and educational goals of the Center. Their contributions to this volume are gratefully acknowledged.

Respectfully submitted,

Robert L. Frantz
Co-Director, Generic Mineral
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Excerpted From The

1988 UPDATE TO THE NATIONAL PLAN FOR RESEARCH IN MINING AND MINERAL RESEARCH

Report to: **December 15, 1987**

The Secretary of the Interior
The President of the United States
The President of the Senate
The Speaker of the House of Representatives

Section 9(e) of Public Law 98-409 of August 29, 1984, (98 Stat. 1536 et seq.) mandates that the Committee on Mining and Mineral Resources Research submit an annual update to the National Plan for Research in Mining and Mineral Resources: "Improving Research and Education in Mineral Science and Technology through Government-(Federal, State and Local), Industry, and University Cooperation."

....

Respirable Dust (centered at Pennsylvania State U. and West Virginia U., with affiliates at U. of Minnesota and Massachusetts Institute of Technology): brings together experts concerned with particles causing potentially disabling or fatal diseases, including pneumoconiosis ("black lung"), silicosis, and asbestosis, the latter of deep concern not just to workers in the mineral sector of the economy but also to the general populace.

....

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LIST OF FIGURES

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1

Bureau of Mines Respirable Dust Program

BUREAU OF MINES RESPIRABLE DUST PROGRAM: AN OVERVIEW OF ACCOMPLISHMENTS AND FUTURE RESEARCH PLANS *

Following passage of the Coal Mine Health and Safety Act of 1969 (Public Law 911173), the Bureau of Mines initiated a research program aimed at controlling respirable dust exposures of coal mine workers. Respirable dust is the dust that gets into, and interacts with, the lungs of those who inhale it. It has long been recognized as a severe health hazard to mine workers. This program has been implemented by a team effort consisting of the Bureau's in-house capabilities, the Generic Center for Respirable Dust, and contractors, as necessary. Over the years, Bureau research has addressed principally three areas:

- Compliance with the Federal 2.0 mg/m^3 dust standard (1970-76).
- Dust control for longwall mining (1976-1983).
- More stringent respirable dust standards due to quartz dust (1983-1987).

In addition, fundamental studies have been conducted by the Generic Center for Respirable Dust, with emphasis on penetration of dust into the lung. Accomplishments have been significant, but problems remain, as noted later.

COMPLIANCE WITH THE 2.0 MG/M^3 DUST STANDARD

The Coal Mine Health and Safety Act of 1969, established a 2.0 mg/m^3 dust standard for all coal mining operations, underground as well as surface. At

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* This material was prepared by Robert A. Jankowski, Supervisory physical scientist, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

the time of enactment of this legislation, the industry was averaging approximately 4.0 mg/m^3. The Bureau of Mines respirable dust research program played a significant role in identifying and developing effective technology to allow better compliance with this new standard, thanks to industry implementation and Federal enforcement.

Improved Dust Sampling Methods and Devices

The respirable dust standard is based on mass (2.0 mg of respirable dust per cubic meter of air). The traditional instrumentation used to determine compliance involves a sampling pump, size pre-classifier, and a pre-weighed filter. Over a working shift, the mine atmosphere is drawn through the pre-classifier and the respirable dust accumulates on the filter. At the end of the shift, the weight difference is measured and the degree of respirable dust exposure is determined. However, this form of measurement was not adequate when, for example, a rapid determination of the effectiveness of different dust control measures was needed for research purposes, or by mine operators or inspectors. To meet these needs, the Bureau has developed an instantaneous, portable continuous respirable dust monitor based on light scattering (fig. 1). This instrument has now become standard throughout the industry for rapid dust measurements; it is currently commercially available.

Design and Development of an Inseam Tester

To limit personal respirable dust exposure, more extensive knowledge was required of the characteristics of different coal seams, as they relate to the generation of respirable dust. To address this need, the Bureau developed an inseam tester (fig. 2), which has provided valuable data on the cutability and friability of different coals. These data cannot be obtained in a laboratory, because of the fracture and cleat structure found in most coal seams. Using

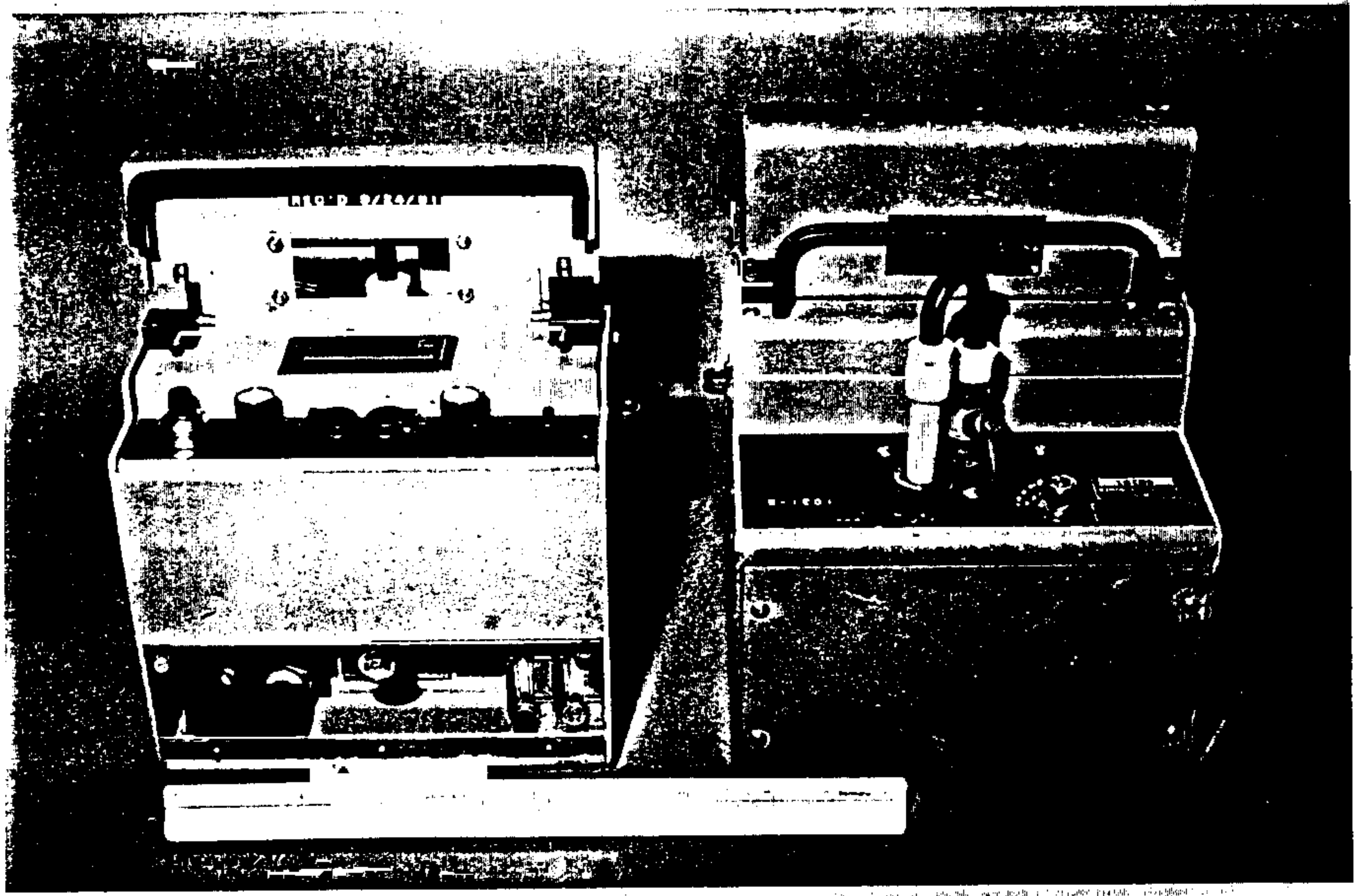


FIGURE 1. - Bureau of Mines portable, instantaneous "Real-Time Aerosol Monitor," RAM-1.

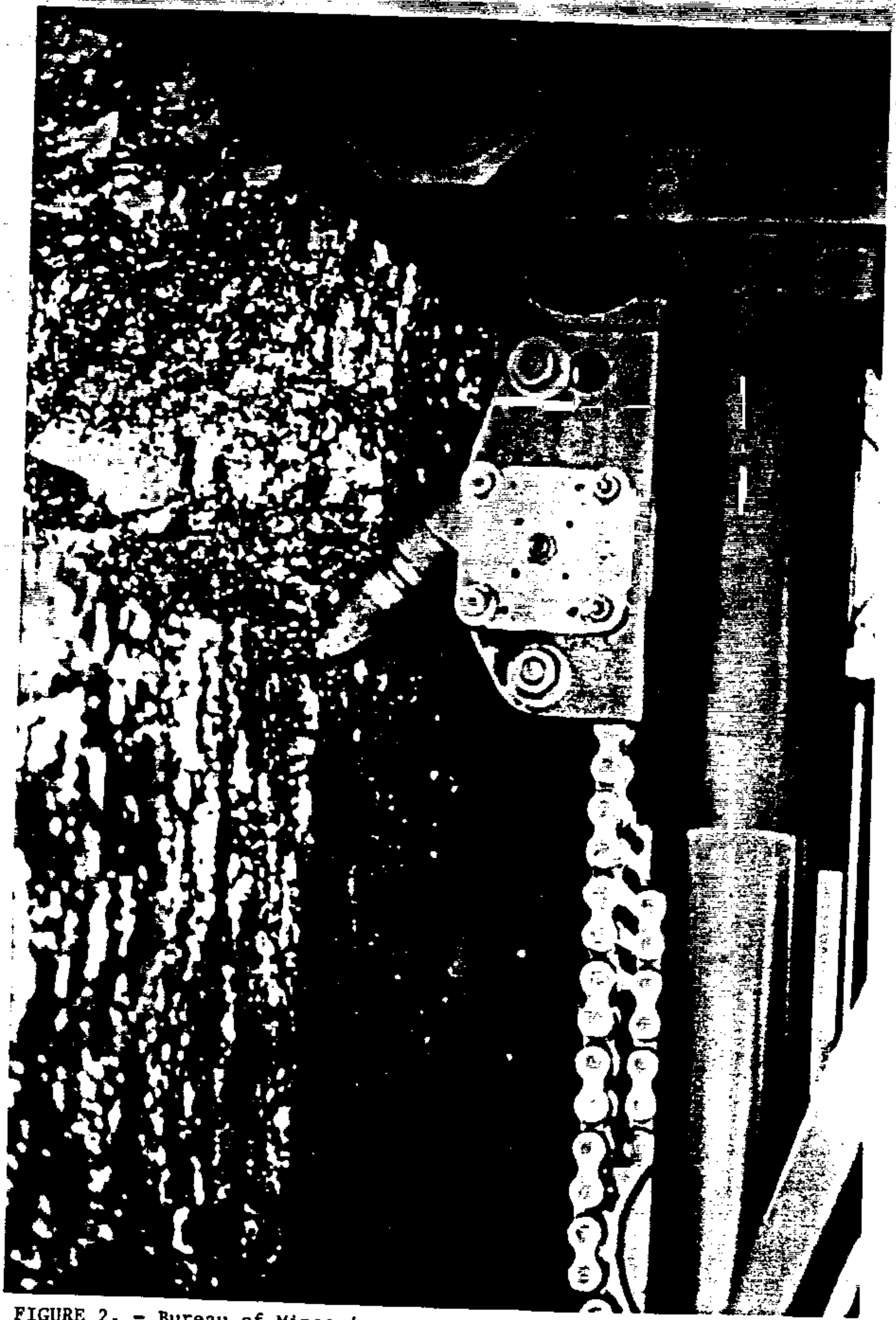


FIGURE 2. - Bureau of Mines inseam tester, used to evaluate in-mine coal seam characteristics.

this device in the actual underground mine environment has yielded valuable information that has led to alternative cutting techniques and new designs for cutting heads. Data acquired with the inseam tester can be used to tailor the cutting system to the specific physical characteristics of individual mining operations.

Improved Water Spray Systems

One of the most widely used and effective dust control techniques is the application of sprayed water. However, the establishment and maintenance of satisfactory water sprays proved difficult in the adverse conditions encountered in operating mines. Principal problems related to the need for fine atomization, and clogging of water spray nozzles by rust scale and other contaminants typically found in an industrial water supply. Figure 3 compares a good water spray system, with one performing unsatisfactorily due to clogged nozzles. Bureau research has found a method that maintains water sprays in effective operating condition; this filtration system, which uses commercially available components, is a cost-effective assembly now used extensively throughout the industry to prevent nozzle clogging.

Improved Personal Protection

In addition to controlling the amount of dust generated and the amount of dust which becomes airborne, Bureau research has addressed alternative techniques to protect the individual miner. Under certain conditions, an airstream helmet (fig. 4) is effective in reducing the amount of inspired respirable dust. This device is now used extensively in some mining operations, such as at longwall faces.

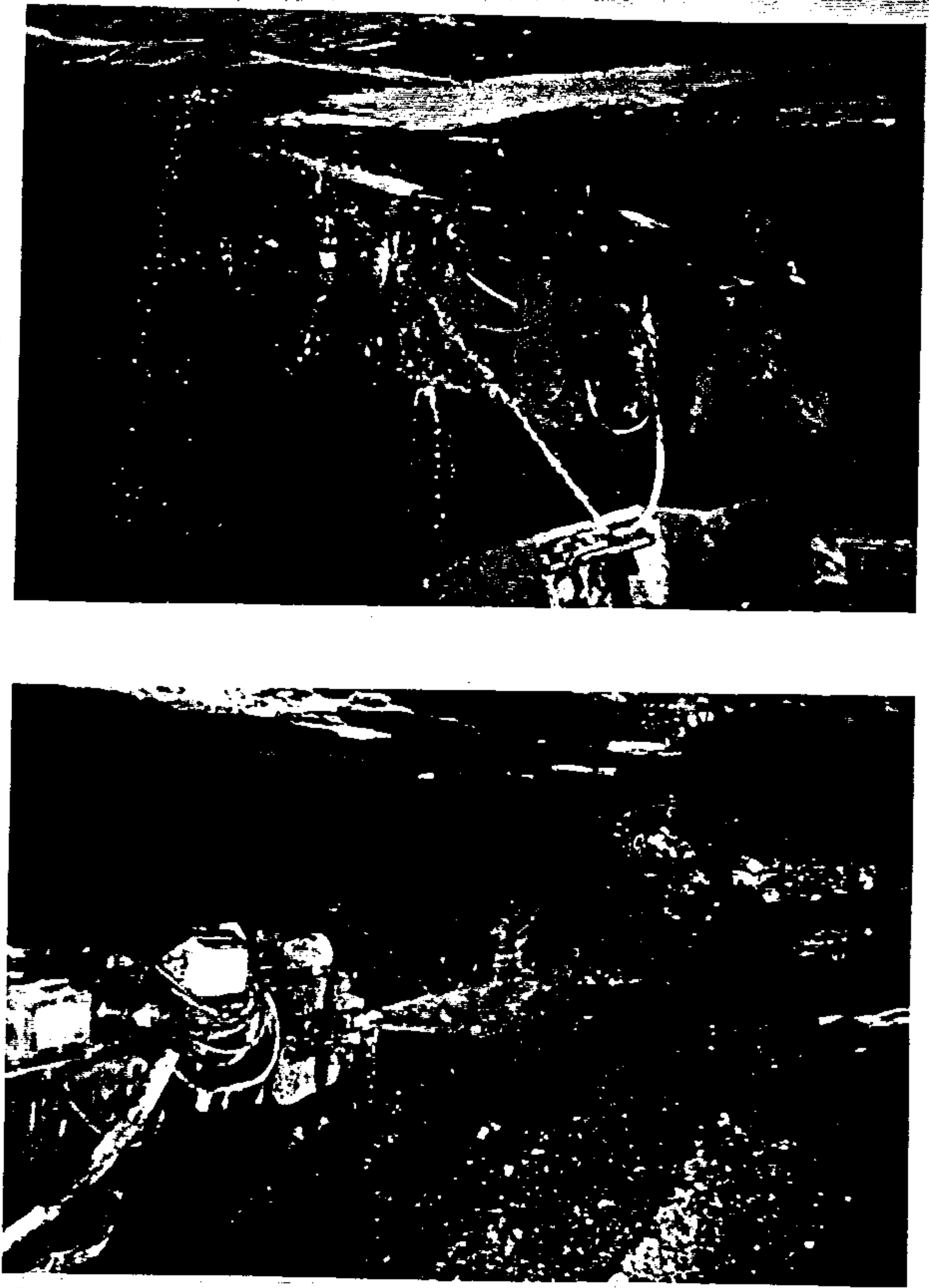


FIGURE 3. - Effective machine water spray system versus unstatisfactory system, due to clogged nozzles.

FIGURE 4. - Airstream helmet, an alternative method to provide improved personal health protection.

Dust Scrubber Systems

While the concept of scrubbers to purify dust laden air underground was attractive from the early days of the program, there were numerous obstacles to be overcome before scrubbers could be utilized successfully in operating mines. The first problem was scrubber efficiency for the fine coal particles (less than 10 microns) present in respirable dust. The Bureau-developed flooded-bed scrubber (fig. 5) has proven to be an effective tool in this regard; collection efficiency for respirable dust from flooded-bed scrubbers exceeds 95 pct. In addition, there were some significant engineering problems involved in integrating scrubbers into equipment such as the continuous miner. However, working in close cooperation with the equipment manufacturers, such integration has been successfully accomplished. Figure 6 shows a continuous miner retrofitted with a flooded-bed scrubber. At this time, over 350 such installations are in use in this country.

Accomplishments - 1970-1976, 2.0 mg/m^3 Dust Standard

When the 1969 Act was promulgated, average respirable dust exposure of the continuous miner operator was in excess of 4.0 mg/m^3 (versus a standard of 2.0 mg/m^3). Thanks to Bureau research, the cooperation of the industry and work by Federal and State agencies, average dust exposure on continuous miner sections is now below 2.0 mg/m^3 (fig. 7). Due to new concerns raised by quartz dust found in respirable dust samples, additional problems are now being addressed, as discussed later.

DUST CONTROL FOR LONGWALL MINING

The second major thrust has been towards longwall mines. In 1976, over 70 pct of the longwall shearer faces in the U.S. were consistently out of compliance. Through an aggressive program, the Bureau has been able to

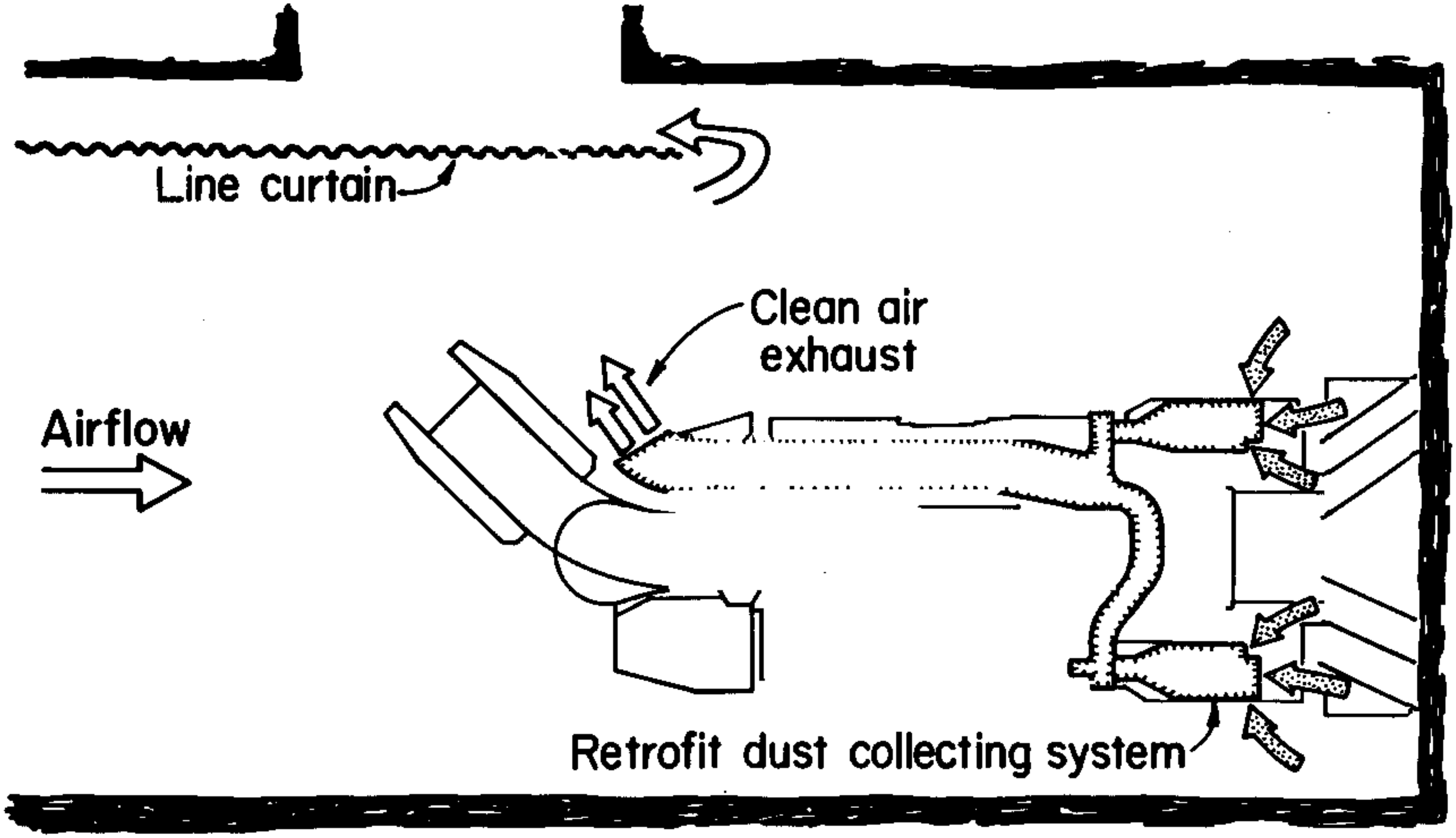


FIGURE 5. - Machine-mounted flooded bed dust scrubber system.

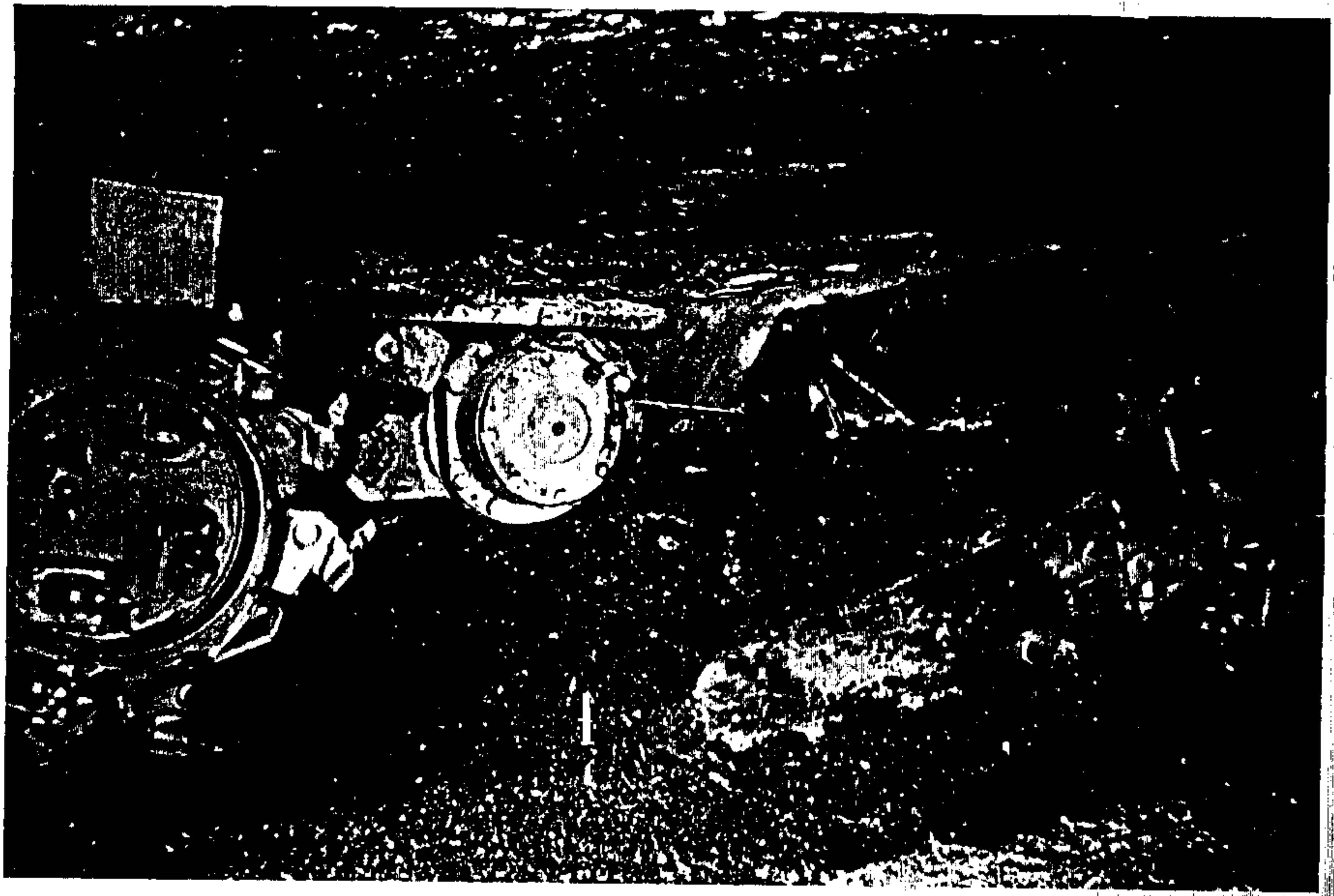


FIGURE 6. - Continuous mining machine, retrofitted with a flooded bed dust scrubber system.

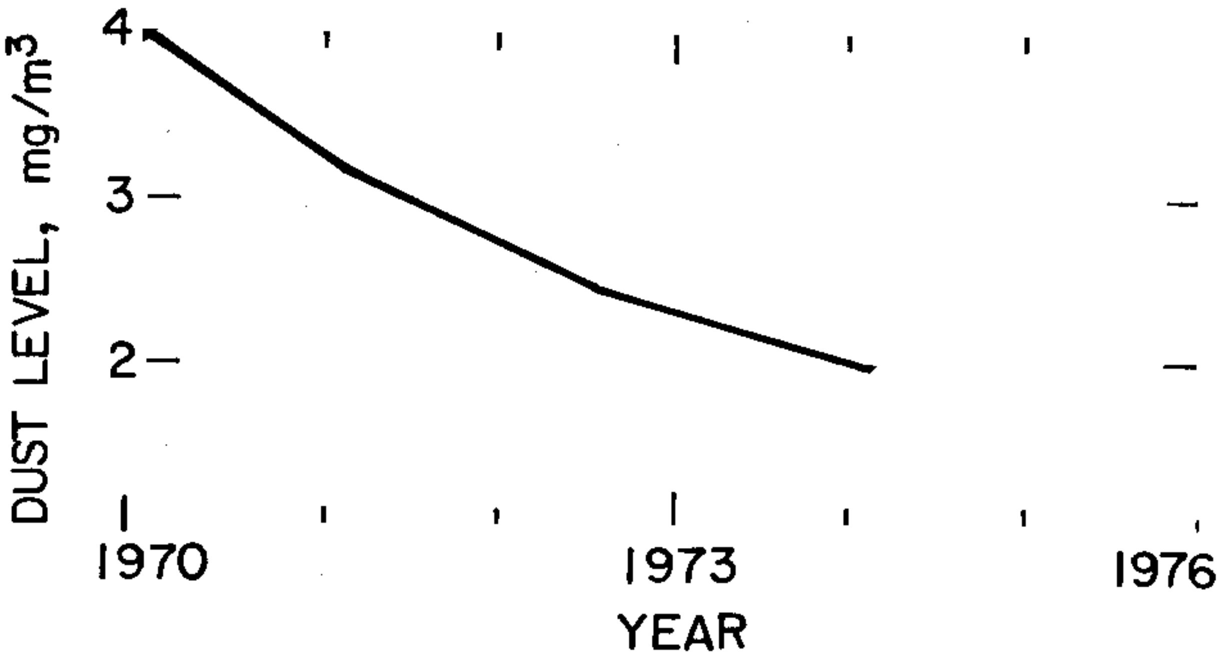
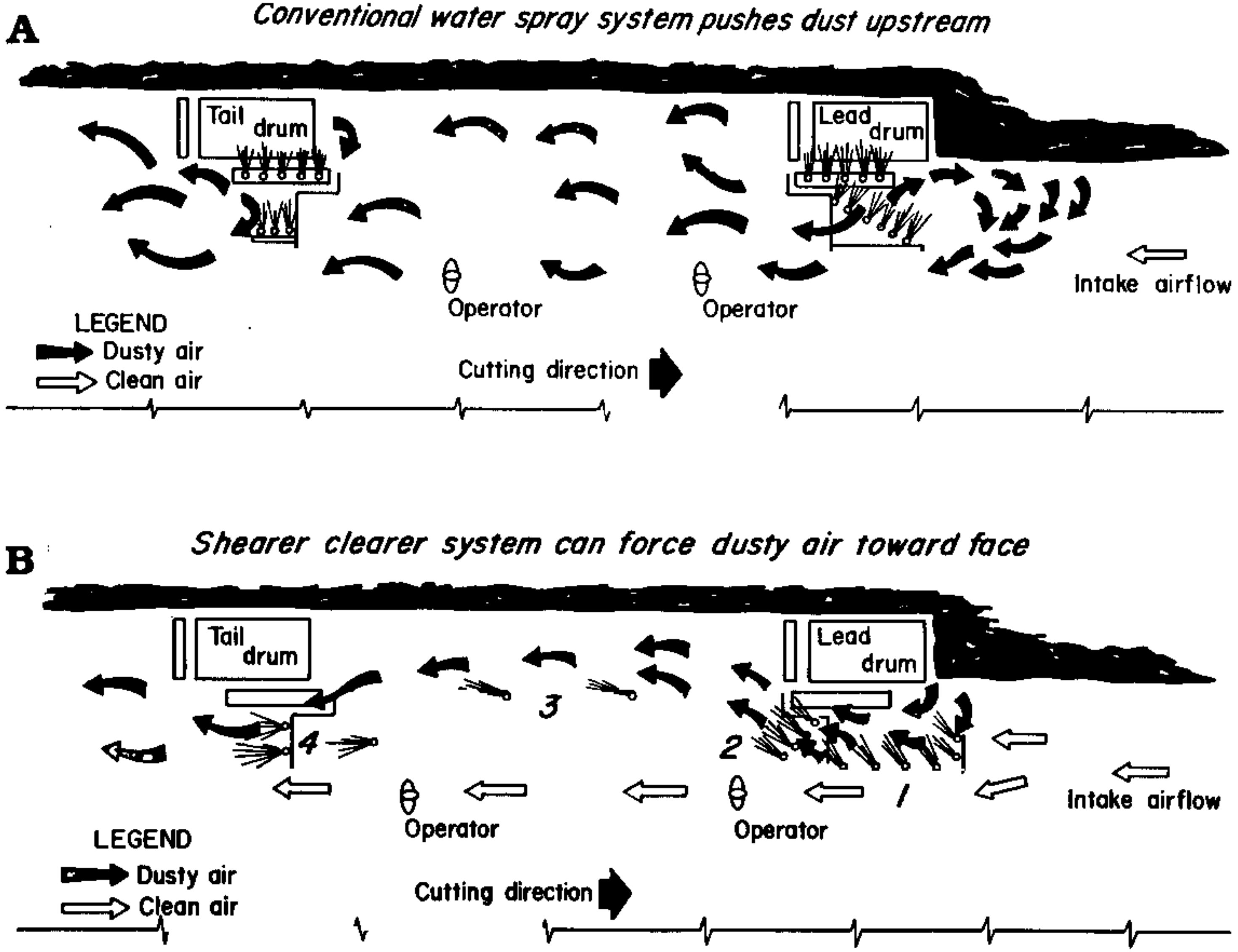


FIGURE 7. - Average respirable dust exposure of the continuous mine operator, 1970 versus 1976.

FIGURE 8. - "A": Dust boil-out caused by improperly oriented machine water sprays; "B": Re-oriented water sprays divert dust-laden air toward the face away from machine operators.



identify alternative technologies to control respirable dust exposure on longwall faces.

BuMines Shearer Clearer Water Spray System

Water sprays have been used extensively by mine operators to control respirable dust. A typical water spray captures about 25 pct of the respirable dust which becomes airborne, the remaining dust is moved about by the air-moving action of the water sprays, and boils out over the equipment operators. Figure 8-A shows the primary airflow moving from right to left, and the secondary air currents caused by water sprays mounted on the shearer body. In actual mining situations, the exposure of the shearer operator can be increased by as much as 50 pct due to this air-moving action. Bureau research has shown that by simply re-orienting the existing water sprays their air-moving capability can be effectively utilized to reduce dust exposure. Re-oriented water sprays are used to divert the dust laden air toward the face and away from shearer operator (fig. 8-B). The shearer clearer concept lowers shearer operator dust exposure by an average of 50 pct. Today, over 80 pct of longwall shearers in the U.S. utilize the shearer clearer system, and the concept has been exported to Canada and Australia. Perhaps the most vivid demonstration of its effectiveness is shown in figure 9, using smoke to simulate the release of respirable dust. A conventional water spray system causes significant dust to boil-out into the walkway, contaminating the face workers' environment (fig. 9-A); the shearer clearer effectively keeps the dust away from the face workers (fig. 9-B). Figure 10 further illustrates the effectiveness of this simple control technology.

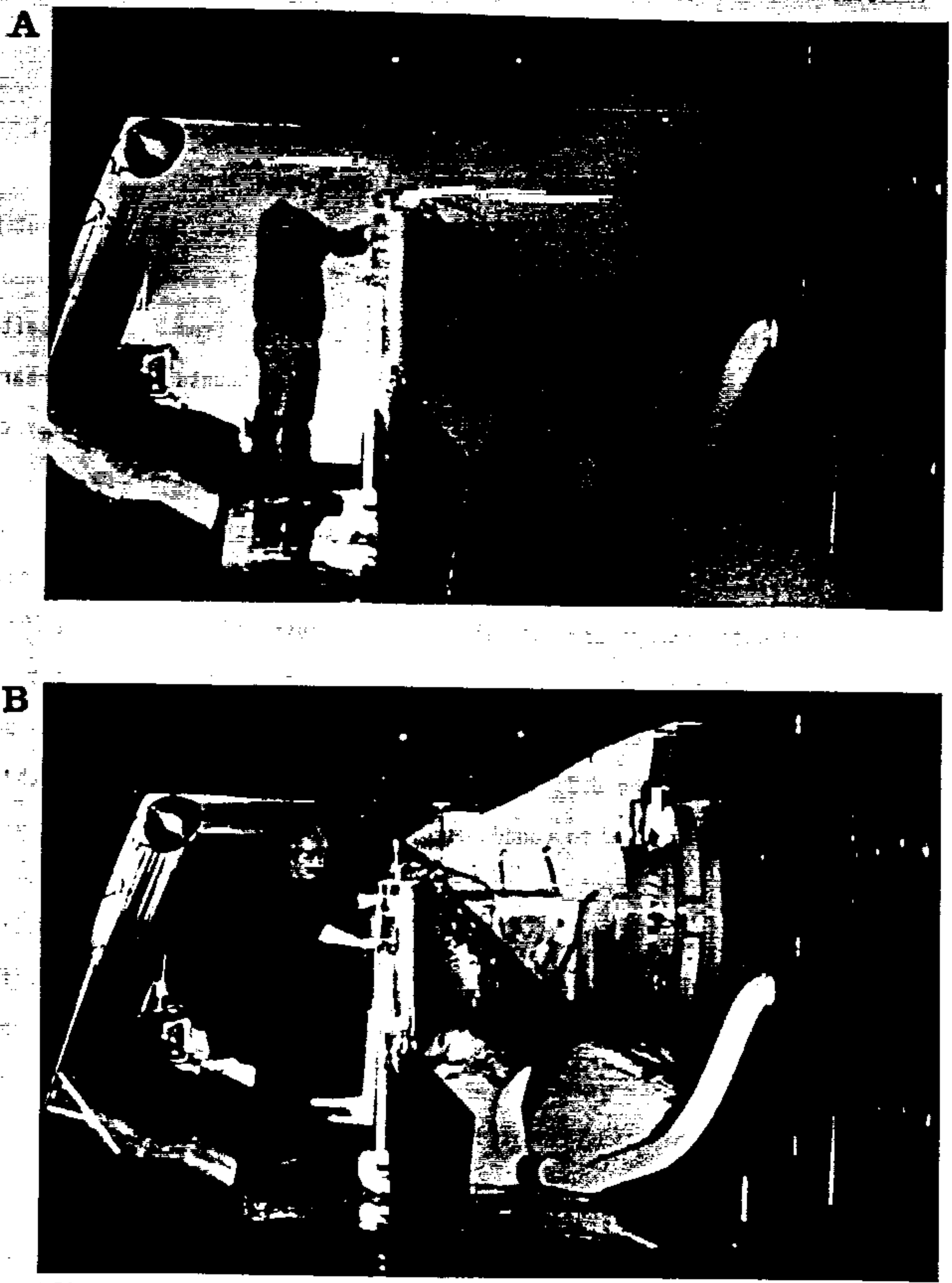


FIGURE 9. - Laboratory illustration of shearer clearer concept, "A": Conventional water sprays; "B": BuMines shearer clearer spray system.

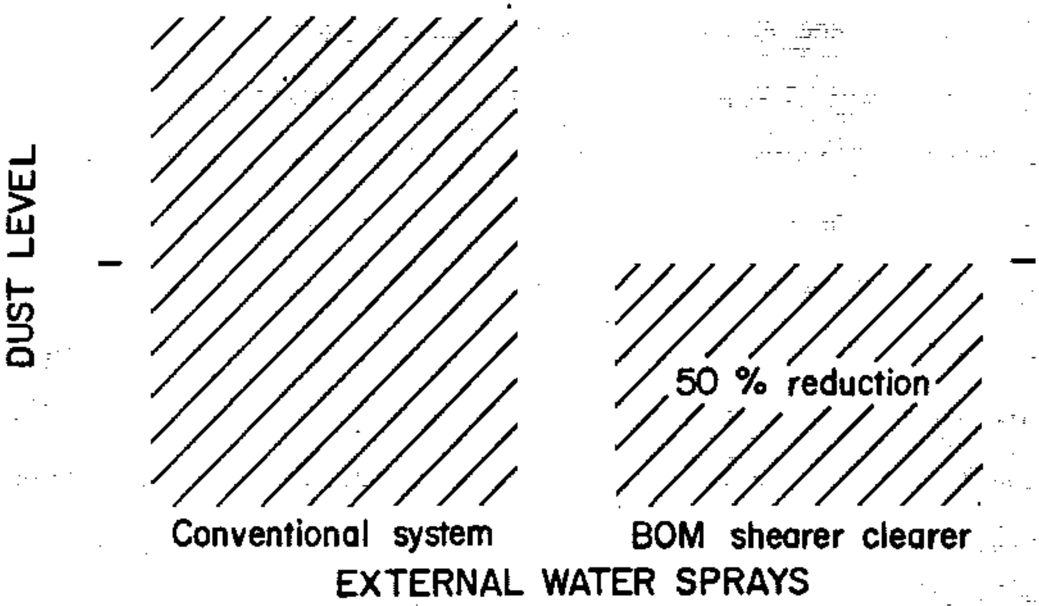


FIGURE 10. - BuMines shearer clearer spray system reduces machine operators' dust exposure by an average of 50 pct.

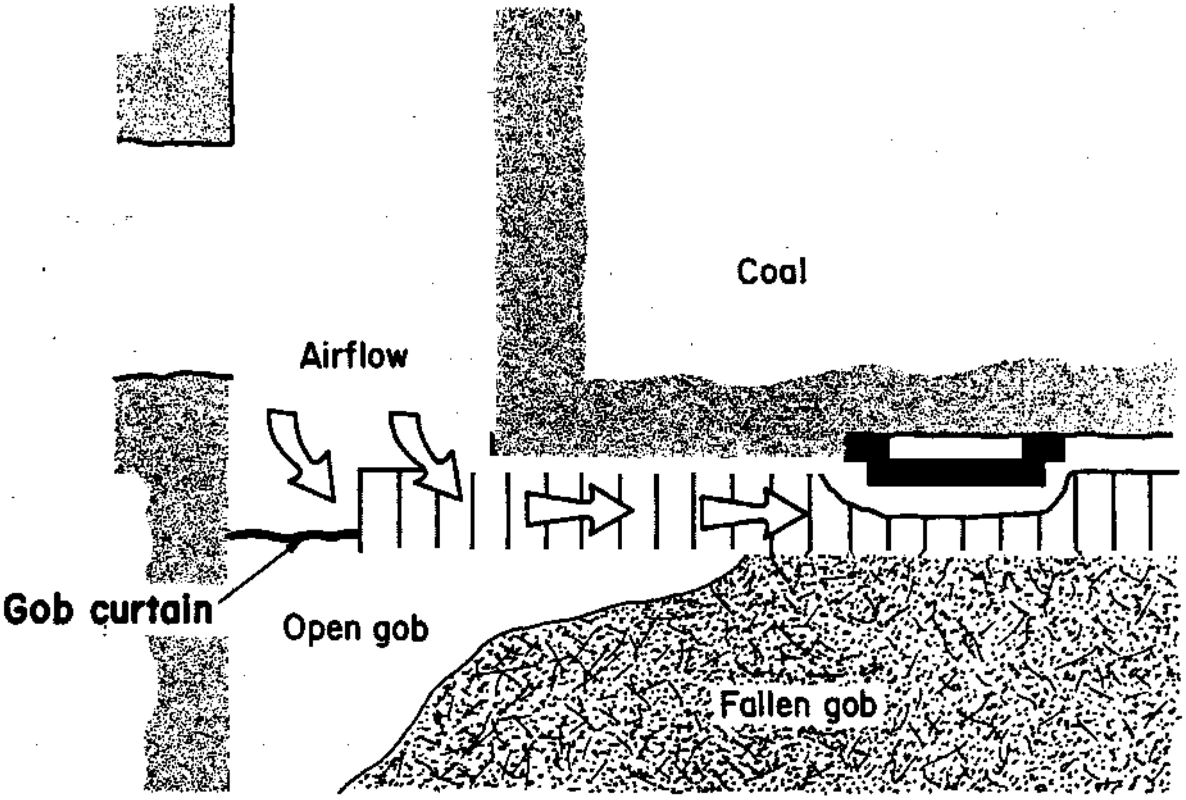


FIGURE 11. - Curtain, used to minimize air leakage into the longwall gob area.

Improved Localized Ventilation Control

Uncontrolled loss and misapplication of face ventilation can significantly affect the respirable dust exposure of longwall face personnel. Examples include the amount of air which leaks into the gob or waste behind the longwall supports in the headgate, as well as how the airflow is directed over the shearer cutting drums when the shearer reaches the headgate. In figure 11 a simple gob curtain is used to direct the primary airflow across the longwall face, minimizing the amount of leakage into the gob. Figure 12 shows a gob curtain installed underground. Bureau studies have shown that gob curtains can improve average face airflow by over 30 pct, and can significantly increase airflow along the entire face (fig. 13). Almost all U.S. longwalls now use gob curtains to manage the primary airflow more effectively and reduce face workers respirable dust exposure.

Modified Cutting Sequence

Currently, over 50 pct of double-drum shearers in operation in the U.S. employ a uni-directional cutting sequence. Typically, the primary cut is taken in the same direction as the face ventilation. The primary source of the shearer operators' dust exposure is dust from the upwind drum which spreads out into the walkway, increasing respirable dust exposure of both operators (fig. 14-A). If the upwind drum is raised (fig. 14-B) and the trailing drum is used to cut the remaining bottom coal during the clean-up pass (modified uni-directional cutting), both operators can work on the intake (clean) air side of the primary dust generating source, significantly reducing their exposure to dust generated during cutting. While uni-directional cutting may affect overall productivity, it has been shown to be an effective tool in helping to maintain compliance with dust regulations.

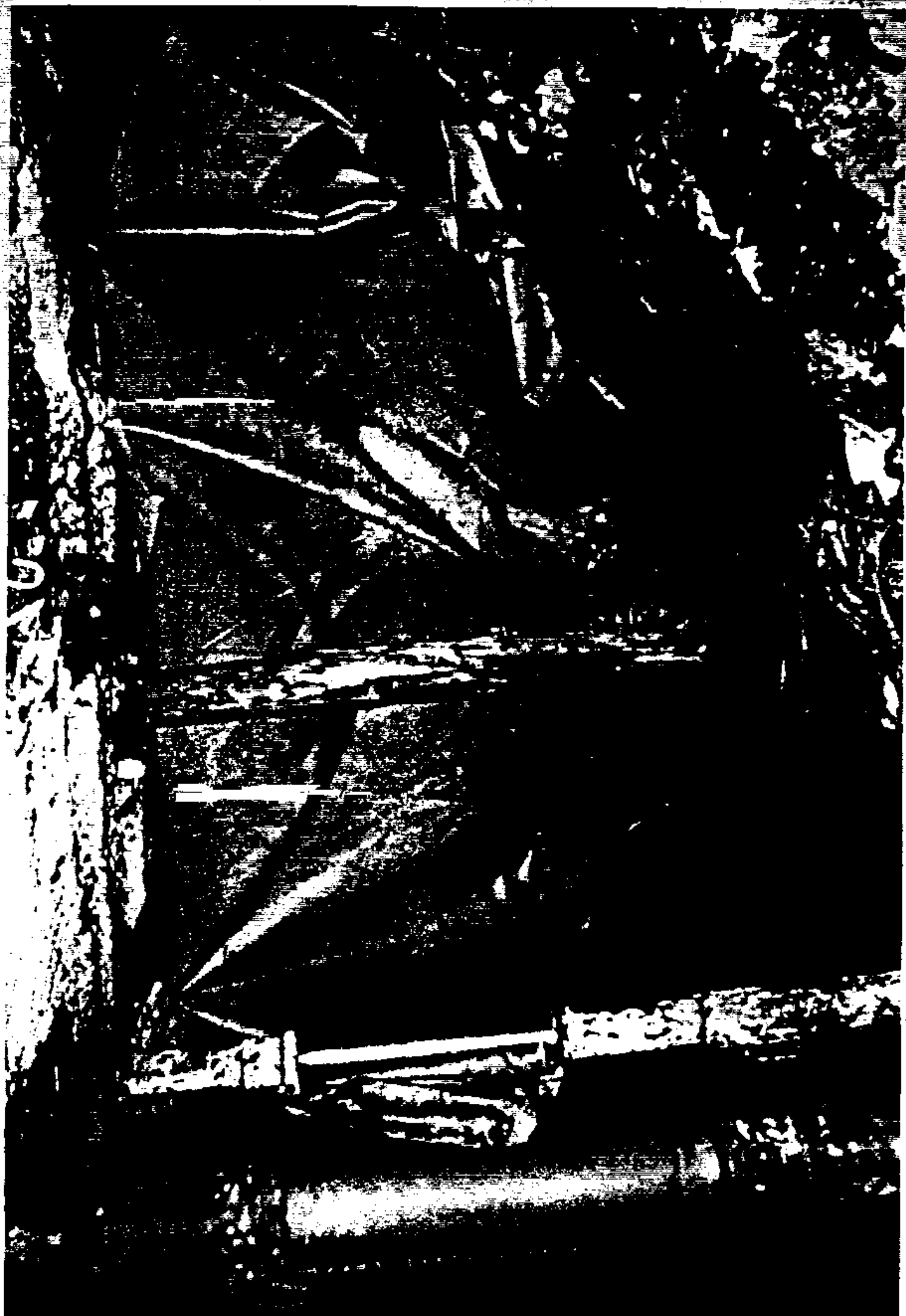


FIGURE 12. - Underground installation of longwall gob curtain.

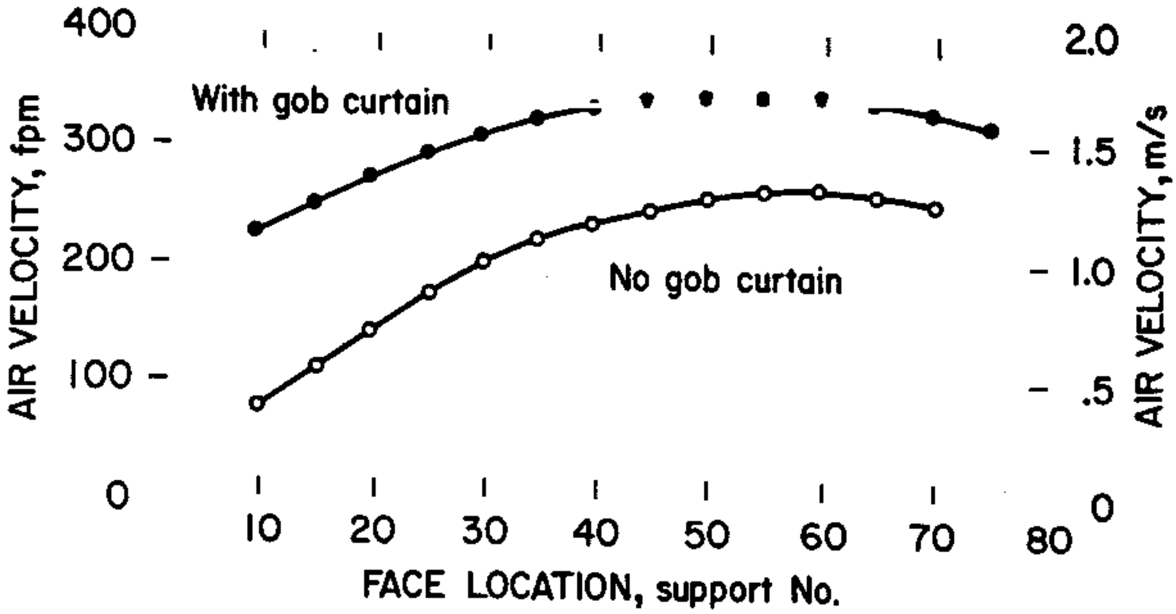


FIGURE 13. - Gob curtain can improve average longwall face airflow by over 30 pct.

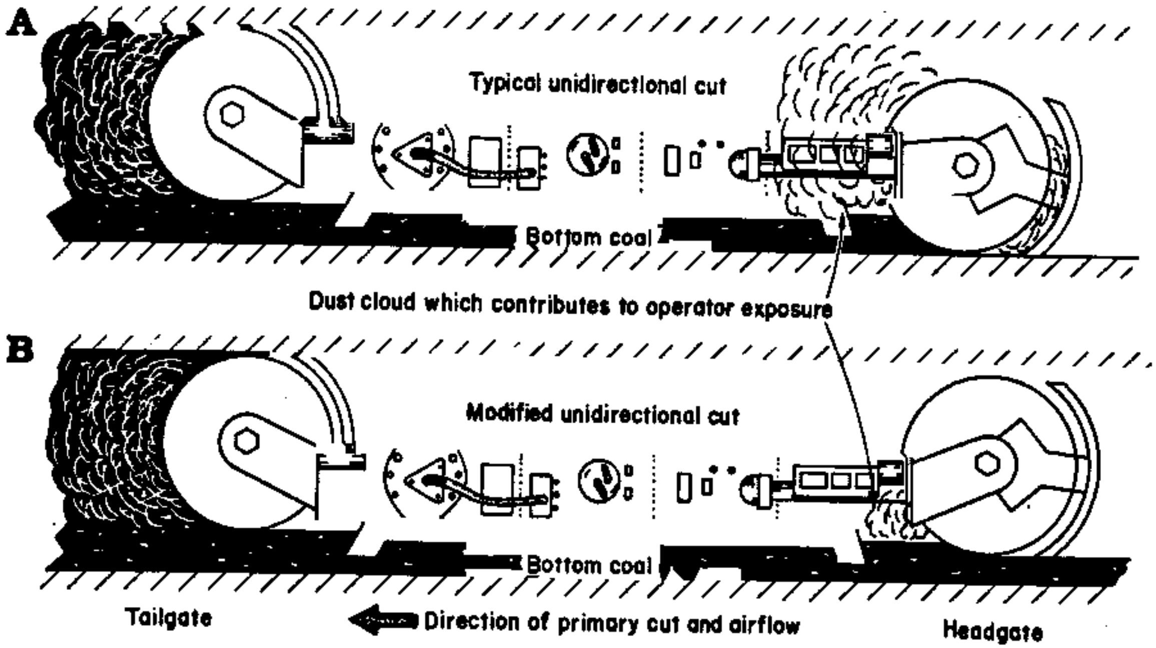


FIGURE 14. - "A": Typical uni-directional cutting sequence increases dust exposure of longwall shearer operators'; "B": Modified uni-directional cutting sequence can be used to reduce operators' exposure to dust generated by upwind drum.

Deep Cutting to Reduce Dust Generation

With deep cutting, larger fragments of coal are removed and fewer coal surfaces are exposed, resulting in a reduction of airborne dust. Extensive evaluation of deep cutting shearers has clearly shown that doubling the depth of the cut can reduce airborne dust levels by as much as 60 pct. While there are some limitations in terms of implementing this technique on existing shearers, with new equipment and/or appropriate modification this has proven to be an effective and well utilized means to promote dust compliance.

Control of Dust Generation During Coal Transport

Assuring a supply of clean intake air to the longwall face area is critical in minimizing face workers' dust exposure. On most longwall operations this is difficult to achieve because of dust generated by the coal crusher and at transfer points outby the face (located in the intake). The Bureau has demonstrated that by enclosing the stageloader/crusher unit and installing water sprays at strategic locations along the unit (fig. 15), the intake dust levels can be reduced by as much as 60 pct. Figure 16 shows an actual underground installation of a system for controlling dust generated during coal transport.

Accomplishments - 1976-1983, Longwall Dust Control

Respirable dust levels on longwall faces in 1976 averaged approximately 6.8 mg/m^3. Through combined efforts of the Bureau, industry, and inspectorates, the average dust level in 1983 was reduced to approximately 2.0 mg/m^3. Compliance levels have risen from 30 pct in 1976, to 85 pct in 1986 (fig. 17). However, increasing productivity on longwall faces continues to make compliance a difficult problem; work is currently underway to identify future research needs in this area.

FIGURE 15. - Enclosed stageloader/crusher reduces intake-air dust contamination.

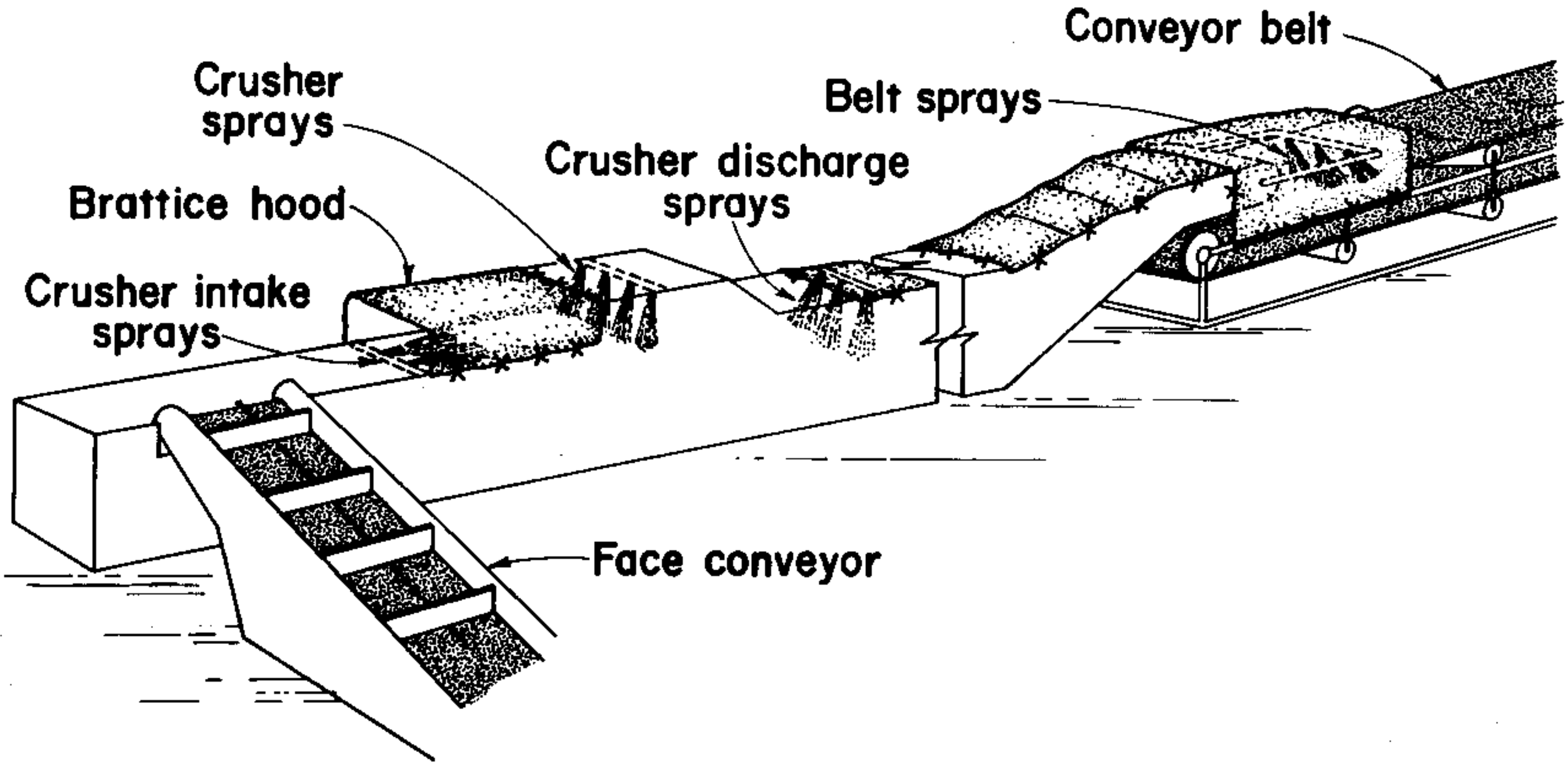


FIGURE 16. - Underground installation of an enclosed stageloader/crusher.

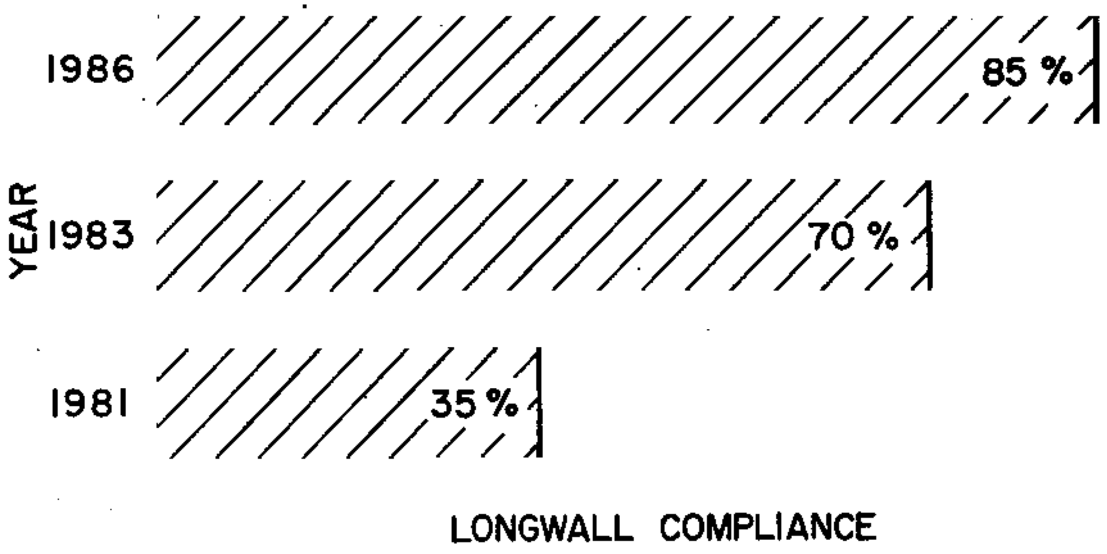


FIGURE 17. - Dust compliance levels of longwall mining sections, 1976 to 1983.

MORE STRINGENT RESPIRABLE DUST STANDARDS

The third major thrust in the Bureau's respirable dust program pertains to quartz dust control. Whenever the quartz content of respirable dust exceeds 5 pct, regulations require the 2.0 mg/m^3 dust standard be reduced further. With sections being placed on more stringent dust standards (below 2.0 mg/m^3), approximately 35 pct of the industry is now affected (fig. 18). Two major sources of quartz dust from underground mining operations are the continuous miner, when cutting floor and roof rock or rock partings within the seam, and the roof bolting machine, while drilling the roof (fig. 19).

Half-Curtain Face Ventilation System

In sections with marginal intake air velocity, the half-curtain can be used to decrease the cross-sectional area of the mine entry, and hence, increase the intake velocity over the miner operator, helping to confine the dust to the face area. Figure 20 illustrates the basic concept, and figure 21 shows an actual installation in an operating mine. With a half-curtain, dust reductions at the continuous miner operator are on the order of 50 pct on mining sections where there is marginal intake air velocity.

Modified Cutting Sequence Reduces Quartz Dust Generation

One primary source of quartz dust is the continuous mining machine when cutting roof rock. A modified cutting sequence has been successfully implemented, the top coal/rock is undercut (fig. 22), and then the coal/rock material near the roof is cut to a free face. This sequence, which generates less dust, also helps to confine the dust cloud under the machine where it can be effectively suppressed by the water sprays before being released into the main airstream. The modified cutting sequence has been shown to eliminate

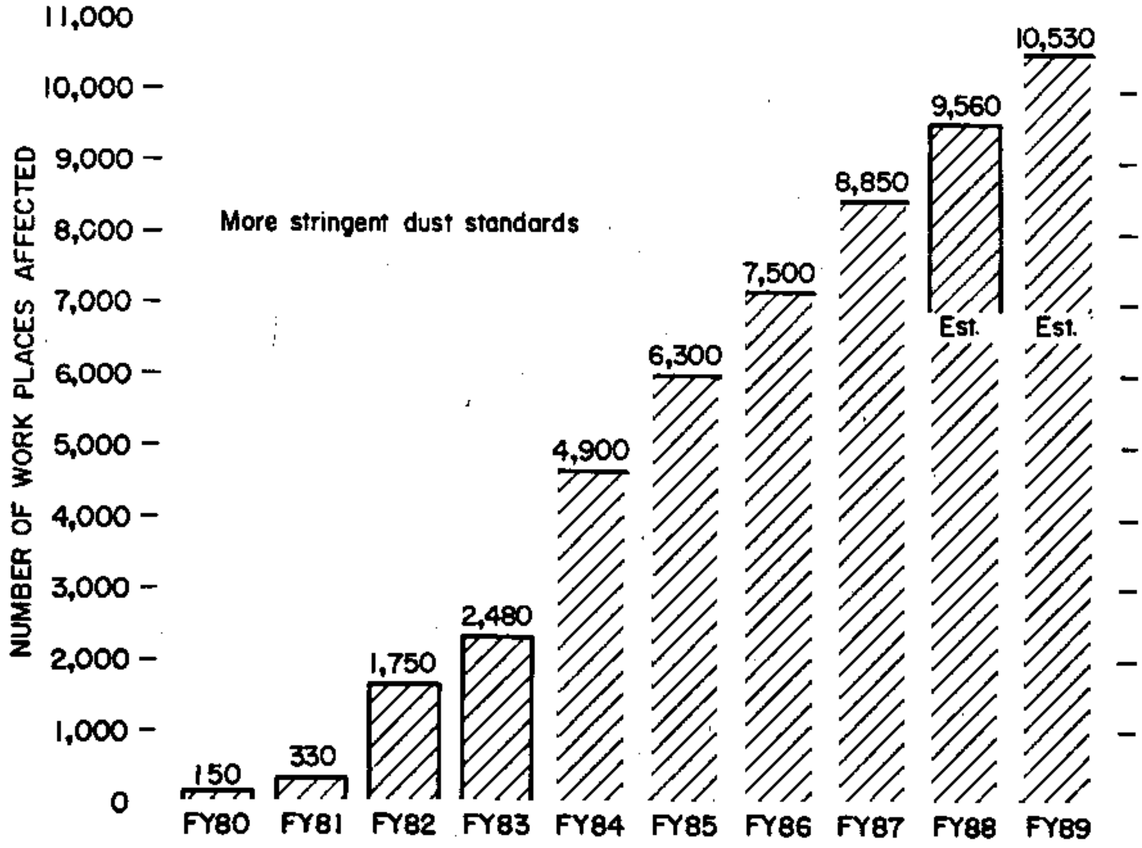


FIGURE 18. - Number of mining sections placed on more stringent dust standards (below 2.0 mg/m^3).

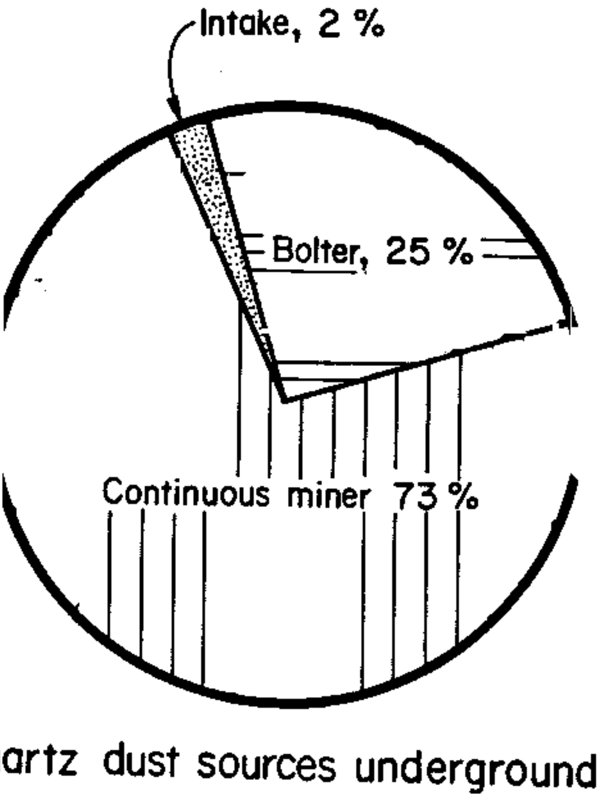


FIGURE 19. - Sources of quartz dust generation on underground mining operations.

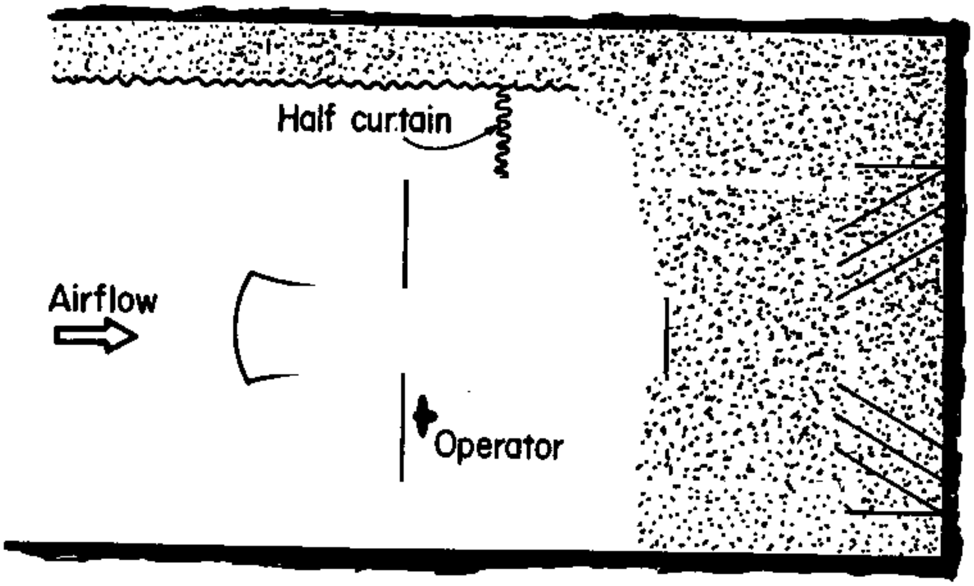


FIGURE 20. - Half-curtain face ventilation technique increases air velocity over the miner operator.

FIGURE 21. - Underground installation of half-curtain.

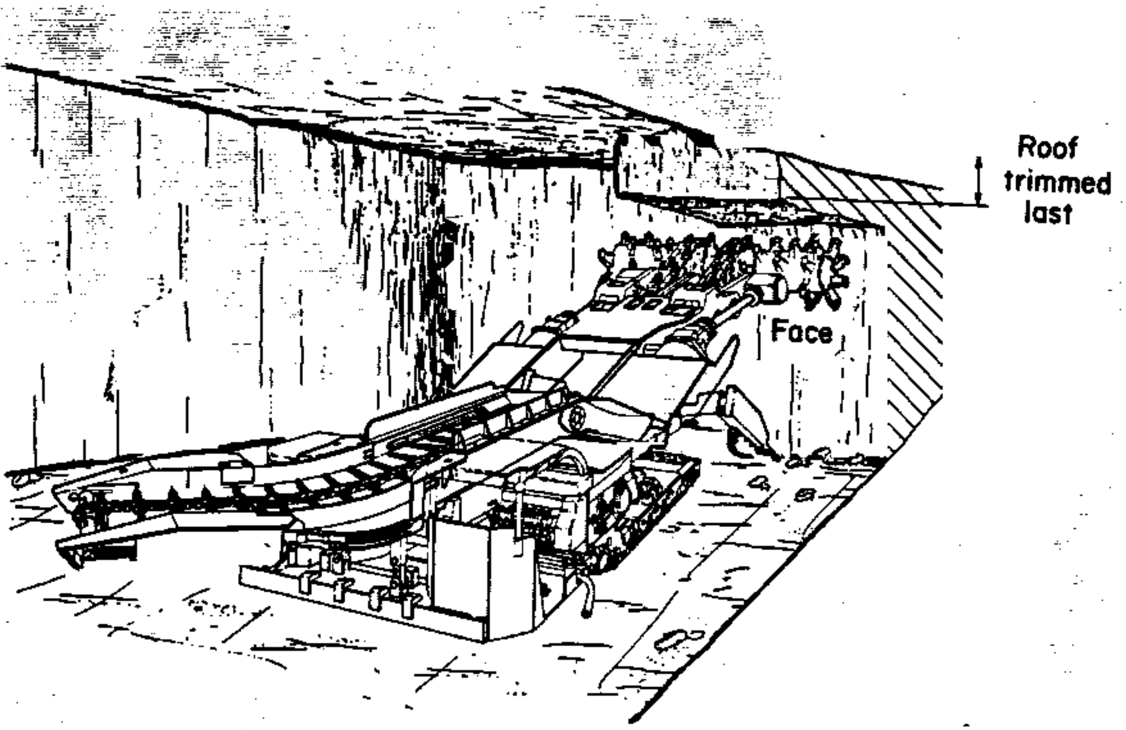


FIGURE 22. - Modified cutting sequence reduces quartz dust generation when cutting roof rock.

operator quartz dust exposure, while reducing quartz dust levels in the return by as much as 65 pct.

Water Sprays for Improved Ventilation Control

One primary factor affecting the miner operator's dust exposure is dust rollback from the face. It is usually caused by low primary airflow, and a poorly designed machine water spray system. Rollback is illustrated in figure 23, where the dots represent excessive dust levels. Water sprays are effective air movers; depending on the specific circumstances, that movement of dust-laden air by water sprays may be advantageous or deleterious. Water sprays which travel a long distance before impacting a solid surface of the machine are effective air movers; the water sprays that only travel a short distance before impacting the cutterhead or another part of the machine are more effective in suppressing dust, and do not exhibit the air movement features of the other spray positions (fig. 24). When the sprays do move the dust-laden air, it tends to rollback toward the continuous miner operator.

Marginal air velocity from the principal air system will cause the localized air movement induced by the water sprays to overpower the primary ventilation system. The Bureau's anti-rollback system and guidelines for its installation have been effective in reducing machine operator dust exposure by as much as 40 pct (fig. 25).

Control of Quartz Dust During Roof Bolting

The second major source of quartz is the roof bolting machine, when drilling into roof rock. The Bureau has evaluated various bit types available to the industry and found a 5:1 difference in the amount of airborne dust generated by different types (fig. 26). Based on Bureau studies, most manufacturers and operators have now adopted the dust hog bit design.

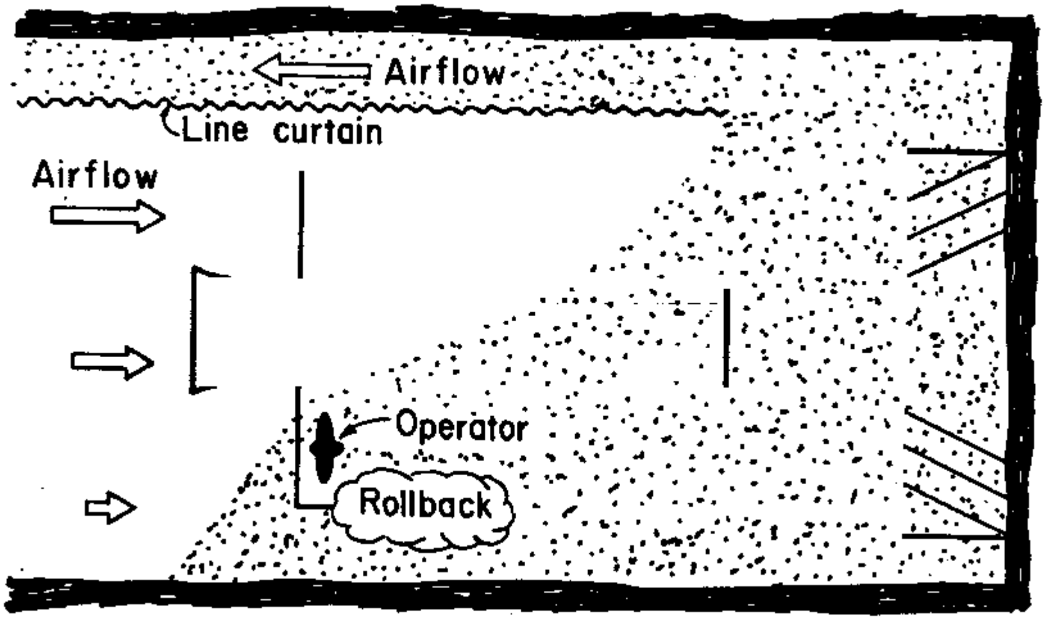


FIGURE 23. - Water sprays can cause dust to rollback to the machine operator's work location.

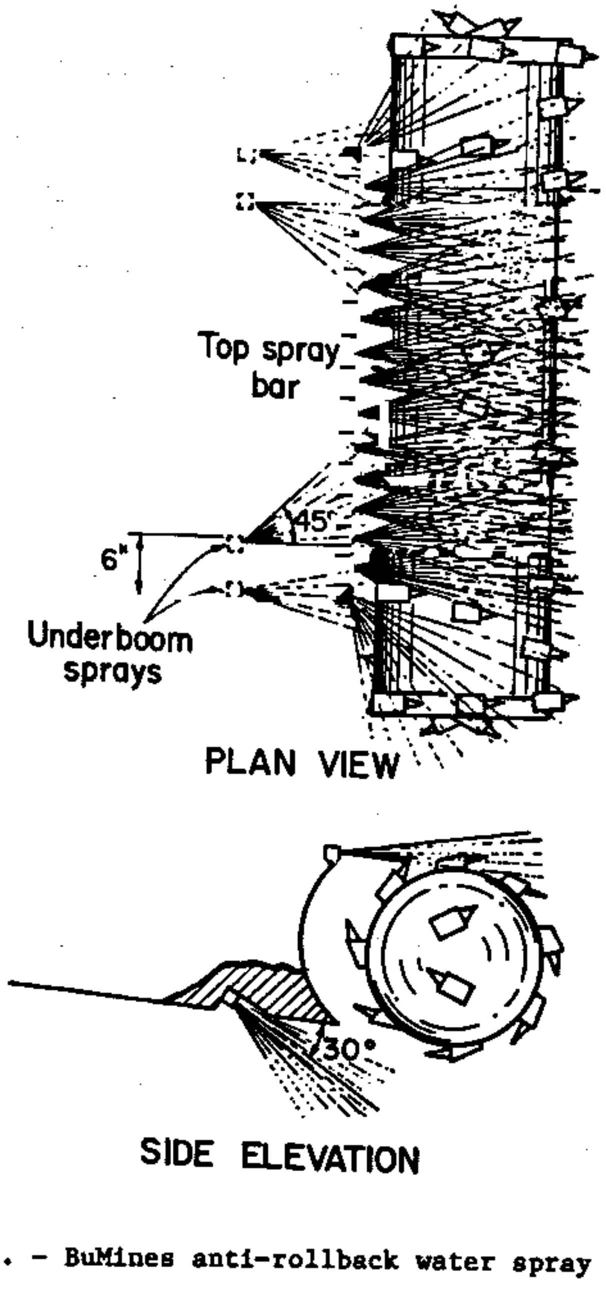


FIGURE 24. - BuMines anti-rollback water spray system.

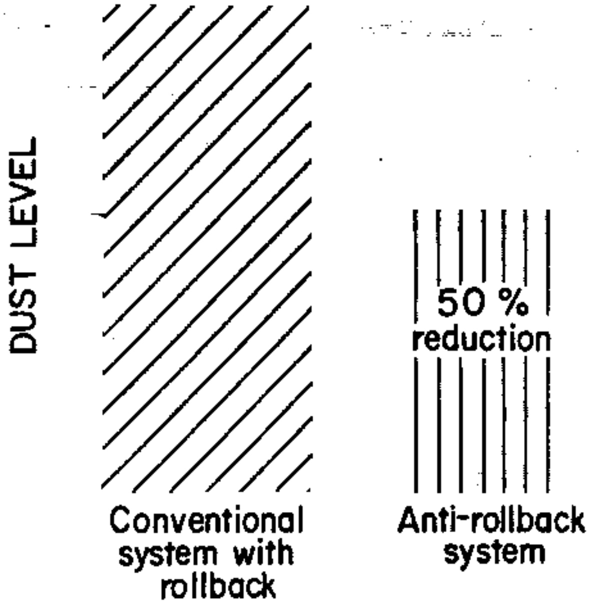


FIGURE 25. - BuMines anti-rollback spray system reduces machine operator's dust exposure by 40 pct when compared to conventional spray systems.

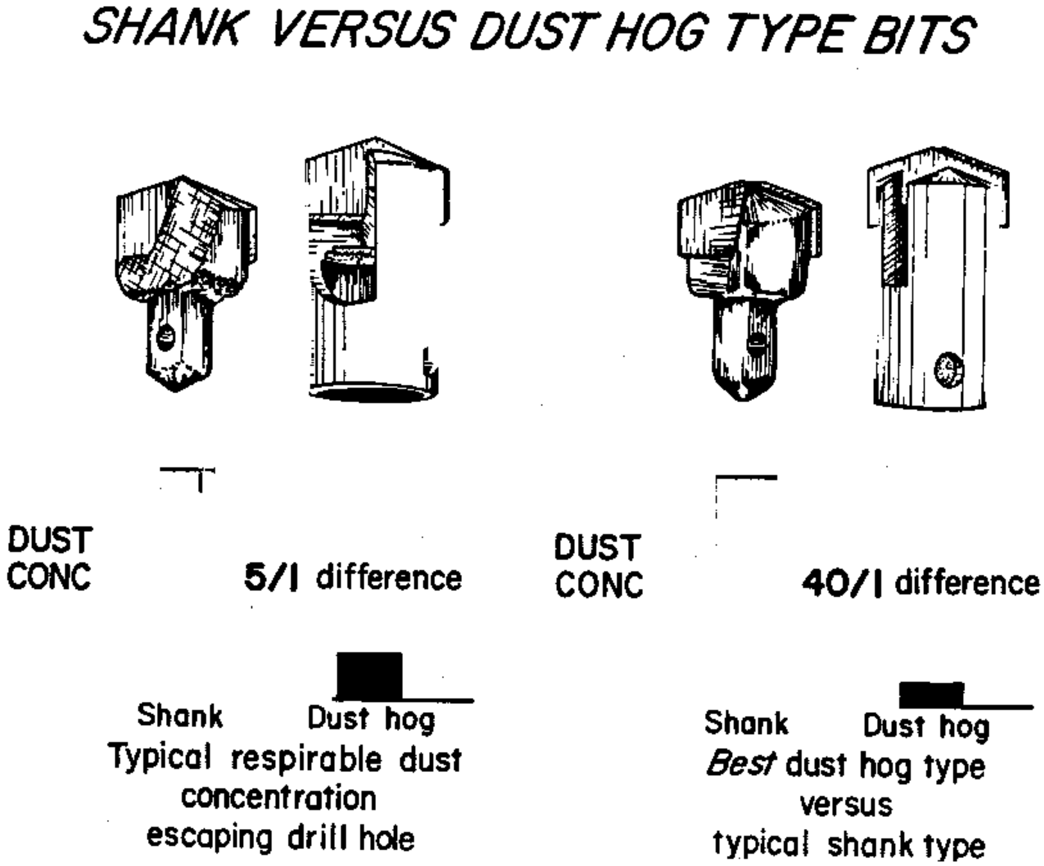


FIGURE 26. - Airborne dust levels generated by various roof bolt drill bit types.

Other Bureau studies have shown that maintenance, especially of the dust collector system, on roof bolters is critical for proper dust control. According to an independent study by the Mine Safety and Health Administration, 90 pct of the sections surveyed are in compliance after implementing the Bureau's recommendations.

Accomplishments - 1983-1987, More Stringent Dust Standards

Over 35 pct of underground mining operations are currently under more stringent (below 2.0 mg/m^3) dust standards. Whereas in 1983, less than 20 pct were able to maintain compliance with these reduced standards, today over 50 pct of sections are able to operate at these reduced dust levels. Through Bureau research and industry implementation, quartz dust generation during roof bolting has been almost eliminated. A fundamental, as well as practical, understanding of quartz dust generation and behavior has been achieved. With continued efforts by the Bureau, industry, and Federal enforcement agents, further improvements in this area are expected.

ONGOING RESEARCH - FY88

Expert Systems

While progress has been made in dealing with the more stringent dust standards, additional work, now underway, offers significant promise of further improvements. The Bureau has developed expert systems for both continuous mining and longwall. These systems provide guidance to the mine operator in all areas of respirable dust control from water sprays and machine design to ventilation concepts. They are operated on the desktop computers, now found in most mining companies. Preliminary field evaluation has been most encouraging, and further expansion and utilization of this technology is anticipated. This will enhance the accuracy and rapidity of Bureau technology transfer.

Scrubbers for Improved Quartz Dust Control

Although 90 pct effective for removing respirable coal dust, the conventional flooded-bed scrubbers, described earlier, are less than 50 pct effective in removing quartz dust particles which are typically 1/10 the diameter of respirable dust particles. This means that the quartz dust collection efficiency of flooded-bed scrubbers is unacceptable. The Bureau is investigating methods to correct this. Preliminary studies indicate that doubling the collection bed density can increase the quartz collection efficiency from 50 pct to 80 pct. The Bureau has also identified and tested a high-pressure water-powered scrubber (fig. 27) for continuous mining machines. Initial results indicate that the system is capable of improving quartz dust removal by approximately 40 pct, compared to flooded-bed units. Additional field evaluation is underway.

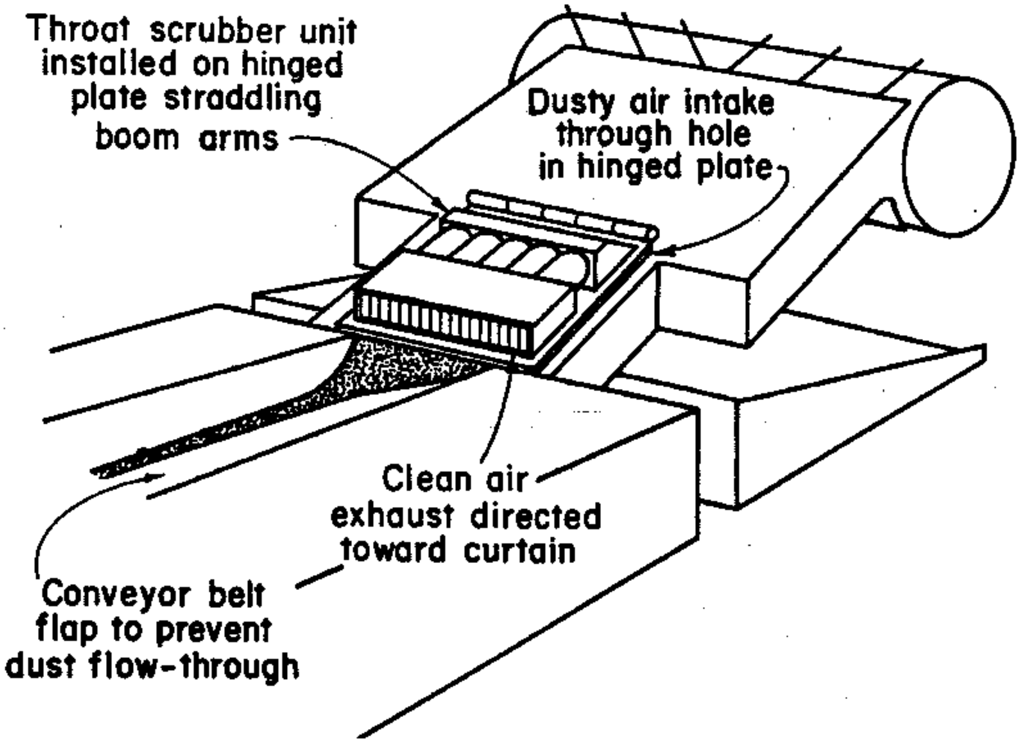


FIGURE 27. - High-pressure water-powered scrubber for continuous mining machines.

Proper Miner Bit Selection

Newer studies have resulted in guidelines for the selection of continuous miner bit types to reduce quartz generation. These studies have shown that slender profile bits with large tungsten-carbide tips generate the least amount of respirable quartz dust (fig. 28). Mining companies and equipment manufactures are now making this transition.

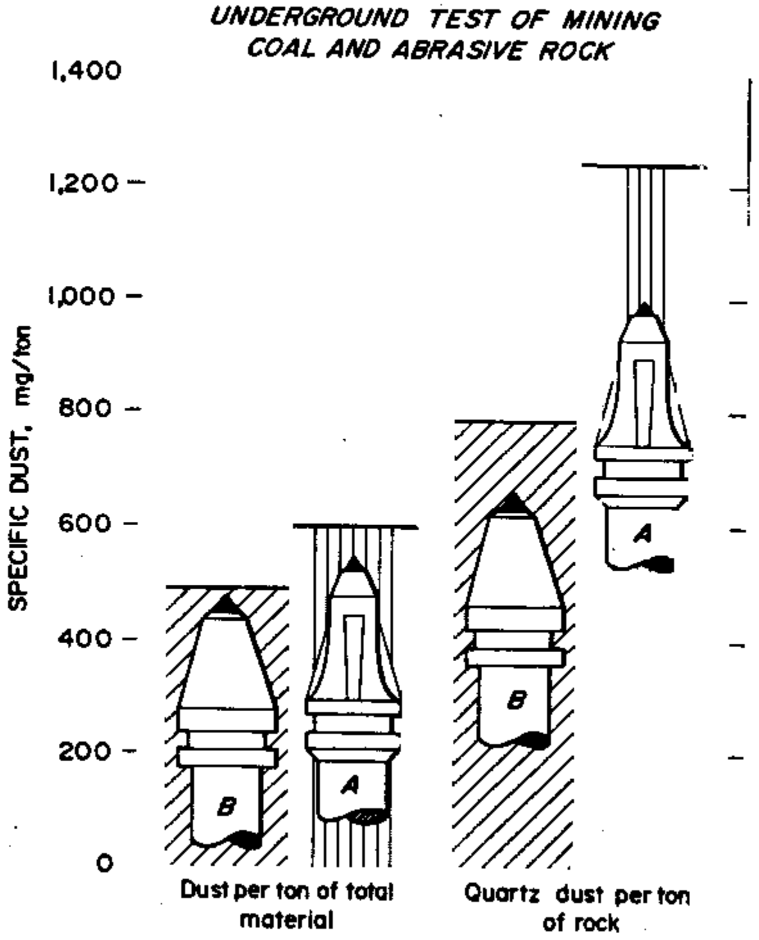


FIGURE 28. - Comparison of dust levels generated by various continuous miner bit types.

Localized Ventilation Control

The Bureau is investigating a novel air curtain system (Coanda air tubes) for confining the dust laden air to the face, and preventing dust rollback. This concept has been used in other industrial applications, and preliminary studies show promise for its use on continuous miners (fig. 29).

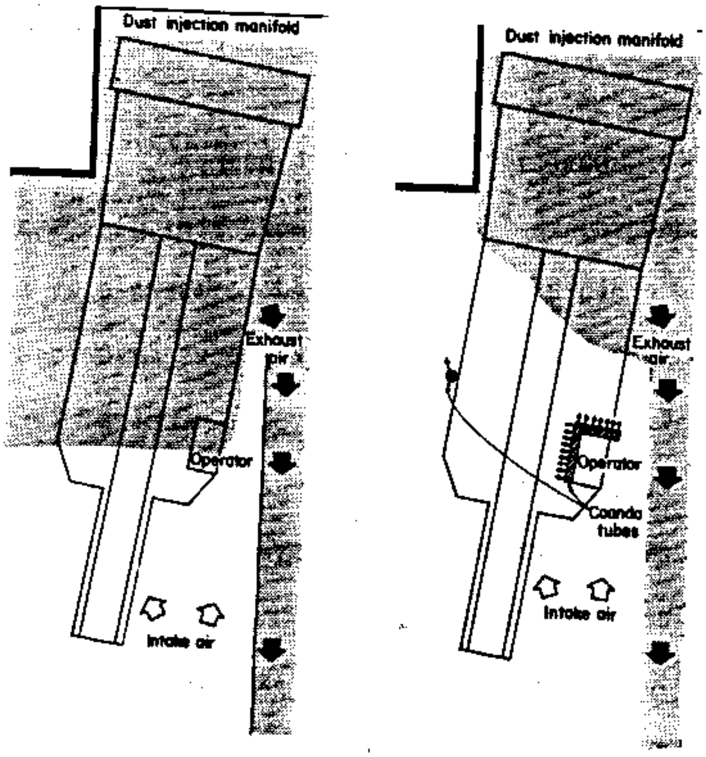


FIGURE 29. - Coanda air curtain prevents dust rollback.

Control of Diesel Particulate

Bureau studies have identified the nature and character of airborne particulate generated by diesel engines. As shown in figure 30, there is a significant difference in the size of respirable coal dust and that of diesel exhaust particulate. On-going Bureau studies are addressing means to more exactly characterize the chemical nature of these particulates and to keep them from becoming airborne.

CONTINUING/FUTURE PROBLEM AREAS

The problem of more stringent dust standards will continue to grow, as illustrated in figure 31. The formula for determining reduced standards is as follows:

$$\text{Dust standard} = 10/\%\ \text{quartz}$$

Based on this standard, the formula for more stringent standards has resulted in many mine operators being required to operate at or below 0.8 mg/m^3. To date, approximately 8,850 work places have been placed on more stringent dust standards due to quartz (fig. 31). Control techniques must be improved if mandated levels are to be met.

As longwall production increases, dust levels will also increase (fig. 32). Average longwall production today is 1,900 tps, with an average dust level of 2 mg/m^3; the 6 top U.S. longwalls produce an average of 4,200 tps, with an average dust level of 3.8 mg/m^3. However, much of the current successful compliance with respirable dust has been accompanied by a significant reduction in productivity of U.S. mining sections. In light of the industry trend toward longwall mining, if no new control technology is available, the Federal dust standard will act as a constraint on future output per hour. This is especially pertinent to longwall mining where the average

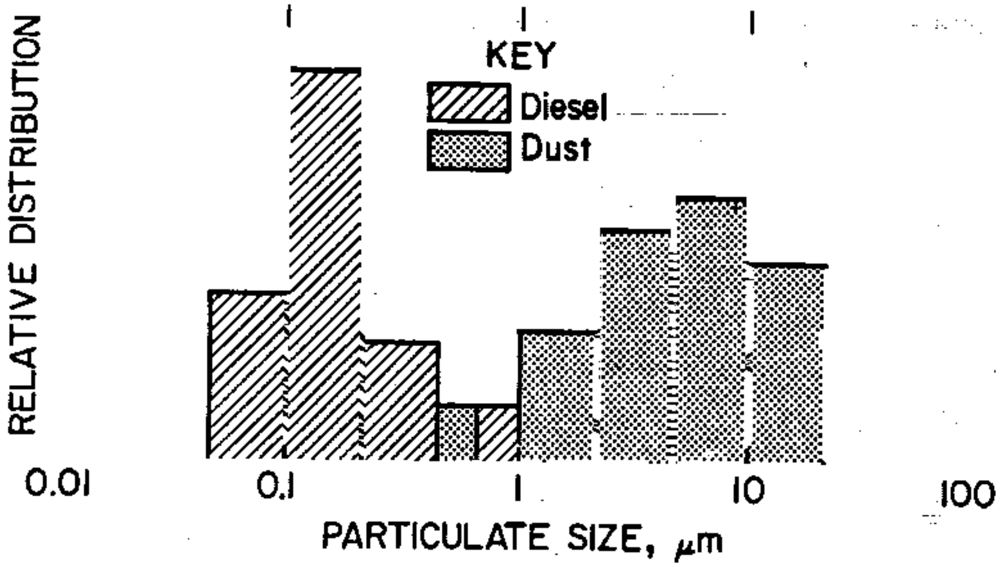


FIGURE 30. - Size distribution of respirable coal mine dust and diesel particulate.

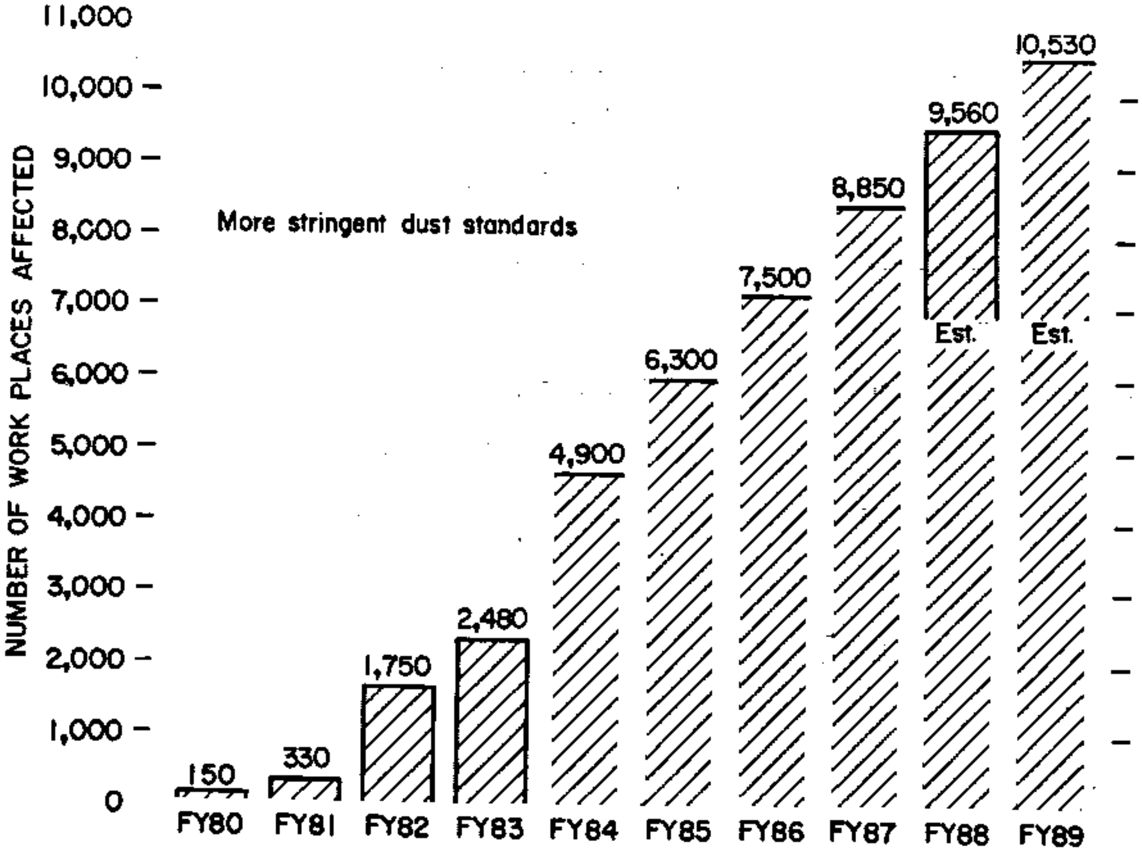


FIGURE 31. - Work places operating under more stringent dust standards, 1981 to 1983.

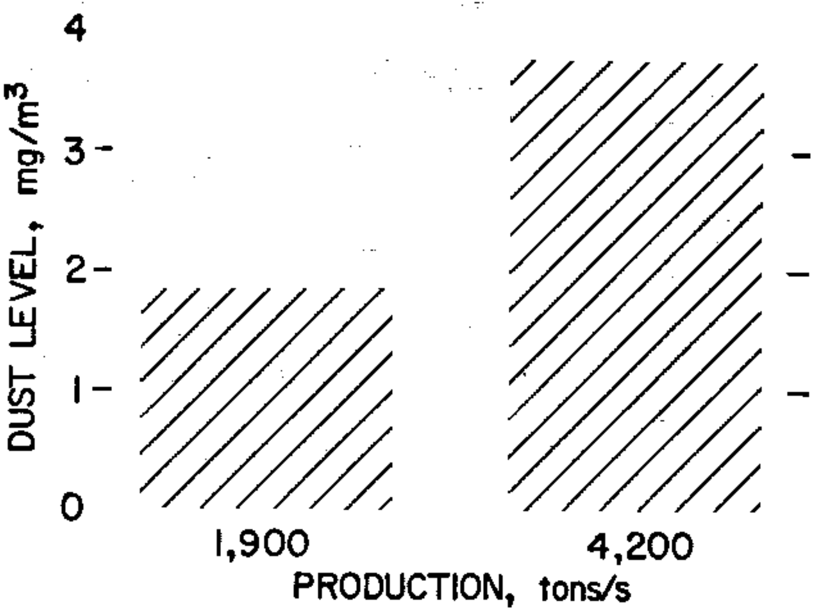


FIGURE 32. - Projection of worker dust exposure versus longwall production levels.

dust level is already 2.0 mg/m^3. The revenue loss in 1985, of altering longwall mining techniques to meet the dust standard, is estimated at approximately $200 million. Although it is imperative that industry meet the required dust standards, the United States must also remain competitive on the international energy market.

The Bureau has recently completed a survey of 18 coal preparation plants; 50 pct of these operate at dust levels which exceed 2.0 mg/m^3. Initial studies have identified viable control measures, some of which have already been implemented; additional work will be directed toward this area.

The 2.0 mg standard for respirable dust is for dust particles which are below 10 µm in diameter. Recent studies by the National Institute of Occupational Safety and Health (NIOSH) have shown that dust in the size range between 10 and 25 µm can cause obstructive airway disease. The Bureau is currently undertaking a study to determine the extent of exposure to dust in this size range from various mining operations. Based on preliminary analysis, the number of workmen compensation cases for obstructive airway disease has significantly increased in the past years, and may be an indication of the extent of this particular problem.

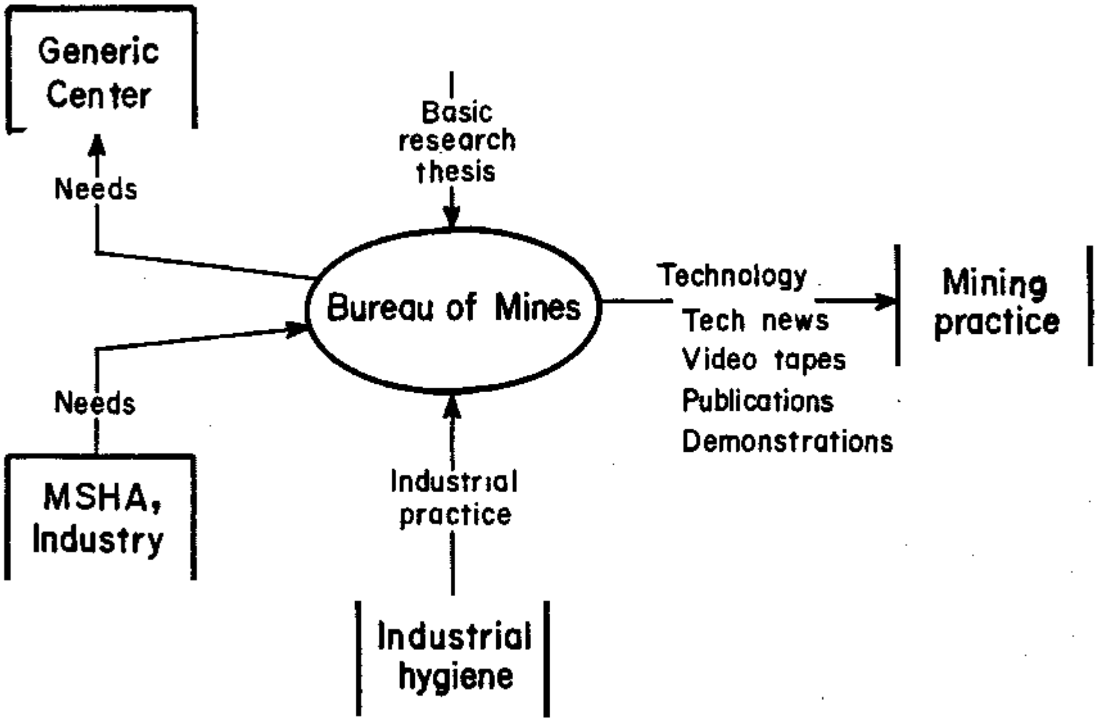


FIGURE 33. - BuMines Respirable Dust Research structure.

2

Generic Mineral Technology Center on Respirable Dust

GENERIC MINERAL TECHNOLOGY CENTER ON RESPIRABLE DUST:

AN INTRODUCTION

The Generic Mineral Technology Center on Respirable Dust was established in August 1983, at the request of the Bureau of Mines, to conduct research that affords "...each miner the opportunity to work underground during the period of (his/her) adult working life without incurring any disability from pneumoconiosis or any other occupational disease". The Center consists of the Mining and Mineral Resources Research Institutes (MRI) of The Pennsylvania State University (PSU) and West Virginia University (WVU) in association with the MRIs of the Massachusetts Institute of Technology (MIT) and the University of Minnesota (UMN). (FIGURE 34) Michigan Technological University (MTU) is also affiliated with the Center in the area of diesel particulates.

The Center brings together experts concerned with particles causing potentially disabling or fatal diseases including pneumoconiosis ("black-lung"), silicosis, and asbestosis. The latter is of deep concern not just to workers in the mineral sector of the economy but also to the general populace. The primary goal of the Center is to reduce the incidence and severity of respirable dust disease through advancing fundamental understanding of all aspects of respirable dust associated with mining and milling, and the interaction of dust and lungs. The research program of the Generic Mineral Technology Center explores these scientific, engineering or medical concerns with the objective of refining existing strategies and developing new respirable dust control techniques and technology that are consistent with the fundamental dust-lung interaction processes that lead to mine worker disability. The work concentrates on five areas (FIGURE 35):

1) Interaction of dust and lungs.
2) Characterization of dust particles.
3) The relationship of the mine environment, geology, and seam characteristics to dust generation and mobility.
4) Dilution, dispersion and collection of dust in mine airways.
5) Control of dust generation.

The fundamental aspects of this work are applicable to the control of respirable dust problems in both hard rock mines and coal mines, and to other dusts such as those generated by diesel equipment. The Center's interdisciplinary activities involve the training of engineers and scientists, graduate students, and undergraduate students through their respective institutions and technology transfer to the industry (FIGURE 36). The research in the Center is fully compatible and complimentary to the existing and ongoing U.S. Bureau of Mines' activities and is integrated into the Bureau's research on dust generation, transport and suppression. Additionally, the expertise and facilities of the National Institute on Safety and Health (NIOSH), Division of Respirable Disease Studies are available as a result of the existing relationship between NIOSH and West Virginia University. The Dust Center also serves as the reference center for publications in the area of respirable dust.

Three coal samples (anthracite, medium-volatile bituminous, high-volatile bituminous) having widely varying characteristics, plus silica, fireclay, and limestone rock dust have been selected to provide the unique common thread of a suite of characterized dust samples for

The Respirable Dust Center

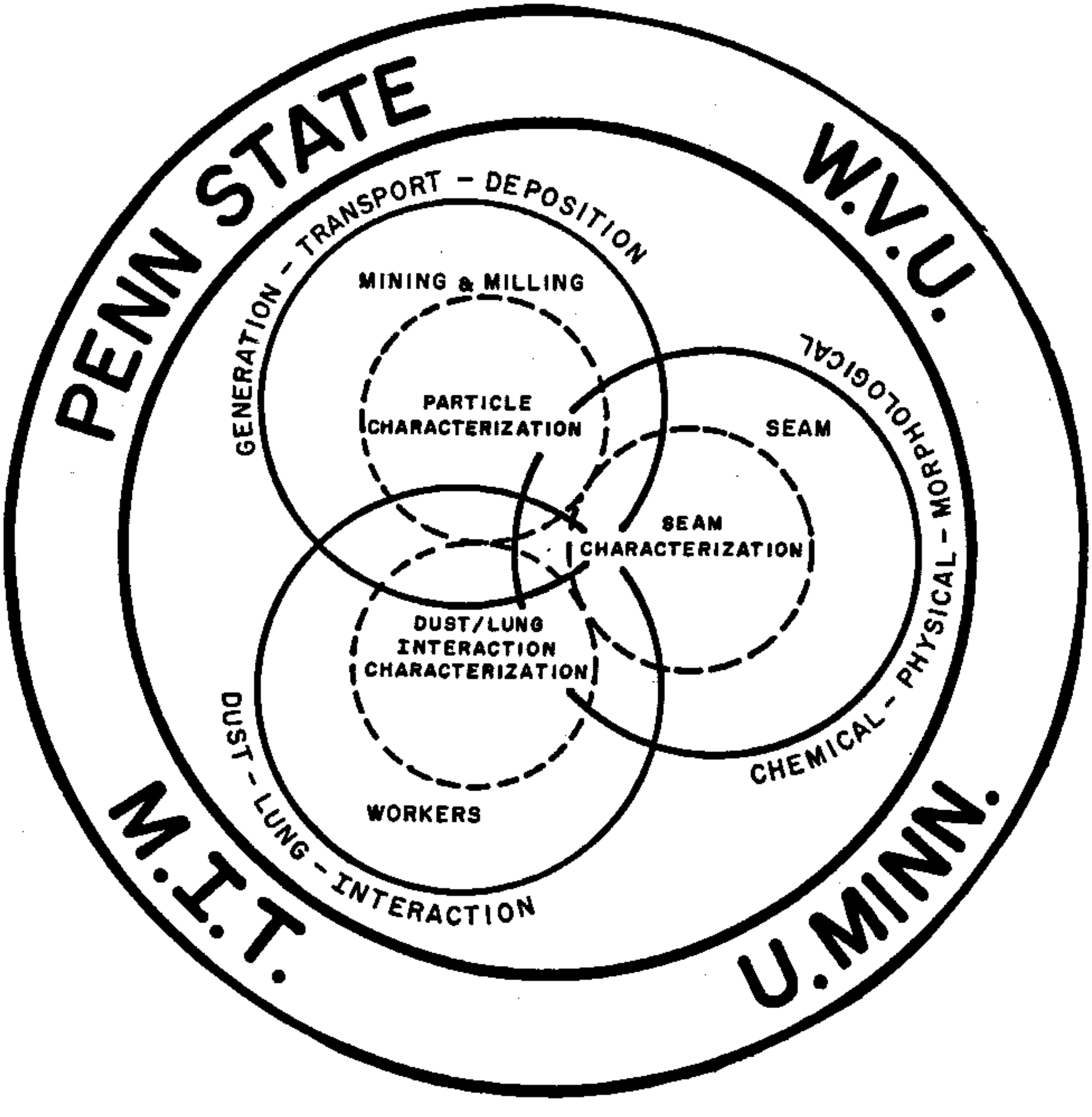


FIGURE 34. - The Respirable Dust Center.

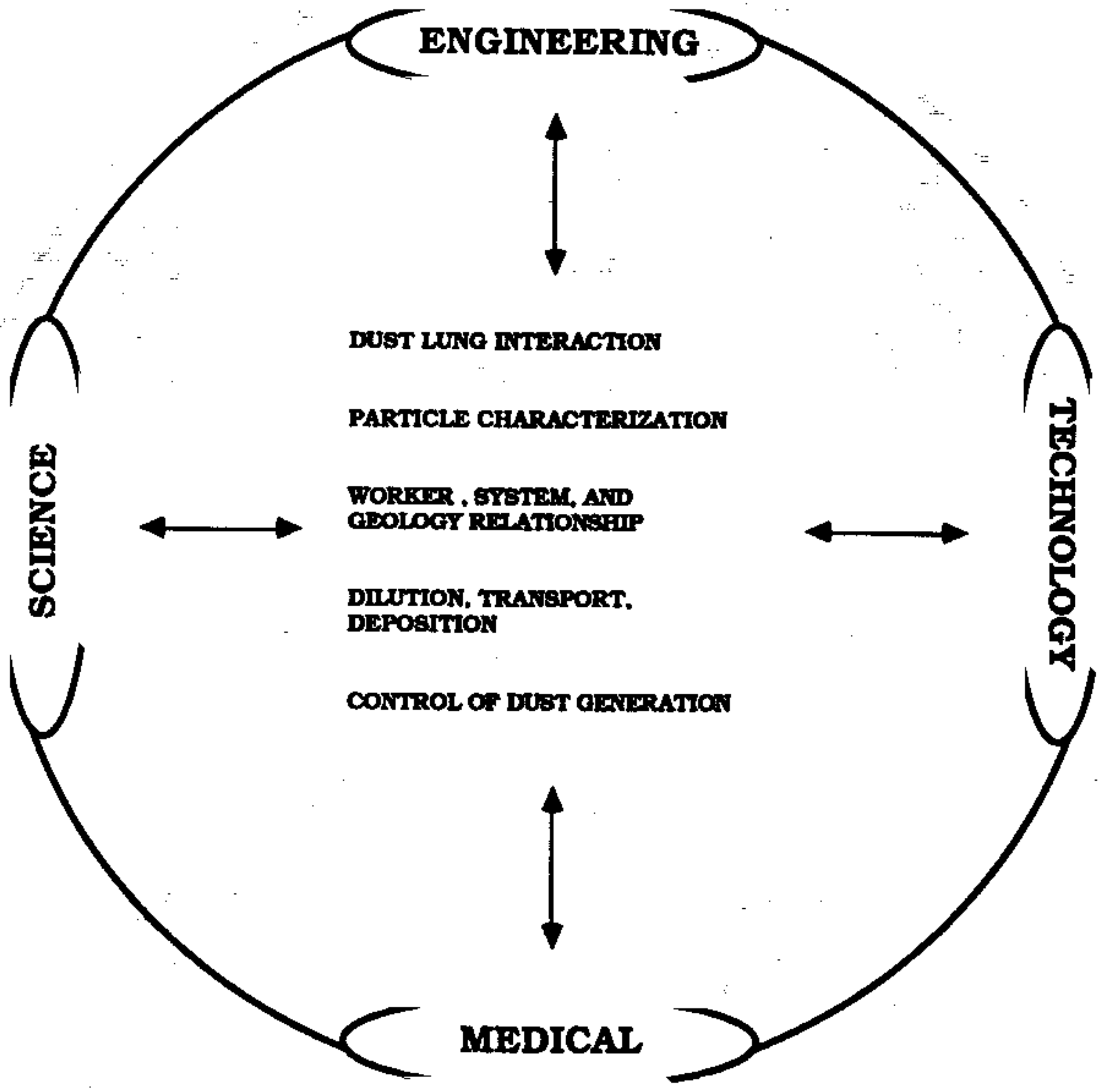


FIGURE 35. - Standardized protocols for Respirable Dust Research in scientific, engineering, and medical areas.

investigation by other center researchers. In their search to reduce the amount and severity of black lung , the center investigates fresh and stale dust particles, seam characterization, worker-mine system relationship and dust-lung interactions. For example, in the dust-lung research the suite of dust samples is being applied to a series of medical investigations involving cell injury, immunology, mucus generation and super oxide formation. Characterized dust studies are also being performed in live animal tests on small animals, dogs and non-human primate lungs. It is proposed to extend the results of animal tests to lavaged lung cells from healthy individuals, as well as black lung patients (FIGURE 37). Through the comprehensive research program of the Center, mechanisms and working conditions which influence the contraction of Black Lung disease have been investigated. Further experiments are being performed by the Center's expert team of nearly one hundred-thirty scientists, engineers, medical personnel and graduate students to identify dust phenomena interrelationships, define more precisely the knowledge base concerning the characteristics of respirable dust, and to extend the findings to non-human primates initially and ultimately to human subjects (FIGURE 38). More details of the various technical investigations of the Dust Center are presented in the following sections.

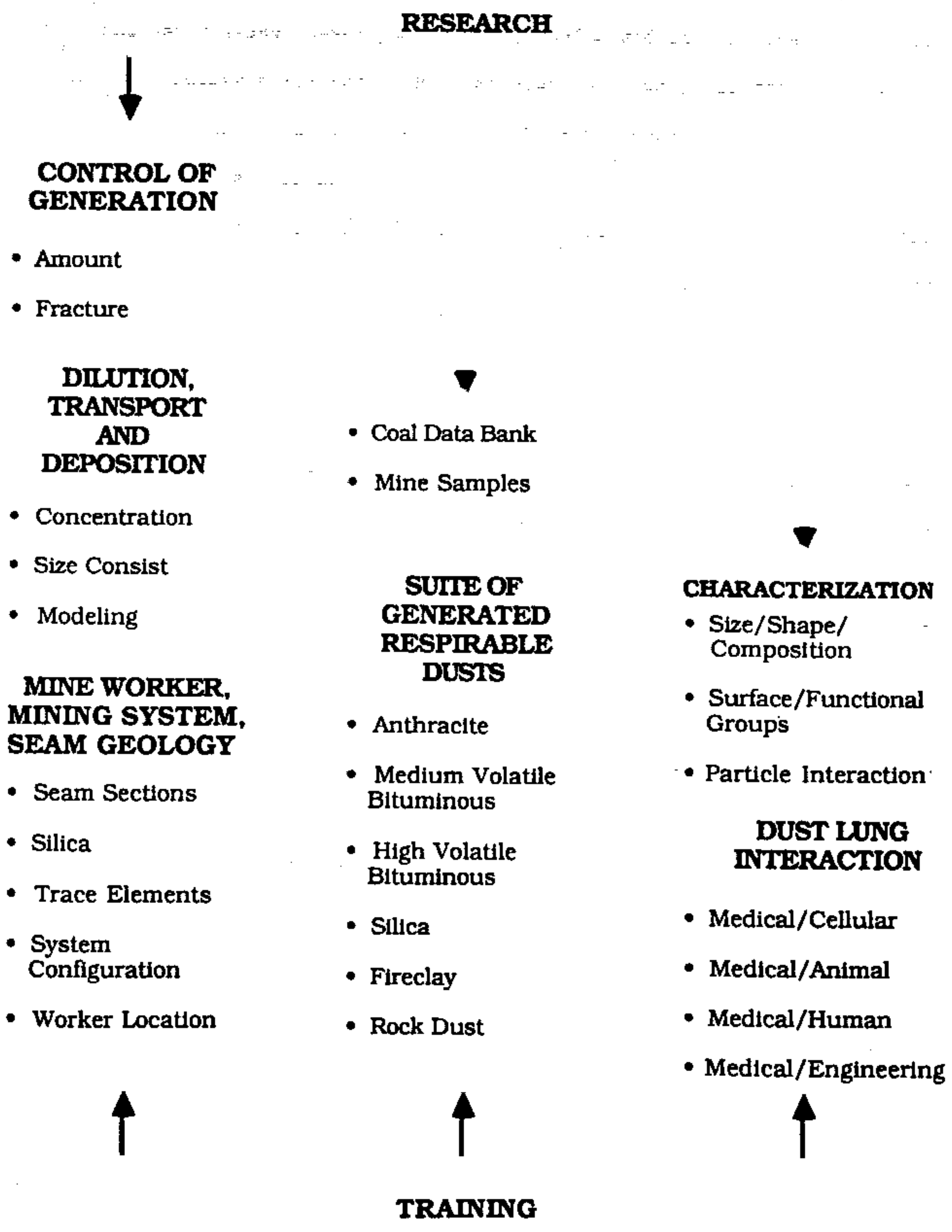


FIGURE 36. - Train engineers, scientists, medical personnel, graduate students and undergraduate students in the interdisciplinary aspects of respirable dust.

The Generic Mineral Technology Center for Respirable Dust

SUITE OF CHARACTERIZED DUST SAMPLES	SAMPLING AND DUST GENERATION METHODS	SUITE OF MEDICAL TESTS
1. Anthracite (Low Volatile)	Dust/Lung Interaction	1. Rats
2. Bituminous (Medium Volatile)	Particle Characterization	2. Guinea Pigs
3. Bituminous (High Volitile)	Mine Workers. Mining System Seam Geology Dust Relationship	3. Dogs
4. Fireclay	Respirable Dust Dilution. Transport and Deposition	4. Non-Human Primates
5. Silica	Control of Dust Generation	5. Black Lung Patients
6. Rockdust		6. Healthy People

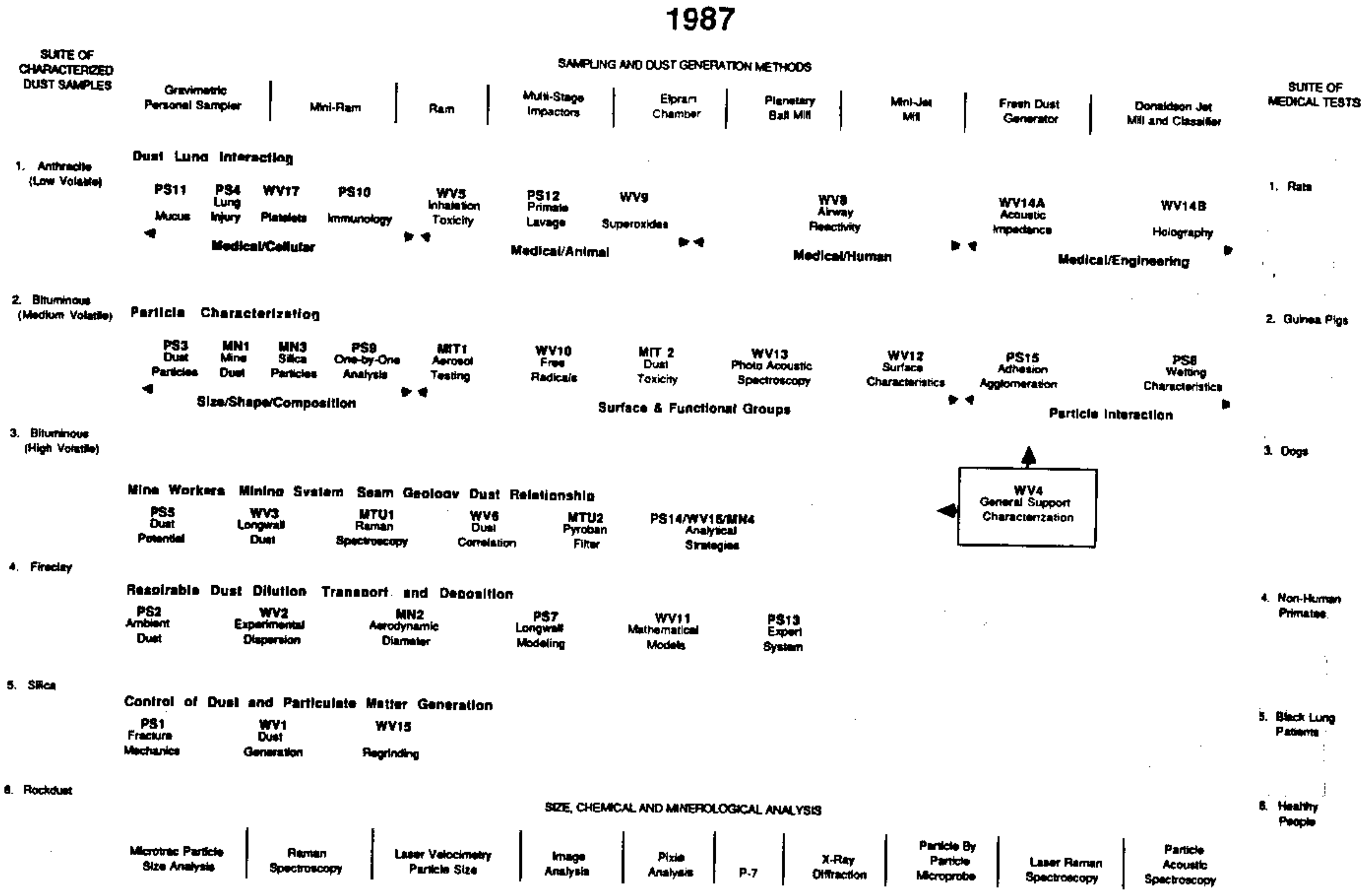
SIZE, CHEMICAL AND MINEROLOGICAL ANALYSIS

Statement of Goal

The primary goal of the Generic Mineral Technology Center for Respirable Dust is to reduce the incidence and severity of respirable dust disease through advancing the fundamental understanding of all aspects of respirable dust associated with mining and milling and the interaction of dust and lungs.

Figure 37. Indentifying mechanisms and conditions which influence respirable dust disease.

FIGURE 38. - The integration of scientific, engineering, and medical research findings into on-going projects.



3

Dust/Lung Interaction

Introduction

The dust/lung research of the Center has several long-range objectives:

- better methods for the early diagnosis of coal workers' pneumoconiosis (CWP);
- methods to modify the disease process;
- tests to identify toxic products; and
- tests to identify individuals with heightened susceptibility to pneumoconiosis.

A major immediate objective is to define the mechanism of dust-induced lung disease. This means determining:

- dust characteristics that are important in causing lung diseases;
- important interactions between dust and lungs; and
- earliest detectable stages of the disease.

Mechanisms

Several of the Center's projects involve exposing lung cells in culture (in vitro) or animal lungs (in vivo) to samples of the suite of characterized mineral dusts described earlier. The responses of the lung cells or tissues to the dusts are being studied in order to better understand how inhaled dusts cause lung disease.

One project is studying the effect of dust exposure on the production of mucus by rat tracheal explants in vitro. Mucus is a major factor in clearing inorganic dusts from the lung . Results thus far have shown that exposure of tracheal cultures to coal dust caused a decrease in micin production in comparison to parallel cultures without dust. To examine the effect of in vivo coal dust exposure, rats were maintained in an inhalation chamber for two weeks, and control rats were in an identical, but dust-free chamber. Tracheal explants results indicate that the effect of in vivo dust exposure is similar to that noted in the in vitro experiments.

Pulmonary alveolar macrophages (PAMs) are a key component of the lung's response to inhaled particulates, and they play several important roles in pulmonary inflammatory and repair processes. PAMs are the cells that actually ingest dust particles. Other studies have shown that they play a critical role in the development of silicosis and asbestosis. The Center is studying the effect of dust exposure on the release of oxygen free radicals (superoxide) by PAMs. Intercellular production of superoxide occurs when PAMs phagocytize particles, such as inhaled bacteria, and is an essential mechanism by which PAMs kill ingested bacteria. A number of complex physiological events occur during this process which are not clearly understood. It is thought that PAMs containing indigestible materials, such as mineral dusts, overproduce superoxide, or inappropriately release it into the surrounding tissues. If true, this would cause toxicity to surrounding lung cells by peroxidation of the lipids in the cell membranes. In vitro exposure of PAMs to low or high doses of kaolin is inert. Preliminary studies indicate that coating the quartz particles with a surfactant reduces toxicity.

PAMs that are responding to exogenous materials also release a variety of signal chemicals ("mediators") that affect the behavior of surrounding lung cells. One of the Center projects is studying the effects of dust exposure on the production by PAMs of one class of mediators, the arachadonic acid metabolites (such as prostaglandin E2 [PGE2], thromboxane [TXA] and leukotriene B4 [LTB4]). A consistent pattern response has been seen following in vitro exposure of PAMs of coal dusts, in the PGE2 production is suppressed, and production of TXA and LTB4 are enhanced. That pattern is generally "proinflammatory", meaning that the other components of the lung will respond as if there had been tissue injury or death. Preliminary studies of cells from rats exposed in vivo to dust aerosols have shown that the basic response pattern is similar to that after in vitro exposure. Two other classes of PAM mediators are the fibroblast growth factors and interleukin-1. Among other actions, these two mediators stimulate the accumulation of fibroblasts, the cells that produce collagen, the scar protein. Results during the first few years of the program, using guinea pig PAMs in vitro, indicated that there was no detectable release of either FGF or IL-1 during 24 hours of dust exposure. Those studies have not yet been replicated using freshly ground dusts. Facilities are being established to provide both "fresh" and "stale" dusts to each of the investigators studying dust-lung interactions. An inhalation facility has been established and is being used to expose experimental animals to dusts. The facilities consists of two Hazelton 2000 chambers. Both chambers receive air (15scfm) which has been filtered and conditioned to 70^{0}F and 50% relative humidity. Animals are selected at random and placed in either the control chamber, which receives only conditioned air, or the exposure chamber which receives coal mine dust in addition to conditioned air. Stale dust is aerosolized using a TSI 9310 fluidized bed aerosol generator while fresh dust is made and aerosolized in a Fluid Energy Processing and Equipment Model 0101-C6P Jet-O-Mizer mill.

The inhalation facility is used to test hypotheses as to the causative agents by alteration of the physical and chemical makeup of the dusts and the reacting cell types are determined by supplying exposed animals to a number of experimental groups who examine different cell types or pulmonary tissue and determine the changes brought about by inhalation of the dusts.

Exposed pulmonary tissues have been supplied to researchers in the Center performing related investigations. These tissues have been used to assess the function and morphology of pulmonary alveolar macrophages, for the determination of the effect on detoxification enzymes in the lung, and for biochemical determination of the extent of fibrosis.

Exposures have been made using stale silica dust and Bureau of Mines Pittsburgh seam (20/20) stale coal mine dusts. To date, examination of animals three months following the termination of exposure has shown that inhalation leads to changes in the makeup of the interstitial space and in the capillary blood space. The changes implicate certain cell types and chemical mediators as being important.

A nonhuman primate (monkey) animal model is being developed for studies of dust-lung interactions.(Figure 39) These animals are considered a useful experimental "bridge" between the small laboratory

FIGURE 39. - Bronchalveolar lavage with the fibroptic brochoscope using an anestethetized nonhuman primate.

rodent models [which can be used only once, and which may differ from humans in unknown ways] and humans [in which intentional exposures and controlled experiments are difficult or impossible]. Twenty monkeys (pigtail and bonnet varieties) are available for dust-research projects. Equipment and procedures have been standardized for bronchoscopy and alveolar lavage of PAMs from monkey lungs. Yields range from 12 to 35 million cells total recovery. Methods for mapping the bronchial tree of individual animals have been developed, making it possible to reproducibly position the bronchoscope into the same lung lobe at separate sessions several weeks apart.(Figure 40) The bronchoscope can also be used to instill particulate material into selected lung segments. Cells recovered from the monkeys are being studied in vitro for their production of arachadonic acid metabolites, FGF and IL-1, and the mucin in the lavage fluid is being characterized.(Figure 41 and 42) In the future, with further standardization of procedures and biological responses, these primates may be available, on a limited basis, as a central resource for other GTC investigators.

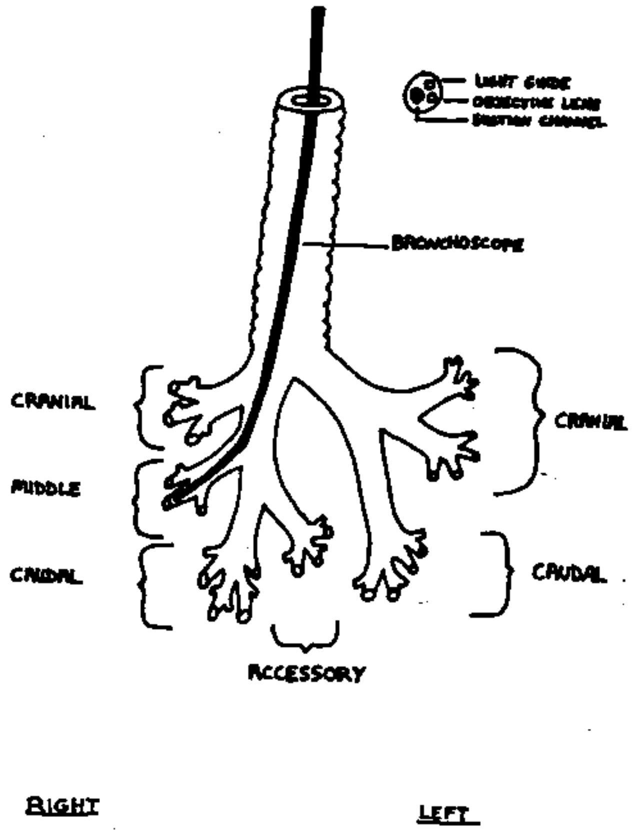


FIGURE 40. - Schematic of the location of bronchoscope following introduction into the bronchial tree.

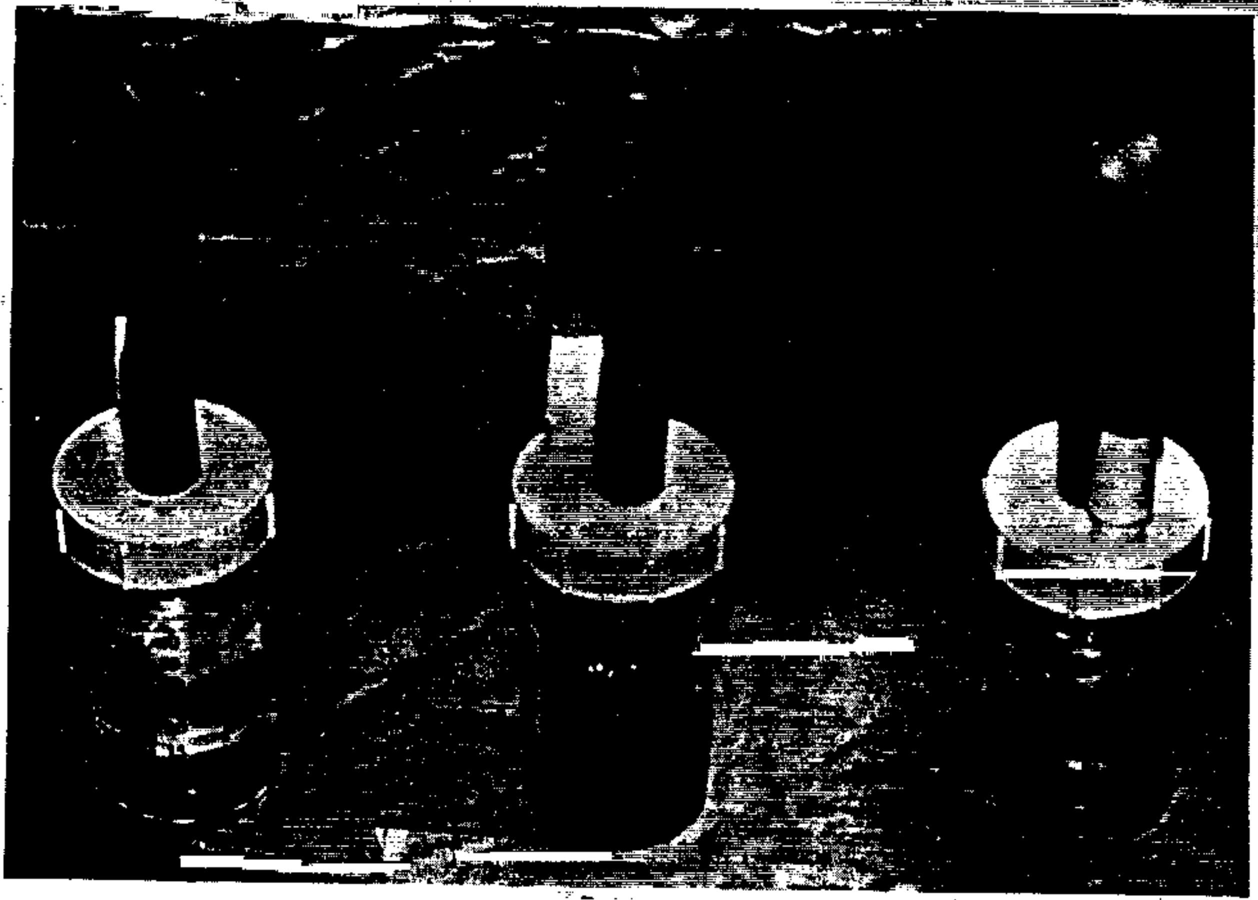


FIGURE 41. - Collection vials containing sterile saline and lung constituents following bronchoalvelar lavage.

Early Detection

Live animals are used to detect the earliest effects of dust exposure including cell injury, scarring, and regeneration. Methacholine is being investigated as a predictor of future changes in lung functions. Work is ongoing to study a group of active coal miners and compare findings with a group of non-mining control people. Respiratory systems are being investigated based on revised standards developed by the British Medical Research Council. Results are being analyzed to determine if increased airway reactivity by Methacholine Challenge is associated with symptoms of chronic bronchitis or decreased ventilatory capacity. To date, a total of 315 volunteers have been enrolled in the project.

FIGURE 42. - Photograph of macrophages collected during a routine bronchoalveolar lavage.

Acoustic impedance may prove useful as a non-invasive detection device, as may laser holography, used in conjunction with spirometry to assess lung functions. The objective of this research is to examine new methods for detecting small alterations in the mechanical properties of the lungs. This may result in the potential for detection CWP in its early stages.

Individual Susceptibility

It is recognized that general susceptibility to disease varies from individual to individual. Center researchers hope to develop a test to identify persons at high risk to dust-induced lung diseases. Such a test would permit taking personalized precaution.

4

Dust Characterization

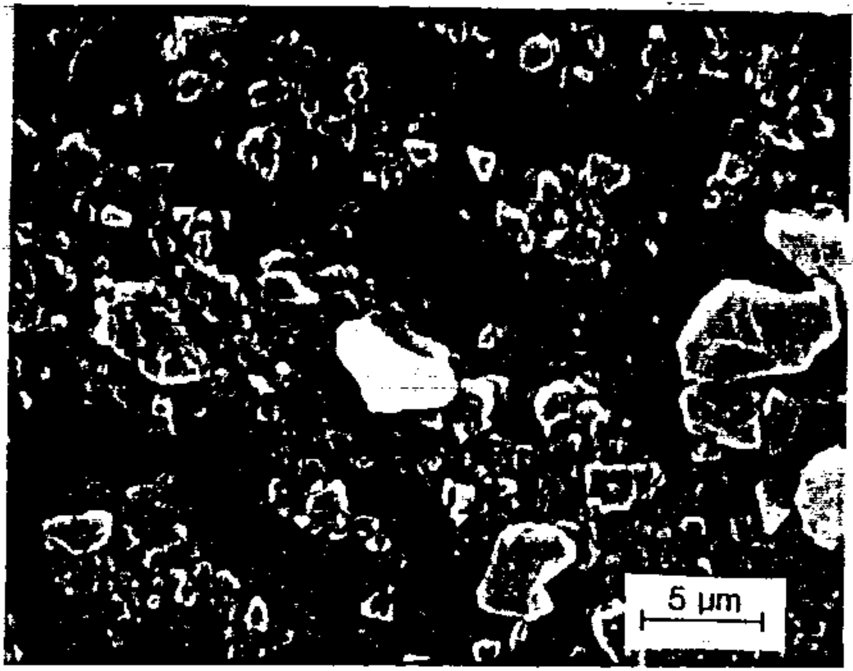
DUST CHARACTERIZATION

There is considerable evidence that all mine dusts do not present the same health hazard. Rank of coal and composition, especially silica content , of the mine dust, shape, and surface charge are risk factors that affect the incidence and severity of CWP. Current efforts of Center researchers involve characterization of:

- size/shape/composition
- surface and functional groups
- particle interactions.

Work is underway to prepare and characterize respirable coal dust samples, and to develop and evaluate techniques and procedures for the characterization of respirable dust. A suite of standard samples including anthracite, medium volatile and high volatile bituminous coals, quartz, clay, and rock dust have been prepared and thoroughly characterized with respect to the distributions of particle size and compositions. A comparison of the morphology of the standard dust particles with similar particles collected in an underground coal mine is given in Figure 43. Samples of these characterized (Standard) dusts have been distributed among various research groups associated with the Center.

The aerodynamic diameter of a particle is a particularly important characteristic since this parameter determines the point of deposition in the human respiratory tract. A 3-dimensional numerical model for theoretically determining the equivalent aerodynamic diameter of irregular shaped particles has been developed and used to analyze coal dust particles and a particle shadowing technique has been developed for



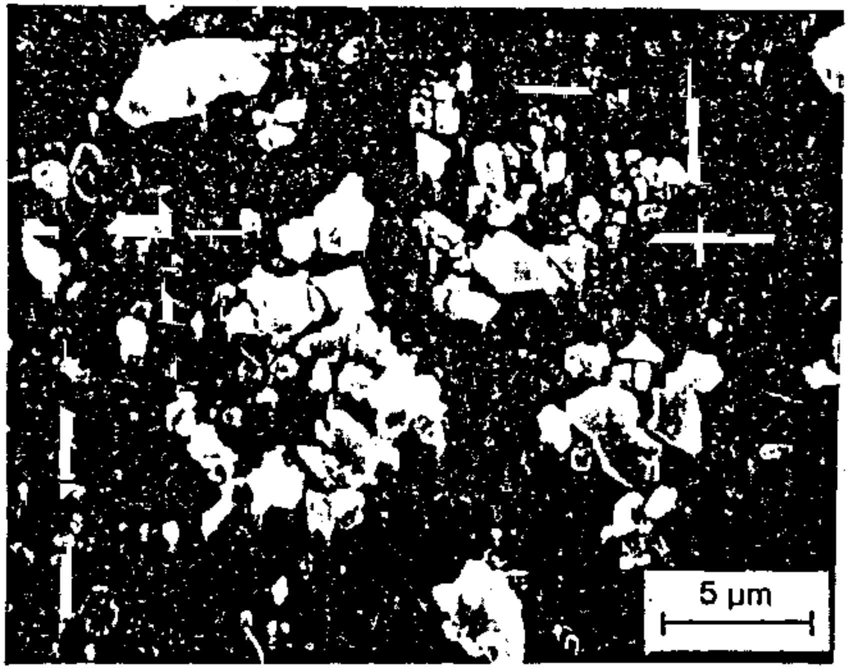


FIGURE 43. - Scanning electron micrographs of a) standard respirable dust from Upper Freeport seam and b) actual coal mine dust from Brookville seam.

experimental 3-dimensional shape analysis (Figure 44). In the theoretical technique, the equivalent aerodynamic diameter of the particle is numerically determined from computation of the fluid drag on the particle. This allows the aerodynamic diameter of any regular or irregular shaped particle to be determined as a function of the particle's orientation or as an average over all particle orientations. The technique is quite accurate in that the aerodynamic diameter of several coal dust particles have been numerically determined to be within 5% of experimentally measured values.

Physical and chemical characterization of respirable dust in mines is severely constrained by the inherently fine size of the particles and by the limited sample quantities (typically milligrams) normally available. Characterization procedures must also take into consideration the problems of sample collection and handling. Research is being carried out on the use of _in situ_ and real-time dust monitoring and also on laboratory analysis of samples brought from the mine. Both of these approaches place further restrictions on the procedures and equipment which can be used: _in situ_ methods are limited by the kinds of equipment which can be operated in a mine, while the laboratory methods present uncertainties due to sample handling problems.

Investigations of in-mine characterization of respirable dust include several basic fundamental studies, evaluations and improvements of instrumentation used for particle size measurement. This instrumentation includes the Micro-Orifice Uniform Deposit Impactor (MOUDI), the TSI Aerodynamic Particle Sizer (APS) and a new personal diesel particle sampler. The MOUDI work has developed an optimized design for the impactor nozzles and a thorough understanding of the

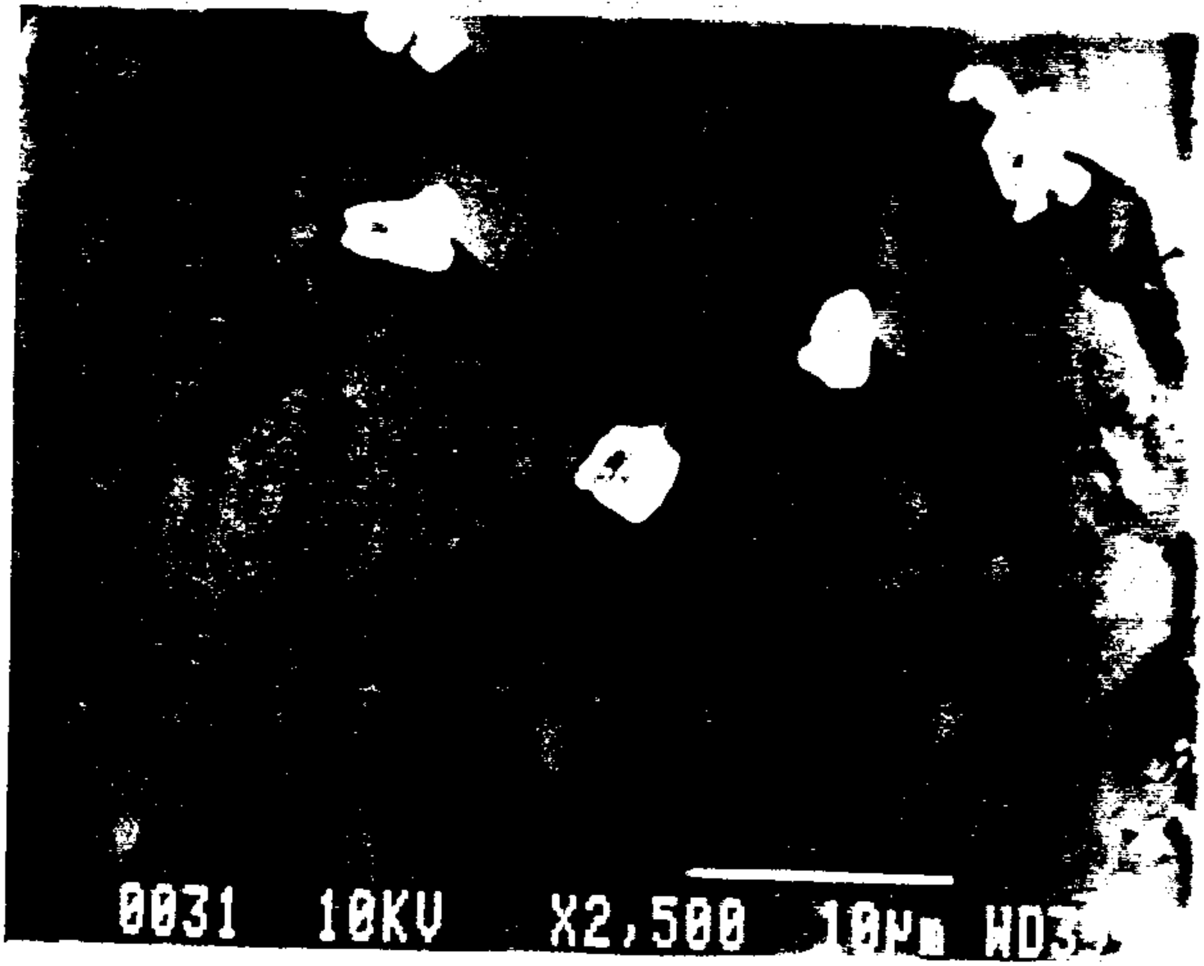


FIGURE 44. - Electron micrograph of coal dust particles shadowed in two orthogonal directions.

operating principles of the impactor. Field work with the MOUDI has proven it to be unique for measuring the size distribution of diesel exhaust and coal dust particle mixtures in underground mines. From the size distribution of the particle mixture, the existence of a bimodal size distribution, that can be separated on the basis of particle size, has been discovered as shown in Figure 45. This finding is currently leading to the development of a personal diesel sampler capable of measuring the respirable mass concentration of diesel particulate matter and respirable mass concentration of coal dust in underground mines. In addition, an important breakthrough for the dispersion of dust samples

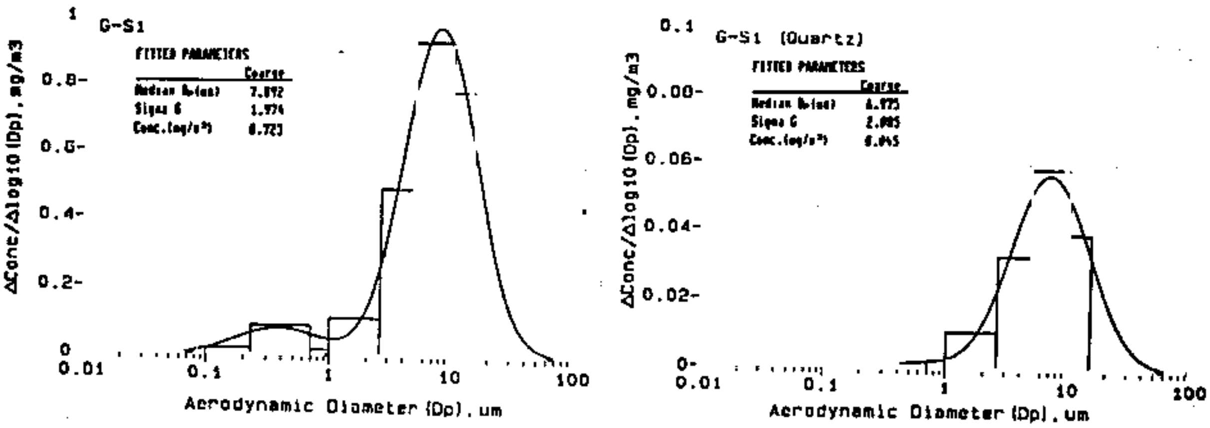
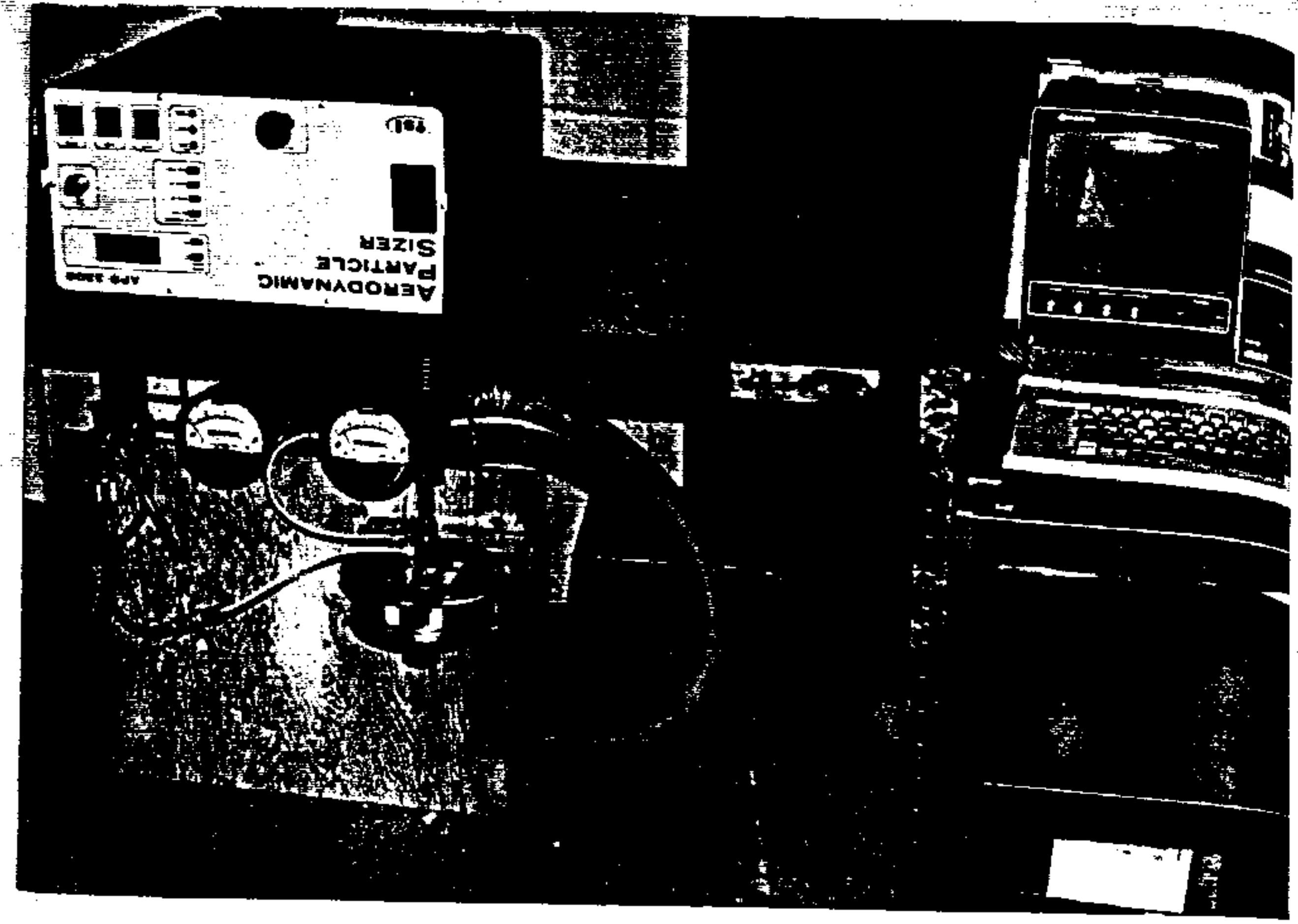


FIGURE 45. - Mass size distribution of coal dust and its quartz component.

has lead to the development of a commercial instrument, the TSI Small Scale Powder Disperser (see Figure 46), and a technique for redispersion of dust particles from filters. With this dust dispersion system, a technique has been developed to collect and redisperse dust particles from filter media for subsequent particle size analysis. The importance of this technique is the ability to collect airborne particle samples at the mine face using a simple filter sampler and then to analyze the particles using instrumentation that can not be taken underground because of non-permissibility and/or the complexity of the measurement technique. The particle redispersion technique is of general use to the aerosol field and has been accepted by the aerosol technology community as a useful tool.

Various other laboratory size analysis techniques including centrifugal sedimentation, Coulter Counter, and laser diffraction/scattering (Microtrac SPA) have been evaluated with regard to their applicability for respirable dust characterization. Comparative studies using the standard dusts indicate that the Microtrac



a) Dust dispersion system

FIGURE 46. - Prototype dust dispersion system and measured coal dust size distribution.

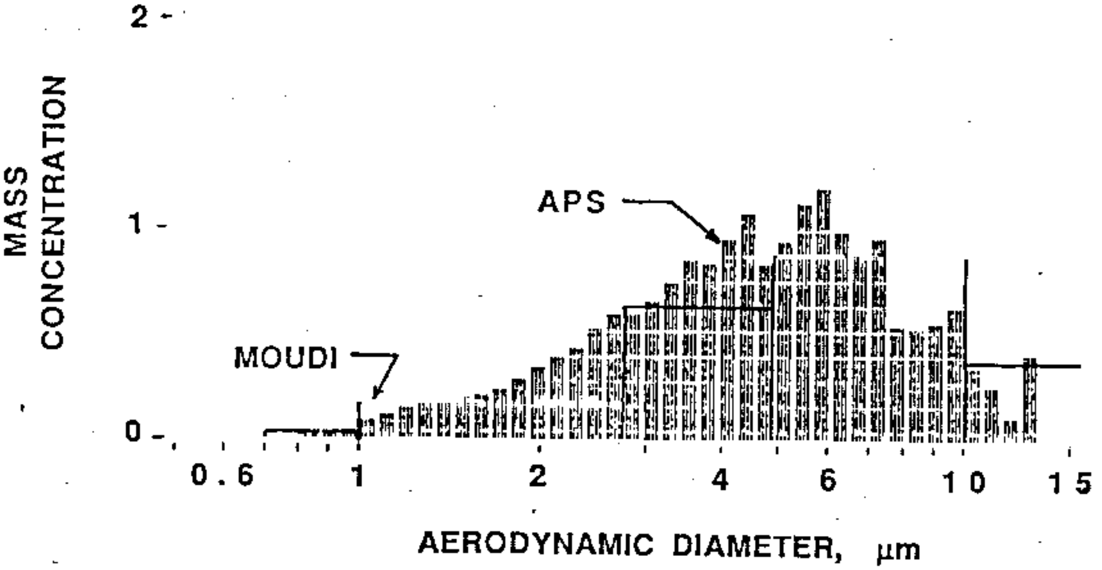


FIGURE 46.

b) Mass size distribution of coal dust as measured with MOUDI in a coal mine and the APS after redispersion from filter.

system is especially suitable for respirable dusts and that test results can be directly correlated with in situ measurements (see Figure 47). Furthermore, there is evidence that comparisons of in situ and laboratory measurements can provide information on the existence of dust agglomeration in the mine environment.

Procedures for evaluating the chemical/mineralogical composition of respirable dust are also being investigated. Included in these studies are a variety of techniques which can provide compositional information at three distinct levels: macroscopic (whole sample), size-by-size, and particle-by-particle. In general, these provide increasingly detailed information but at the cost of increasing experimental complexity and with some loss of overall precision. Techniques for macroscopic

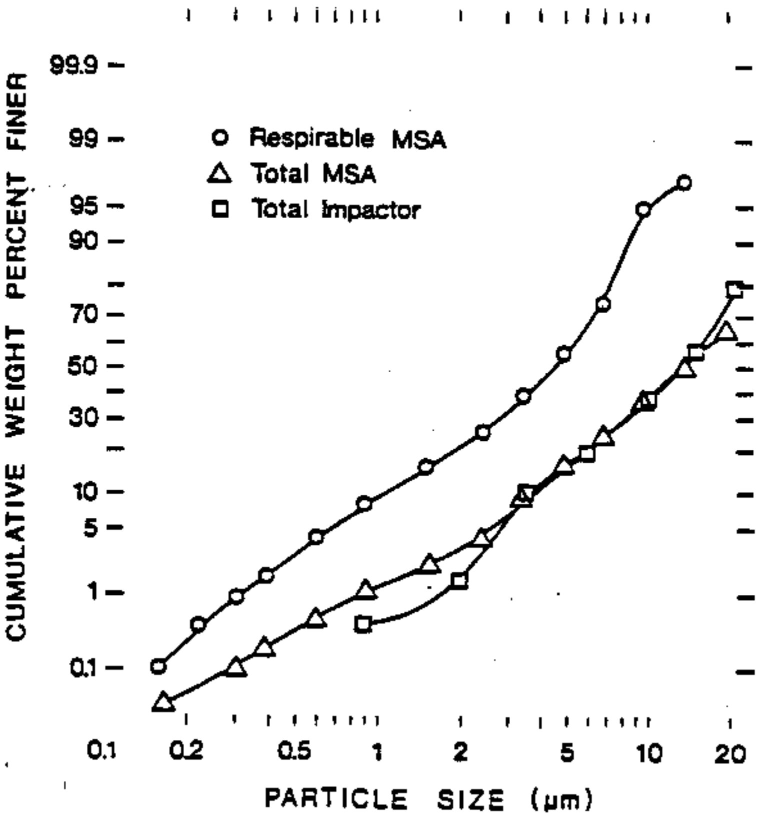


FIGURE 47. - Aerodynamic size distribution of dust collected at Mine A with a modified MSA personal sampler (converted from microtrac SPA data). Cascade impactor size distribution is included for comparison.

characterization include bulk chemical and mineralogical analyses and the P7 method for quartz determination in very small samples. Size-by-size analyses require fractionation of the sample on the basis of size or composition followed by analysis of the individual fractions. Fractionation methods studied include cascade impactors and specific gravity separations using heavy liquids. Procedures for determining the composition of individual size fractions are being investigated. These include the application of Proton-Induced X-ray Emission Spectroscopy (PIXE) to the individual stages of standard cascade impactors and a modification of the P-7 technique applied to stages of the MOUDI instrument. Alternatively, size distributions for individual, composition-based fractions can be obtained by standard techniques such as Microtrac SPA.

The use of a computer controlled scanning electron microscope (SEM) in conjunction with an energy dispersive x-ray detector for the simultaneous determination of size, shape and composition on a particle-by-particle basis is also being investigated. Size and shape analyses are quite reliable within the resolution limits of the instrument. Compositions determined by SEM are in good agreement with bulk spectrochemical analyses for particles larger than about 10 µm (see Table 1), but become increasingly unreliable for smaller particles due to a significant reduction in the volume of material excited by the electron beam. Emphasis in these studies is placed on the need for precise, quantitative analysis of each particle in order to provide a basis for determination of the carbon content by difference.

Another dust characteristics study has grown out of the observation that fresh dusts have a higher level of free radicals than dust that has been stored for some time. Biological effects of "stale" versus "fresh" dust are being compared. Preliminary studies have established a positive correlation between the higher concentration of free radicals and biological toxicity.

Investigation of the relationships between physical characteristics of respirable dust particle surfaces and their potential cytotoxicity is in progress. Crystalline and amorphous silicas have been studied. The ability of the particles to cause lysis of erythrocytes has been related to a variety of physical properties determined by zeta potential measurements, BET adsorptometry, scanning electron microscopy, and infrared spectrometry. It has been found that treatment by calcination and with alkaline solutions alter significantly the cytotoxic level of particles. Zeta potential measurements performed over a range of pH 2 to 10 reveal that for each temperature treatment a unique profile is observed. BET adsorptometry shows a decrease in specific surface area of particles treated at 950C and 1100C for both the amorphous and crystalline silicas. IR analysis by FTIR and photoacoustic spectroscopy indicate that the silanol mechanism for cytotoxicity is not applicable for fumed silica dusts. For crystalline dusts, the cytotoxic activity seems not to be sensitive to the concentration of silanol groups on the surface. The zeta potential shows better promise as a diagnostic tool for the surface condition of respirable size silica particles.

The properties of respirable quartz dust which are responsible for its strong pathogenicity for pulmonary disease induction as compared to alumino-silicate dusts are unknown. While quartz is highly cytotoxic to pulmonary macrophages in vitro, clay dusts such as kaolin dust are comparably cytotoxic. It has been found that incubation of quartz and kaolin respirable sized dusts in a fluid similar to the material which coats the lung results in complete neutralization of the cytotoxic potential of both dusts. Thus, it appears that mineral dusts are promptly de-toxified upon deposition in the lung. A reasonable hypothesis is that these coated dust particles are then subjected to uptake and digestion processes by lung cells, resulting in removal of the protective coating from the dust surfaces and re-toxification of the dusts within the cells. Experimentally, this is being modelled by incubating a quartz and a kaolin dust with the primary component of the surface active materials coating the lung, and then by incubating the coated dusts with phospholipase enzymes. The rate of restoration of quartz cytotoxicity by this modelled digestive process is found to be one to two orders of magnitude greater than that for kaolin. Current research using radiolabelled surfactant to monitor digestion rates in the interior of the cell is designed to determine if this rate difference can be the basis for distinguishing the relative disease inducing potentials of the two dusts.

Coal, quartz or other mineral particles in dusts undergo several kinds of interactions in mine and lung environments. For example, the amount of dust becoming airborne is influenced by the relative effectiveness of two basic processes which occur naturally and serve to prevent the majority of the dust particles from becoming airborne. These are: adhesion of dust particles to larger fragments and agglomeration of airborne particles to form larger aggregates. Similarly, the behavior of inhaled particles depends upon interactions of particles with surfactants and other lung constituents. Furthermore the effectiveness of water sprays in the capture of dust particles depends upon the nature of the interactions between water droplets and airborne particles. As a part of the research supported through the Center, research is underway to delineate the nature of such interactions.

Particle-particle and particle-substrate interactions are important in agglomeration, deposition and redispersion of dust. Research is being conducted to establish the relationships between various characteristics of dust and their response in the above mentioned phenomena. One of the objectives is to compare the response of freshly generated dust with the aged or stale dust. A fresh dust generator has been recently designed and fabricated as a part of this research program. With the aid of this device it will be possible to study characteristics of dust particles within a few seconds after they are generated.

Dust suppression in coal mines using water sprays is inherently difficult because of the nature of the coal seam, as mined. The raw coal particles show a great variation in their degree of hydrophobicity due to such factors as coal rank, degree of surface oxidation and the nature of contained mineral matter. These properties affect the interaction of coal particles with surfactants and water droplets. Figure 48 shows that the rate of wetting of coal depends strongly on the coal type and the surfactant concentration. For the ethoxylated octylphenol surfactant used in this series of tests the wetting rate followed the order:

anthracite > HVA bituminous > Sub-bituminous

The investigations conducted as a part of this research program have shown that the effectiveness of a surfactant as a wetting agent for coal depends upon coal rank, the degree of surface oxidation and the nature of the hydrophobic and hydrophilic functional groups in the surfactant. These studies suggest that a wetting agent should be tailored to the specific coal dust to be suppressed. Investigations are under way to understand the nature of coal-surfactant interactions and to relate them to their performance as wetting aids.

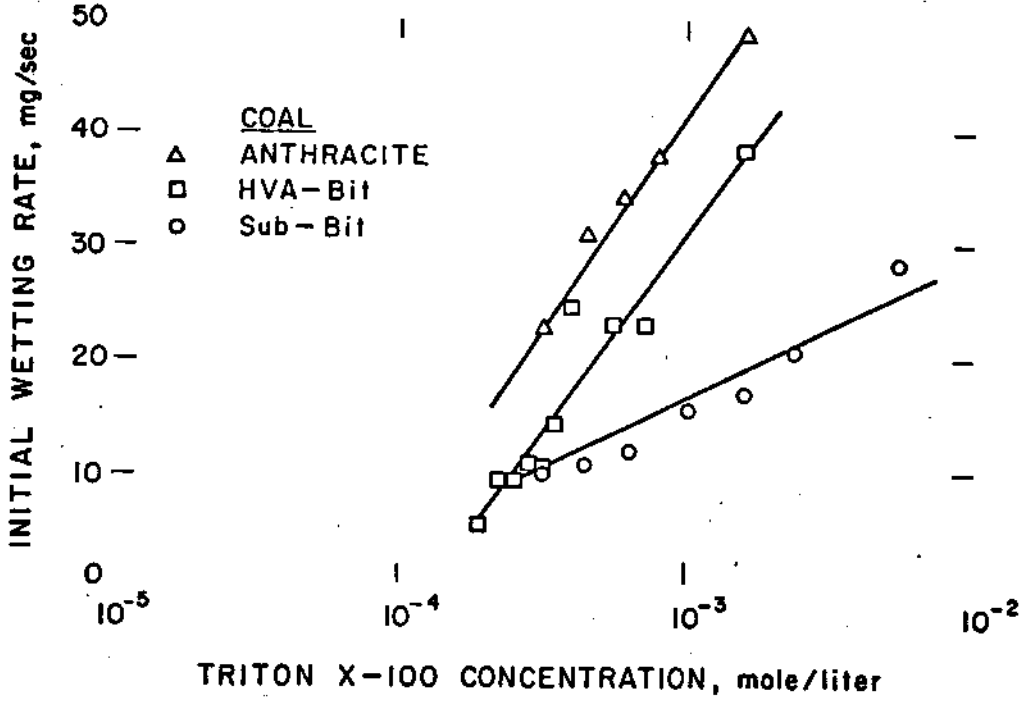


FIGURE 48. - The effect of coal type on the initial wetting rates as a function of Triton X-100 concentration. Triton X-100 is a emoxylated octyl phenol surfactant.

		Weight Percent	
Element	Spectrochemical	Polished	Dispersed
Na	10.5	7.1	8.3
Mg	2.2	2.1	2.7
Al	0.5	0.1	-0.04
Si	33.5	32.7	33.5
S	0.06	0.98	1.07
K	0.12	2.17	1.82
Ca	5.9	7.6	7.1
Fe	0.2	0.9	0.7
O	46.0	46.4	47.8
'C'	1.0	0.05	-2.8

Table 1 Chemical compositions of 20 μm glass spheres as determined from 100 dispersed and polished specimens using manual microprobe of the SEM. Spectrochemical analysis of the spheres is given for comparison.

5

Relationship of Mine Environment, Geology and Seam Characteristics to Dust Generation and Mobility

RELATIONSHIP OF MINE ENVIRONMENT, GEOLOGY, AND SEAM CHARACTERISTICS TO DUST GENERATION AND MOBILITY

It is evident that the incidence of coal worker's pneumoconiosis (CWP) or black lung disease varies in different coal producing regions of the United States. Many people have hypothesized about the reasons for the differing occurrences. Because underground coal mining involves many mining methods under changing geological conditions, several factors may be involved in contracting CWP such as: the amount of quartz in the respirable dust, the trace elements in the respirable dust, the rank of the coal that produced the respirable dust (bituminous, anthracite), the amount and size of respirable dust, etc.

Recognizing the uniqueness of underground coal mining and CWP, research investigations involving seam characteristics, mining system and worker position are being conducted in the center to establish standard procedures for characterizing some coal properties that may be involved in workers contracting CWP. This has been accomplished by the in-mine sampling of airborne dust at various worker locations and mining system configuration and by performing laboratory analyses of mined material (coal and rock) taken from the mines. (FIGURE 49 and 50)

The investigations includes a method of classifying coal seams according to their potential to generate respirable dust. It includes statistical analyses of the size and locational variations of the elemental compositions of respirable coal mine dust in operating underground mines from seams located in the eastern, midwestern, and western United States, and is currently completing research which is investigating the relationship between the elemental compositions of

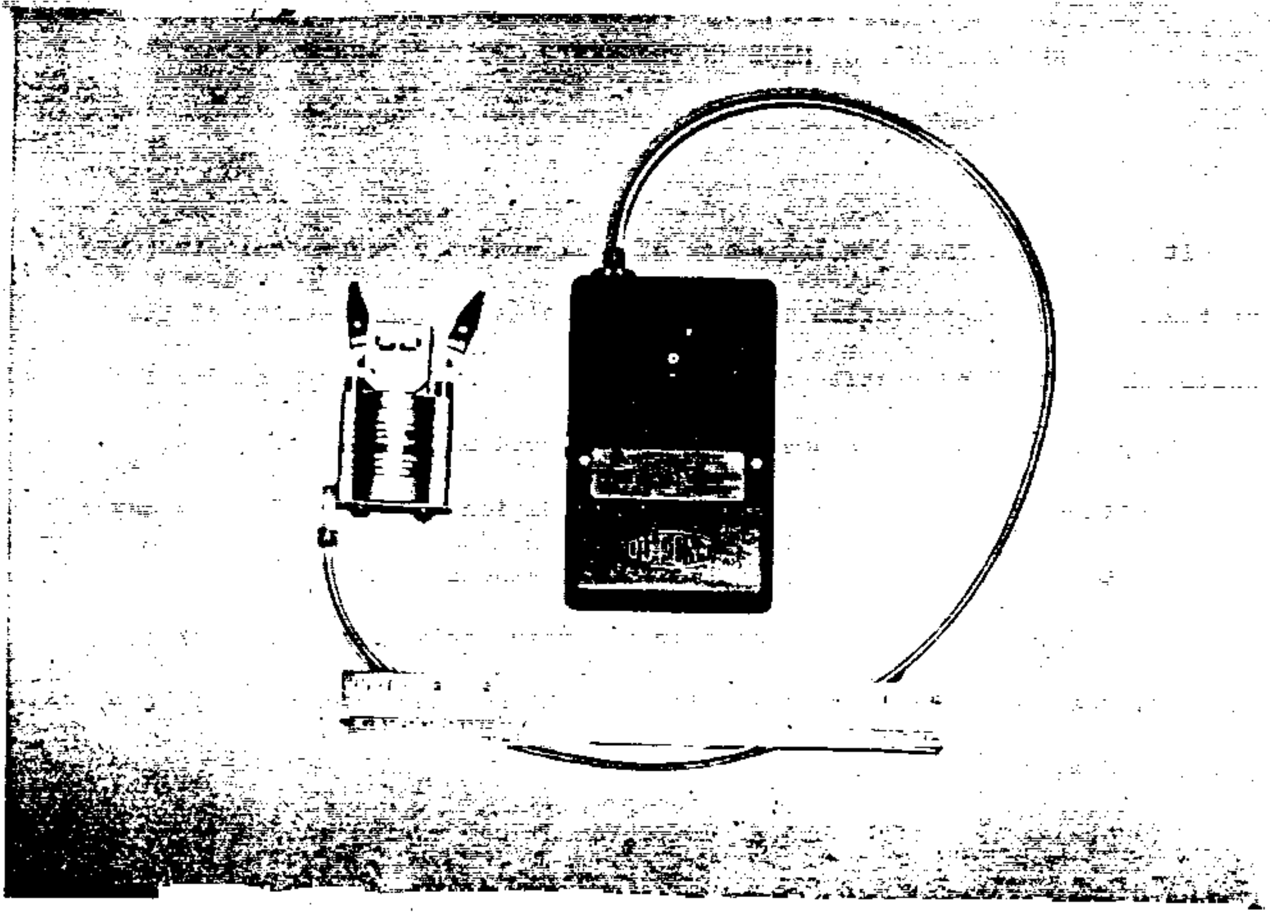


FIGURE 49. - Basic package for underground particulate sampling including the Anderson model 298 multi-stage impactor and the Dupont model 2500B pump.

respirable dust sampled near a continuous-mining machine and a laboratory-produced respirable dust.

A major area of investigation in the center has been the formulation. evaluation, and verification of improved dust sampling and analytical strategies for use in surface and underground mines and preparation plants. A particular concern has been the need for obtaining valid dust samples with a larger mass for use in scientific, medical and engineering research studies. Methods of analysis that can improve the reliable determination of dust characteristics are also being studied. This includes the proper methods of synthesizing, collecting, storing, and utilizing respirable dusts and the effects of other contaminants and particulates that exist in the mine atmosphere.

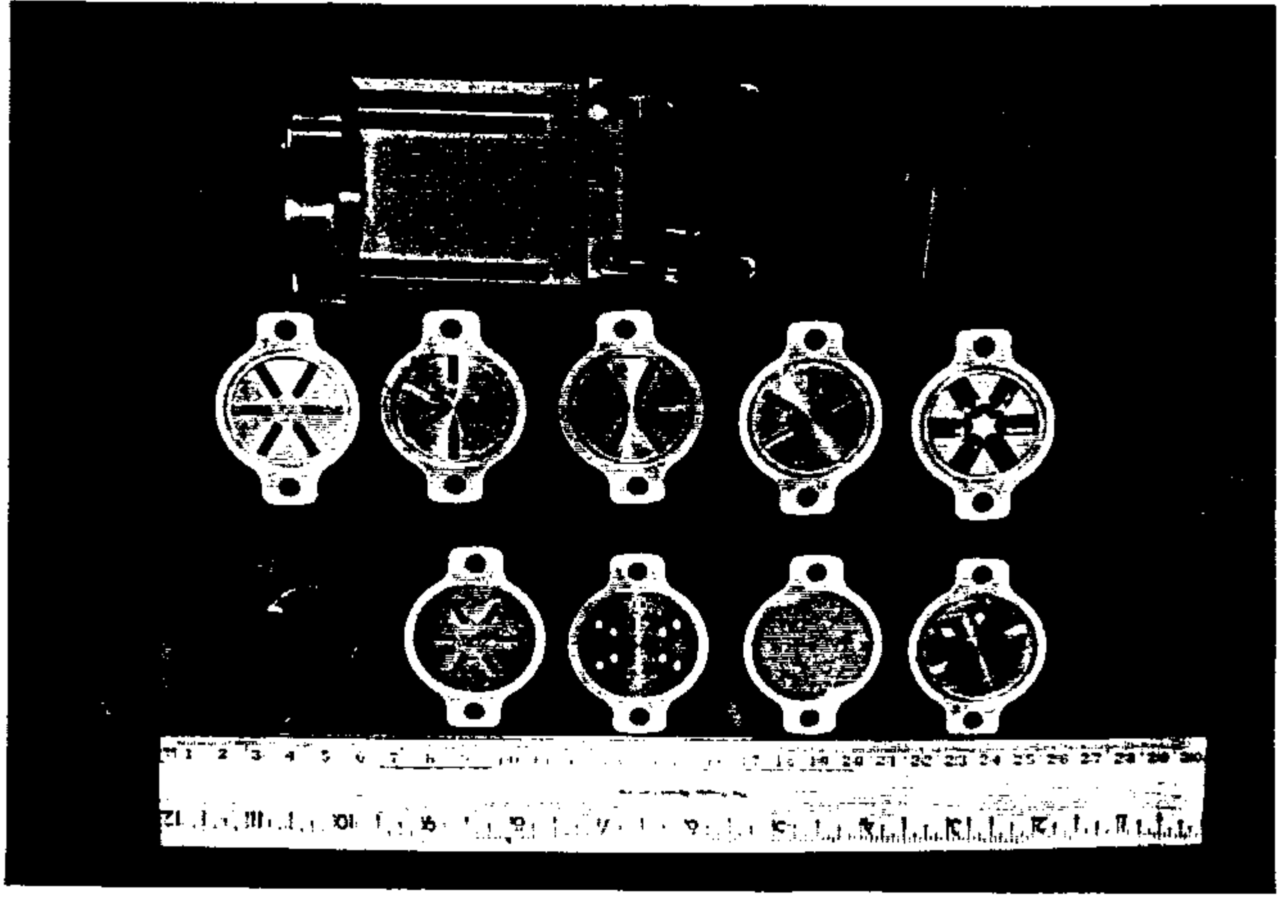


FIGURE 50. - Components of the Anderson model 298 impactor.

A definition of fresh versus stale dust has been achieved. While the research group has been concentrating initial efforts on coal dusts, the ramifications of silica, diesel particulates, asbestos, and other confounding variables have been a major topic of concern for characterized and standardized field investigations. After standard procedures have been established, certain factors contributing to increased CWP may be identified and prevented during pre-mine planning, or remedied by engineering controls in an operating mine.

For example, in a diesel underground coal mine, the engineering control of airborne particulate to which a miner is exposed requires that the diesel particulate fraction be measured accurately. In mines throughout the U.S., respirable coal dust samples are presently collected on filters and the airborne particulate concentration is calculated using the weight of material collected and volume of air sampled. While diesel particulate often makes up 50% or more of the sample, there is no fully-proven quantitative measurement method which can distinguish the diesel and coal particulate on a filter. Earlier Bureau of Mines sponsored research had successfully demonstrated the ability of the Laser Raman Quantitative Analysis (LRQA) method to determine the fractions of diesel and coal particulate on filters prepared in the laboratory containing coal/diesel particulate mixtures (FIGURE 51). The present research involves testing and refinement of the LRQA method on samples of diesel/coal particulate collected in an underground mine (FIGURE 52 and 53). Methods to collect and measure diesel-only (FIGURE 54) and coal-

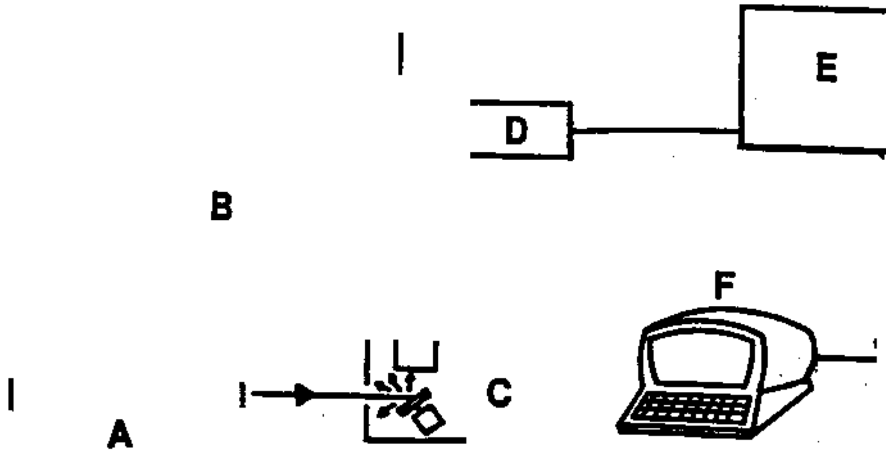


FIGURE 51. - Schematic diagram of Raman instrumentation used to collect coal/diesel particulate spectra.
- A) Laser
- B) Spectrometer
- C) Sample chamber with spinning sample holder
- D) Photomultiplier tube
- E) Interface between spectrometer and computer
- F) Computer-graphical spectral analysis and spectrometer control

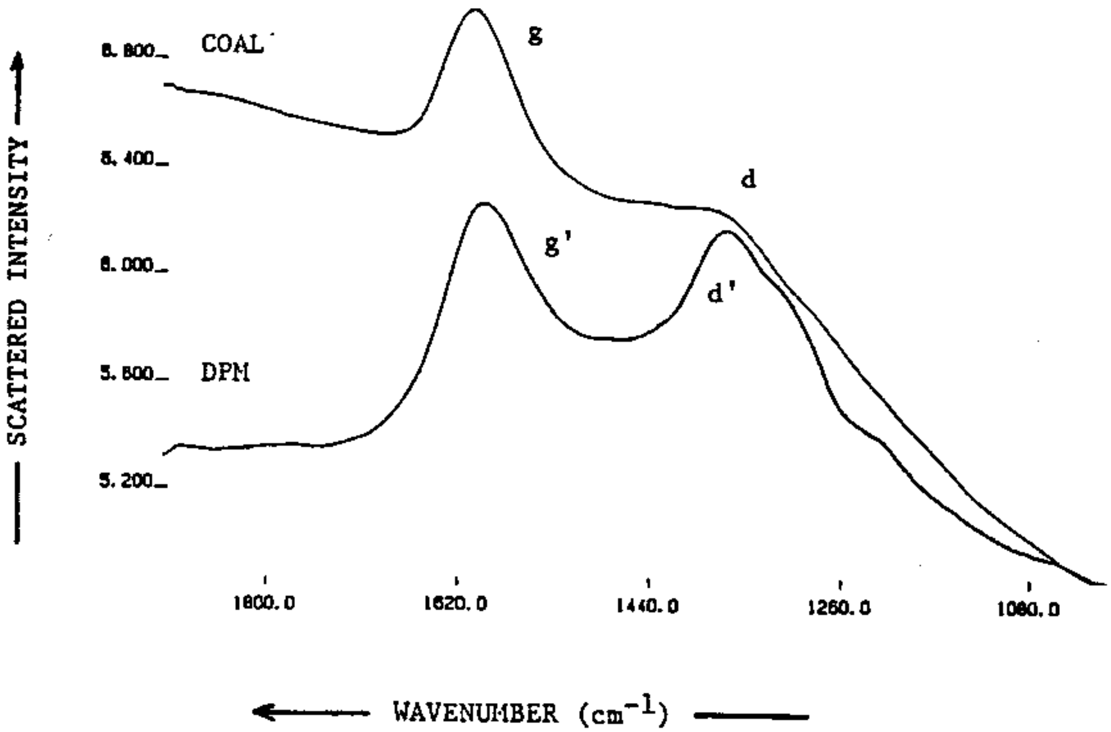


FIGURE 52. - Raman spectra of coal and diesel particulate matter (DPM), showing the difference in peak intensities (d'/g' d/g). A mixture will exhibit an intensity ratio (D/G) between these two extremes (See Figure 53).

only reference samples needed for quantitative LRQA have been developed and proven successful. Initial comparison of composition measurements for samples collected simultaneously and analyzed by the LRQA and size-selective methods show reasonable agreement. The initial analyses of mine samples has shown that further refinements can increase precision and accuracy. These refinements are being made and tested.

Additional diesel research involves the engineering control of airborne particulate and gaseous pollutants to which a miner is exposed in a diesel underground coal mine. Pollutant concentrations must be accurately measured to control them. This research is directed at the development of both measurement and control techniques. The measurement methods under study were developed in earlier Bureau of Mines supported research. The control technology under study is the Pyroban dry-type

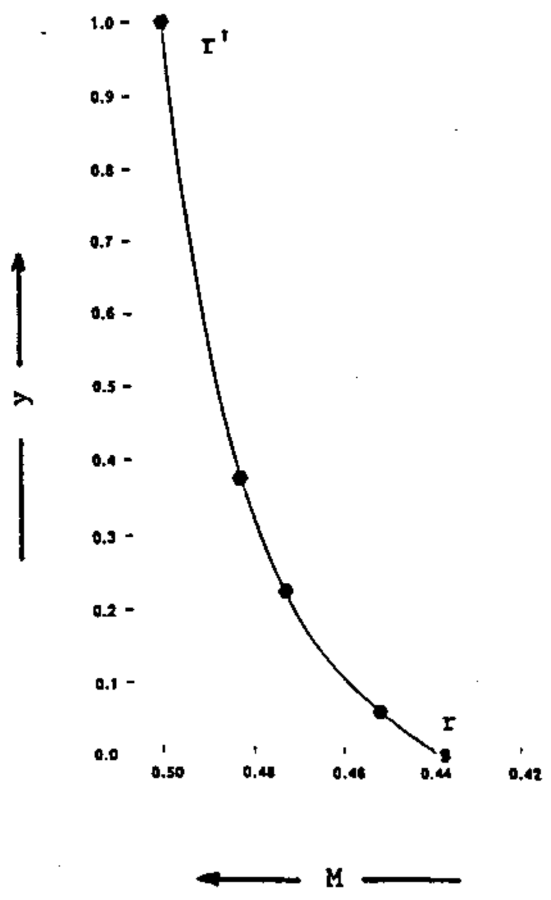


FIGURE 53. - This graph is used to obtain filter composition, % DPM (y), from the experimental mixture ratios (M). The solid line is calculated using the coal-only (r) and diesel-only (r') reference samples.

explosion-proof safety package and diesel particulate filter (DPF). which earlier Bureau of Mines sponsored and in-house research have found to be the most advanced of the diesel-vehicle controls under development.

Center participants are also cooperating with the Bureau of Mines and the Colorado Mining Association in the current evaluation of the Dry System/DPF. The underground research involves testing and safety, durability, and effectiveness of the system on a diesel-powered haulage vehicle in an underground production coal mine. (FIGURES 55 and 56)

The determination of significant variations in coal mine dust characteristics occurring in different coal seams, at different worker locations and for different longwall mining methods has also been

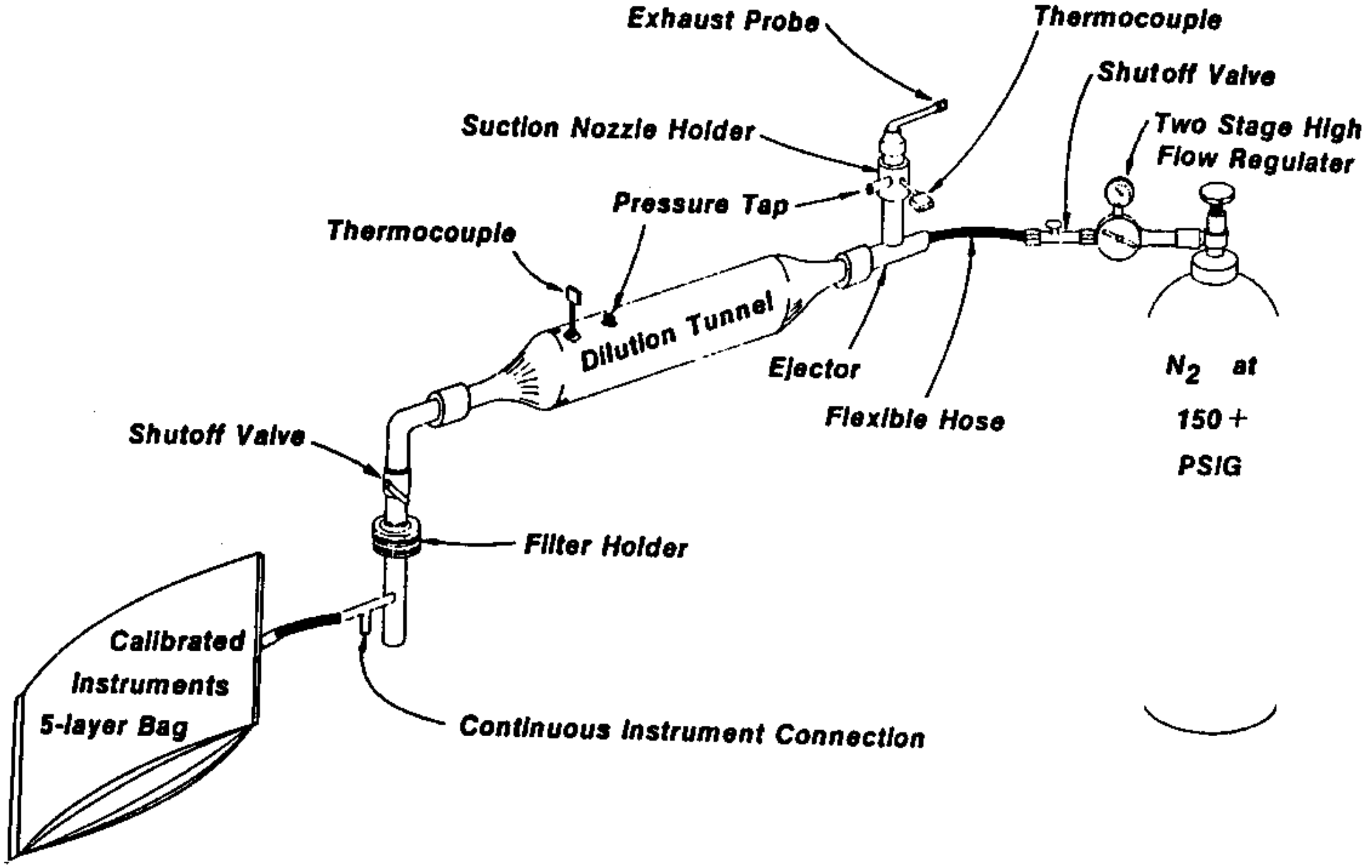


FIGURE 54. - Apparatus used to collect diesel-only tailpipe samples for laser Raman quantitative analysis of coal/diesel particulate mixtures.

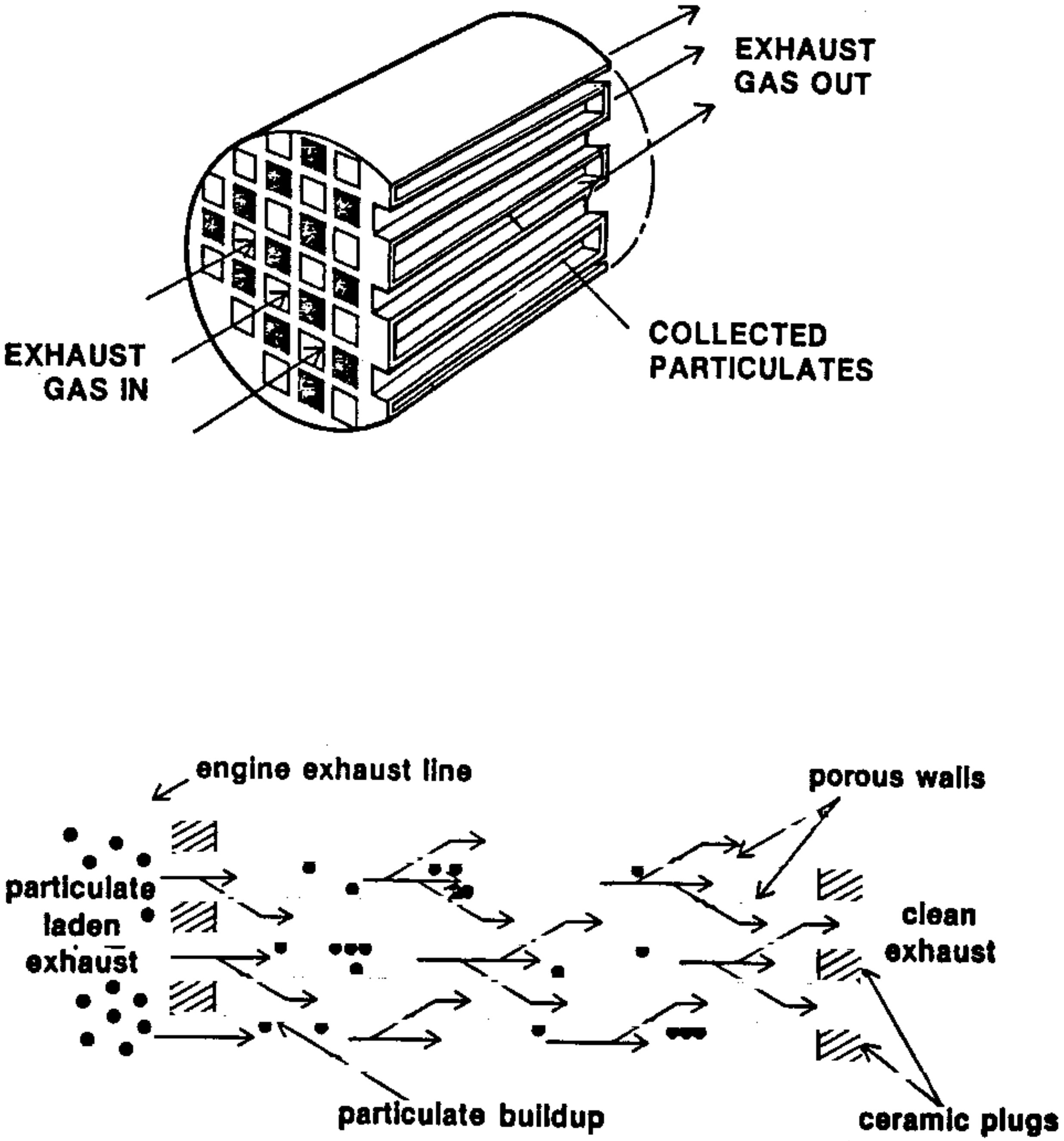


FIGURE 55. - Schematic illustration showing how ceramic monolith diesel particulate filter works.

DPF + DRY SYSTEM: INTEGRATED CONTROL SYSTEM

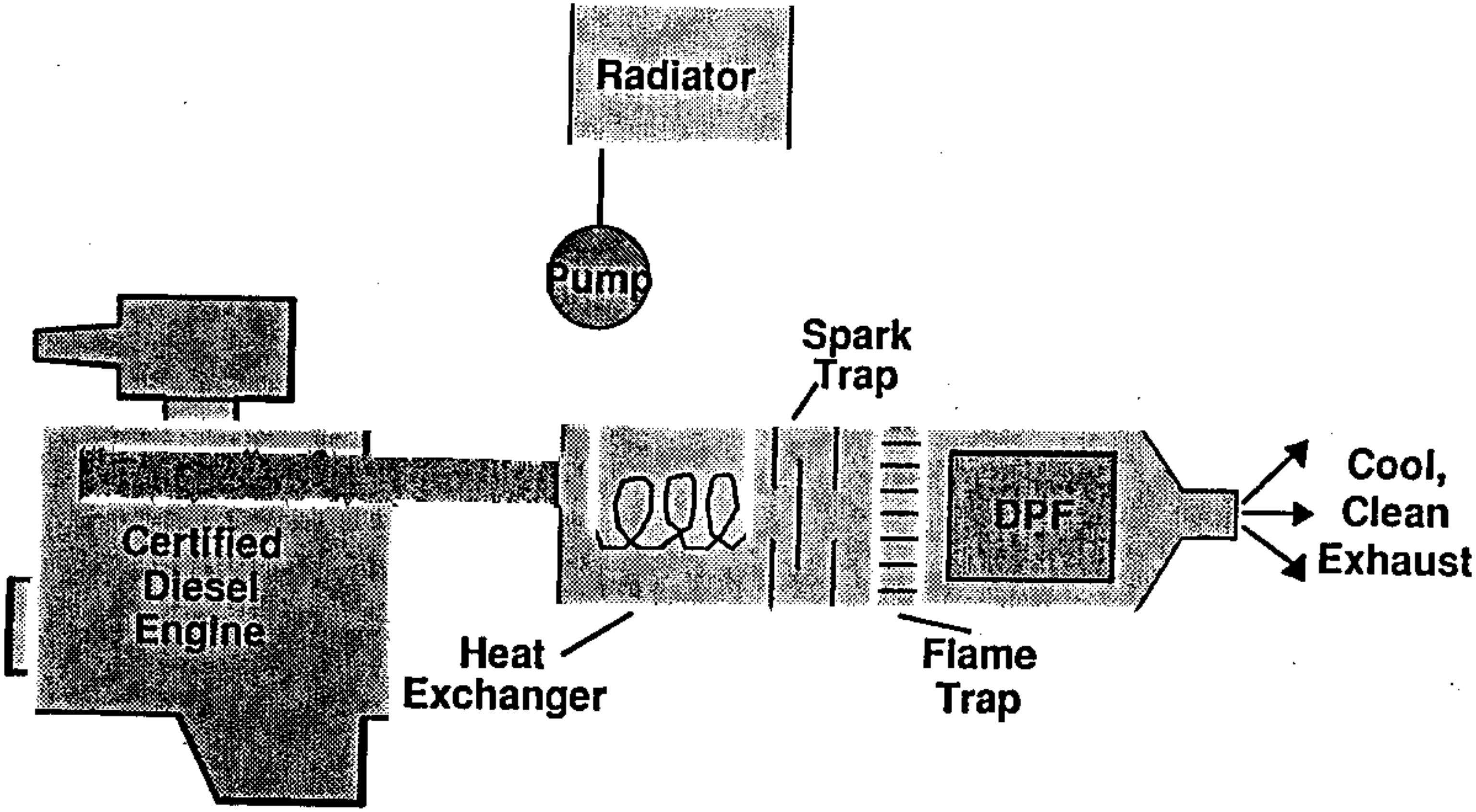


FIGURE 56.

investigated. Coal mine dust particles, which range in size from less than one micrometer in aerodynamic diameter to just less than ten micrometers, have been studied using a scanning electron microscope (SEM). The elements composing particles can be determined using an energy dispersive x-ray (EDX) detector and spectrometer interfaced with the SEM. Particle sizing and imaging can also be accomplished, thereby permitting characterization of particles by both physical and chemical parameters. Knowing the relative elemental occurrences within a dust particle, one can determine its mineral species. Thus information has been obtained about both elemental and mineralogical compositions of dust sample. Thus far in this research investigation, results for two coal seams of very different rank indicate that not only is the mineralogical composition different for the seams but so, too, is the contamination of mineral species with respect to the stoichiometric elements that comprise them.

In coal mining, the roof and floor strata, the inclusions and partings, often are stronger than the coal. The mass of adverse dust generated can be much more than when coal alone is cut, especially if quartz and other potentially toxic materials are present. Therefore, the relationship between coal and out-of-seam dilution material is being explored. These dust samples are also being characterized for chemical and mineral content, as well as size and shape consistency. Results from this project can be useful in predicting the variation of the mineral constituents in respirable coal mine dusts be worker locations in a mine, and using this information to "construct" respirable dust exposures. (FIGURES 57, 58, 59, and 60) An example of constructing such an exposure follows:

> A coal miner had worked ten years as a shearer operator on a longwall in the Pittsburgh seam, and fifteen years as a support operator on a plow-type longwall in the Beckley seam. The seams are very different, as is the exposure for different work positions. For the Pittsburgh seam, the mineral matter constitutes only about 15 pct of the respirable dust, with the rest being organic (coal) particles. For the Beckley seam, mineral matter was greater with a higher quartz content. In the Pittsburgh seam, 28 pct of the quartz particles were uncontaminated, while 68 pct of the quartz particles from the Beckley seam were "pure".

This research should help to understand the inter-relationship between exposure levels, mineral types, work positions, and the development of CWP in various mine environments as more fundamental knowledge is gained in medical and scientific investigations concerning the potential toxicity of various mine dust components.

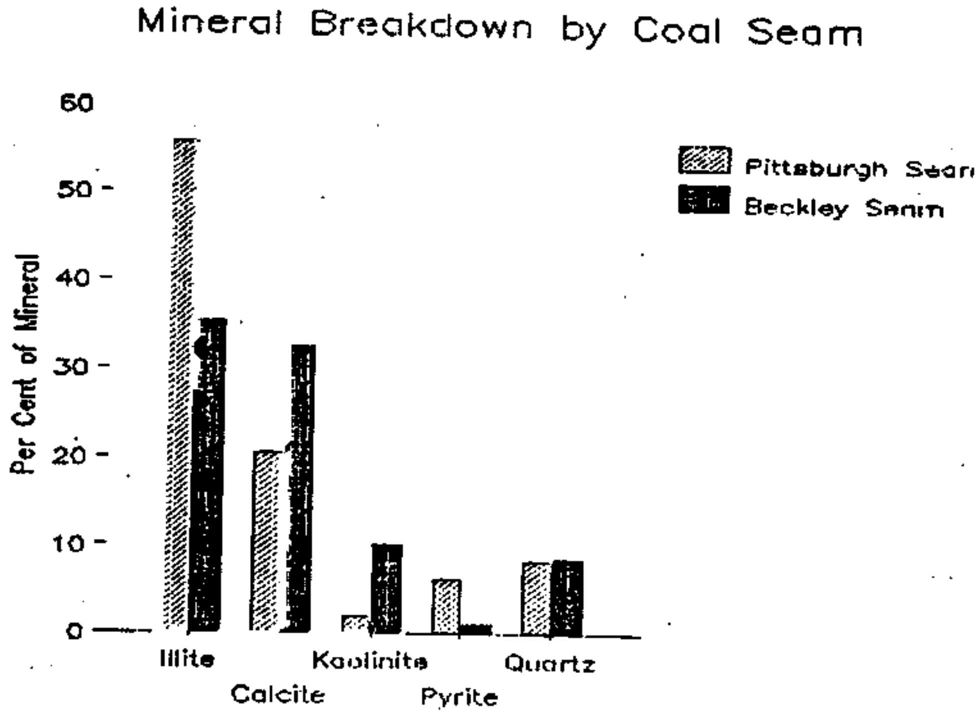


FIGURE 57.

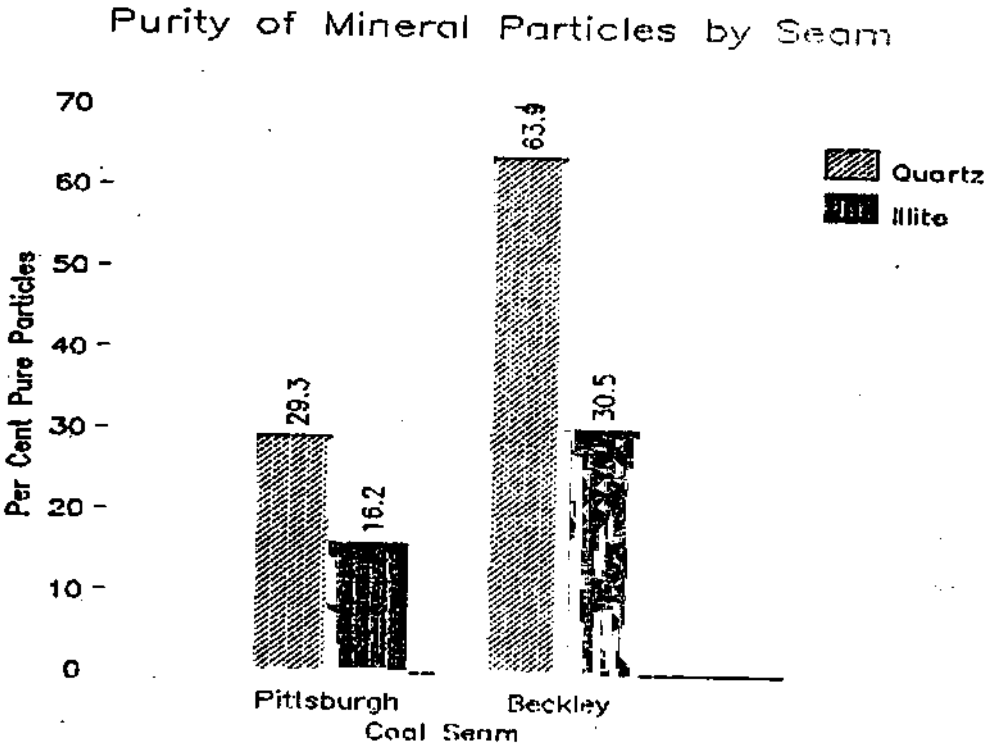


FIGURE 58.

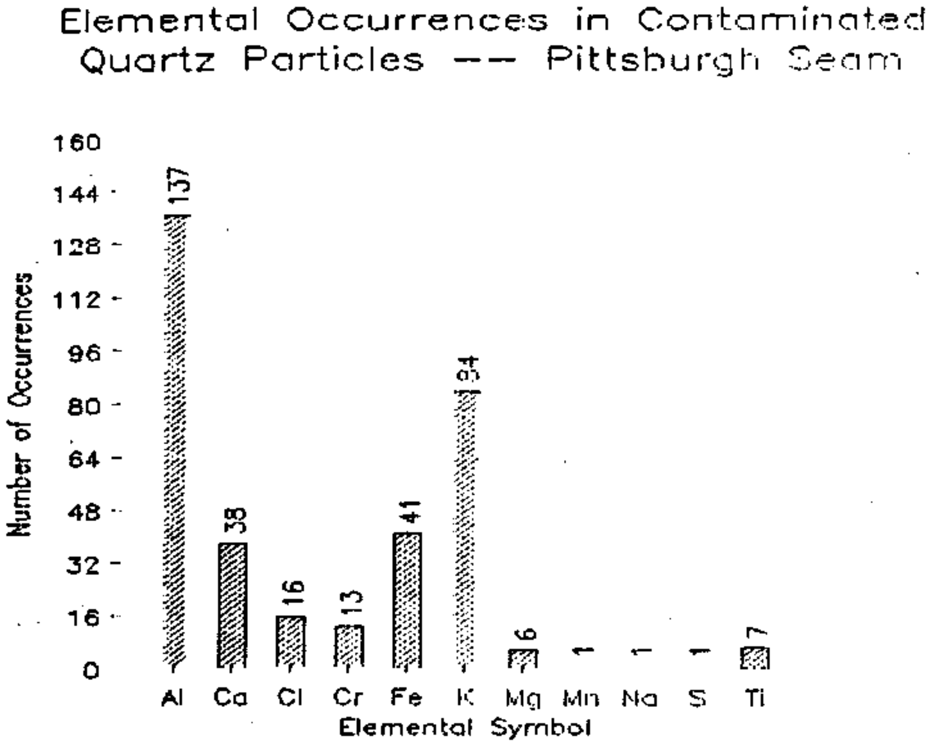


FIGURE 59.

Risk Index and Rank by Coal Seam in West Virginia.

		Rank Factors	
Seam	R_{IS}	BTU/lb	%VM
Pocahontas	3.02	14,670	17.9
Sewell	1.50	14,640	23.7
Eagle	2.13	14,420	32.8
No. 2 Gas	0.94	14,200	34.7
Cedar Grove	0.61	13,940	35.8
Pittsburgh	0.45	13,660	39.7

Note: Increasing BTU value and decreasing percent volatile matter (VM) positively correlate with increasing rank of a coal seam.

FIGURE 60.

6

Dilution, Dispersion, and Collection of Dust

DILUTION, DISPERSION, AND COLLECTION OF DUST

Prediction of Ambient Dust Concentrations in Mine Atmospheres

The major thrust of this research is directed towards a better undstanding of the behavior of airborne dust particles in underground mine airways. Figure 61 shows a schematic of dust flow in mine airway. The work included development of a mathematical model of dust behavior in mine airways, experimental study of the behavior of dust clouds and comparison of computer model output and experimental results. Re-entraiment is a secondary source of dust in mine airways and factors affecting re-entrainment are being identified.

Investigations have encompassed both experimental and theoretical research into the behavior of dust in mine airways. Experiments were performed in mine airways under both controlled and normal operating conditions (Figure 62). The controlled experiments included the documentation of the concentration and desposition patterns for two types of dust under three different velocities. Real-time dust concentration data were obtained using real-time aerosol monitors (RAM-1) (Figure 63).

On the theoretical front, a convection-diffusion model of the dust flow phenomenon in mine airways was developed considering dominant mechanisms affecting dust transport and deposition in mine airways. Mechanisms modeled include turbulent and gravitational deposition, coagulation, and dispersion. Comparative analyses of results of the controlled experiments with the predictions of the mathematical model were carried out. In addition to the overall validity, the adequacy of the individual components of the model, such as deposition in the total and

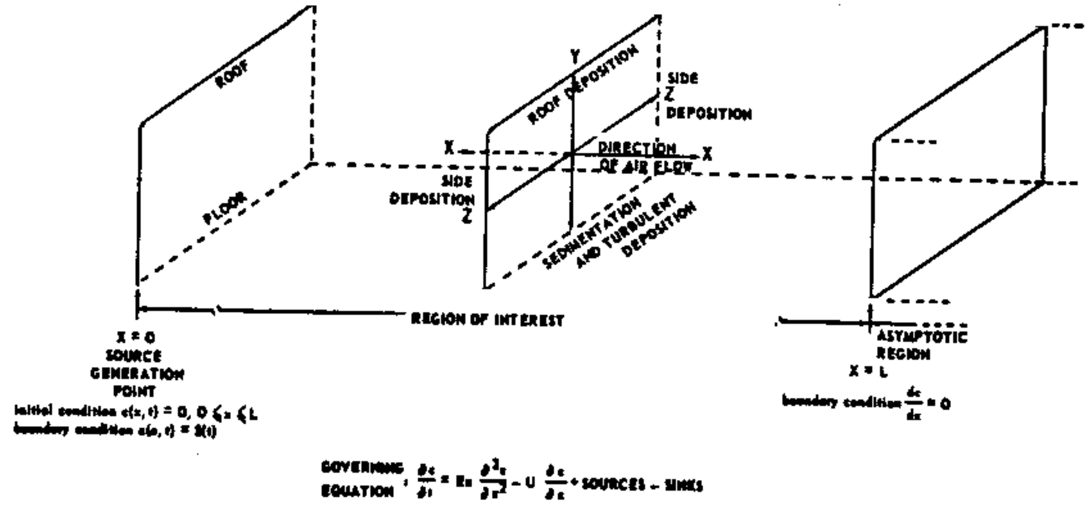


FIGURE 61. - Schematic of dust flow in mine airway.

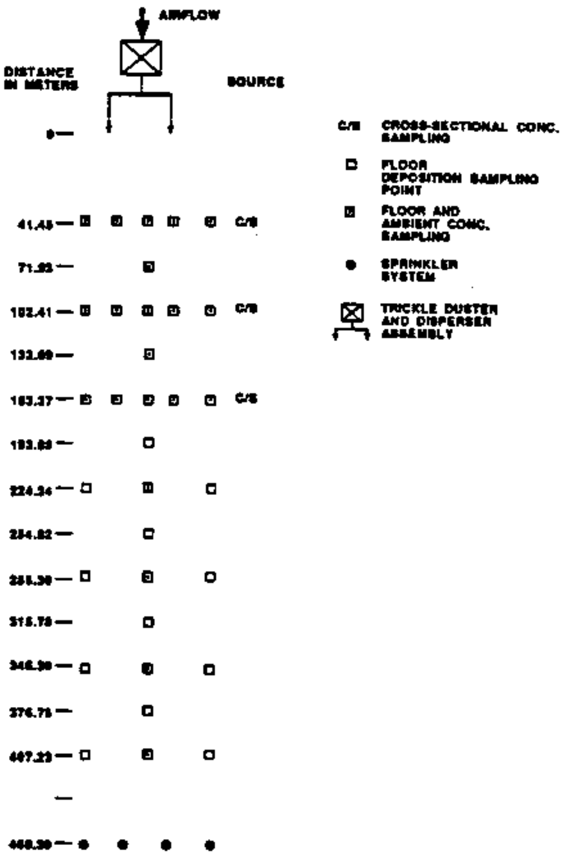


FIGURE 62. - Schematic of the airway showing locations of the sampling points (Experiment 6).

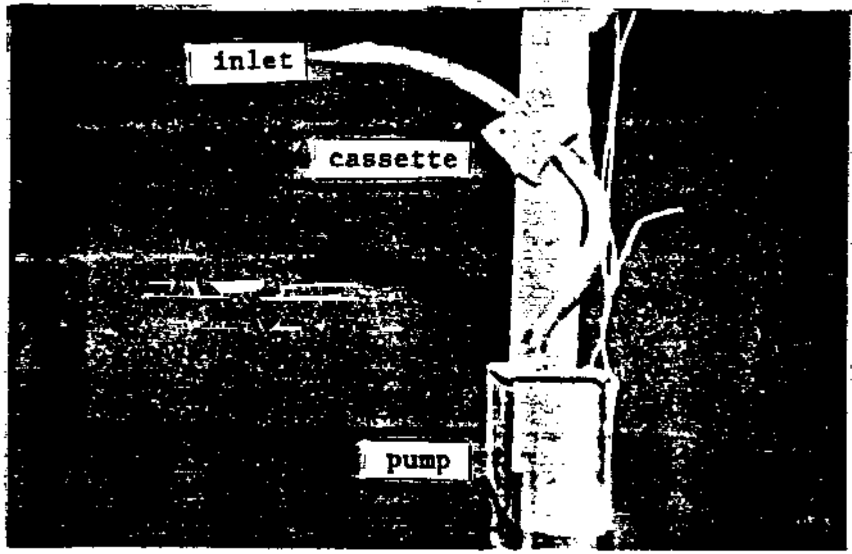


FIGURE 63. - Assembly for ambient concentration sampling.

respirable range, and dispersion were examined in light of the experimental observations.

The experimental data from controlled experiments compared more favorably with model predicted results for similar conditions as opposed to the comparative analysis results for in-mine experiments. Specifically, the model predictions for a 800-meter stretch of a mine airway reveal some significant differences from the behavior noticed in the mine. The deposition was lower than that predicted by the model. The comparative analyses have shown that, in general, the floor deposition part of the model is better correlated with experimental data, while the ambient concentration is better predicted at lower flow velocities (Figure 64).

Potential applications of the model include prediction of ambient dust concentrations and depositions in straight sections of airways. This can be helpful in designing mine ventilation systems and estimating rock dusting requirements. The impact of multiple dust sources can be studied using the superimposition concepts.

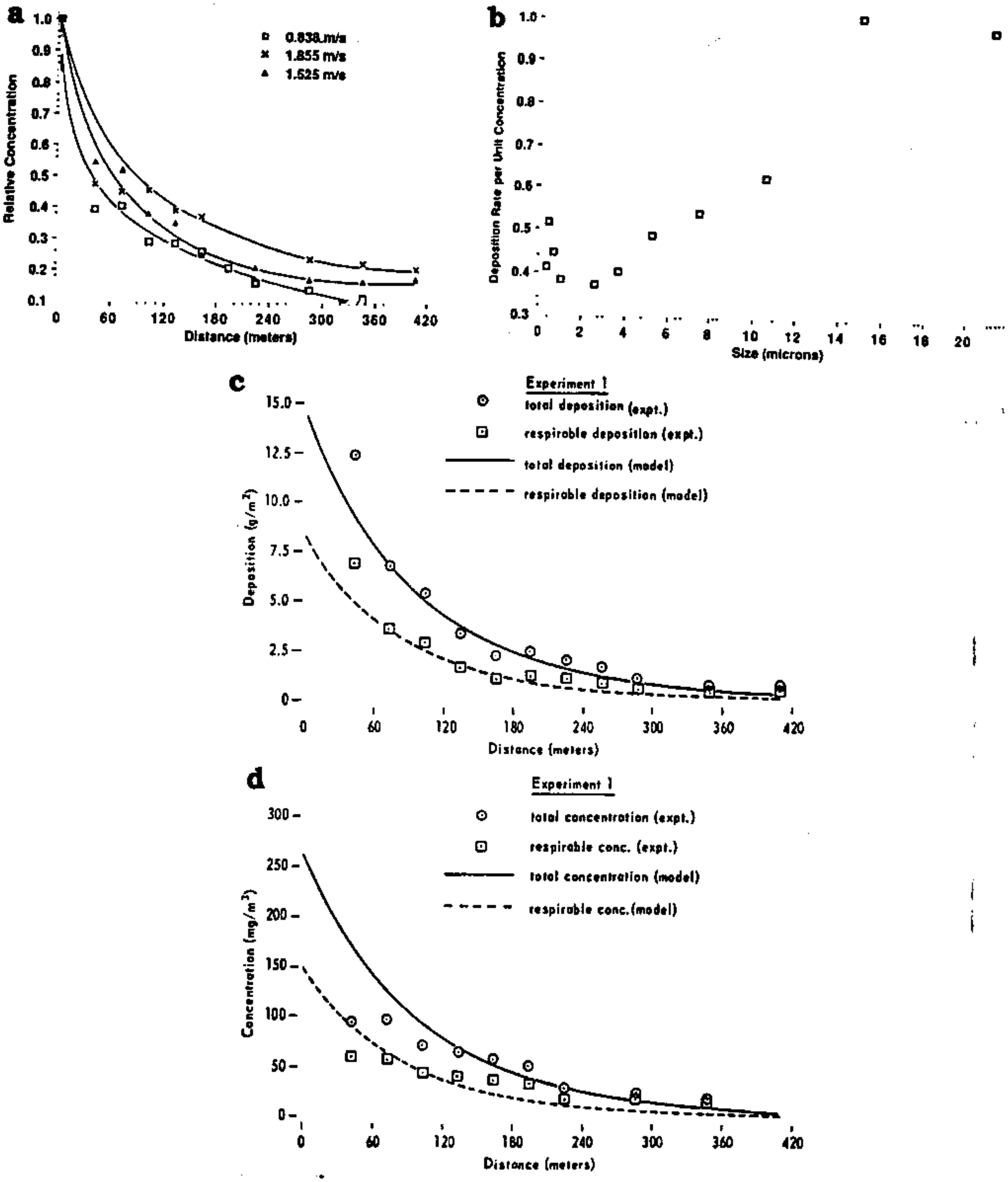


FIGURE 64. - Theoretical and experimental results
a. - Effect of velocity on total airborne dust concentration (semi-anthracite).
b. - Deposition rates for various particle sizes (controlled Experiment 1).
c. - Comparison of model predicted floor deposition with experimental data.
d. - Comparison of model predicted concentration with experimental data.

Computer Modeling of Longwall Face Ventilation

The objective of this research is to contribute to a better understanding of longwall ventilation schemes with particular reference to dust concentrations along longwall faces. The research includes experimental design and underground experiments in both operating longwall faces (Figure 65) and the Lake Lynn Laboratory Mine of U.S. Bureau of Mines (Figure 66), development of a mathematical and computer model for describing and predicting airborne dust concentration in longwall face, and comparative analysis of model outputs and experimental results.

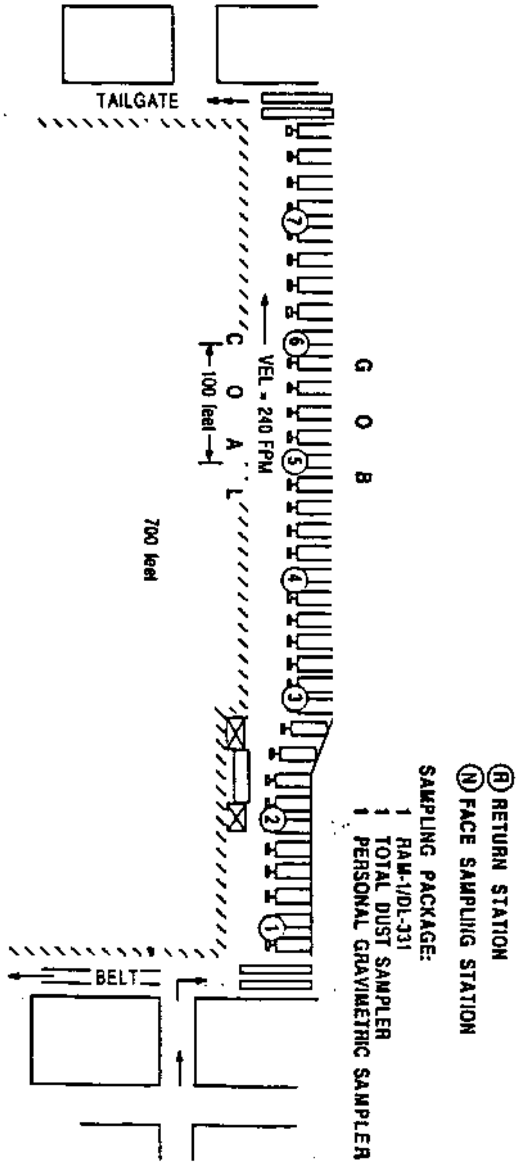


FIGURE 65. - Longwall face airborne dust sampling plan.

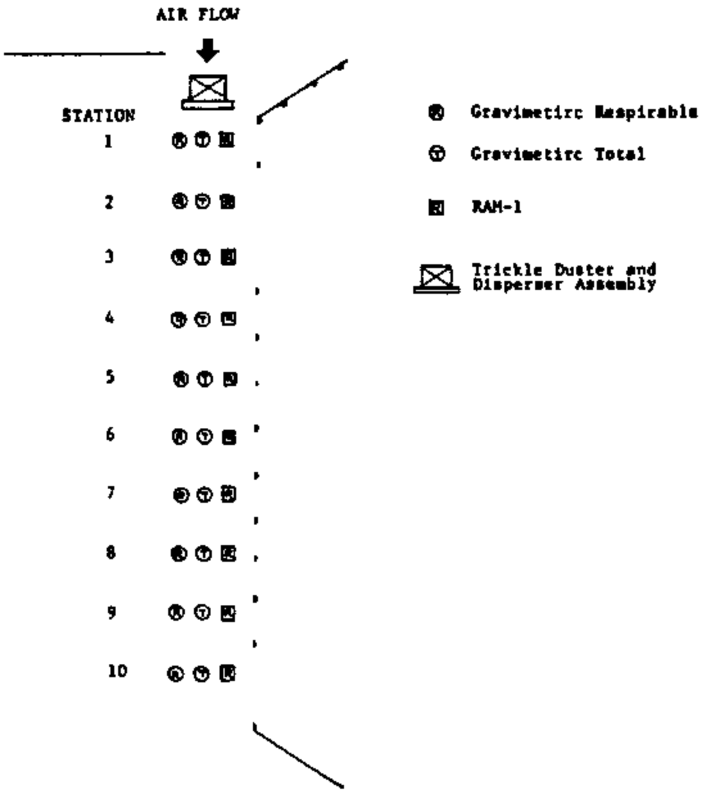


FIGURE 66. - Sampling plan of controlled mine experiments.

Gravimetric total and respirable dust samples were collected in three sets of preliminary experiments in fully operational longwall faces. These samples provide average total and respirable airborne dust concentrations along longwall faces. The instantaneous respirable airborne dust concentration were recorded using real-time aerosol monitors (RAM-1)(Figure 67).The moving dust source makes the longwall dust problem unique and complex. Therefore, time study data of cutting activities in longwall face are extremely important when interpreting RAM-1 data.

The experimental results obtained so far (Figure 68) show that the cumulative effect on dust level along longwall face is more significant when the shearer is cutting in the direction of air flow that when it is cutting against air flow. There is a significant amount of leakage in the longwall face (Figure 69).

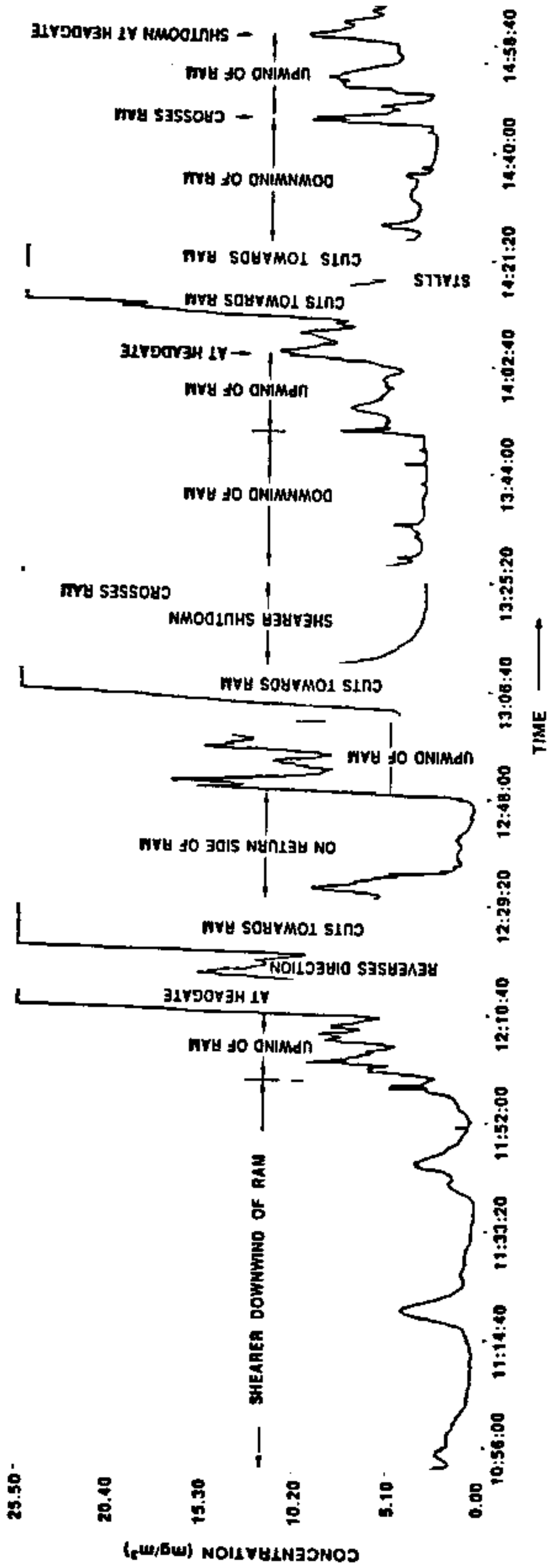


FIGURE 67. - RAM-1 output of dust concentration along longwall face.

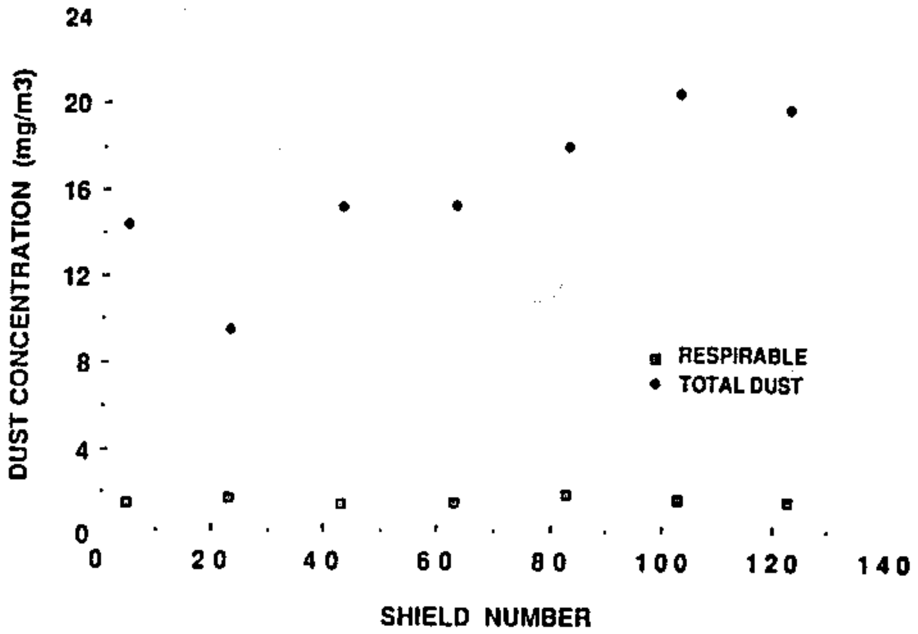


FIGURE 68. - Dust distribution along longwall face (Mine C, Experiment 1).

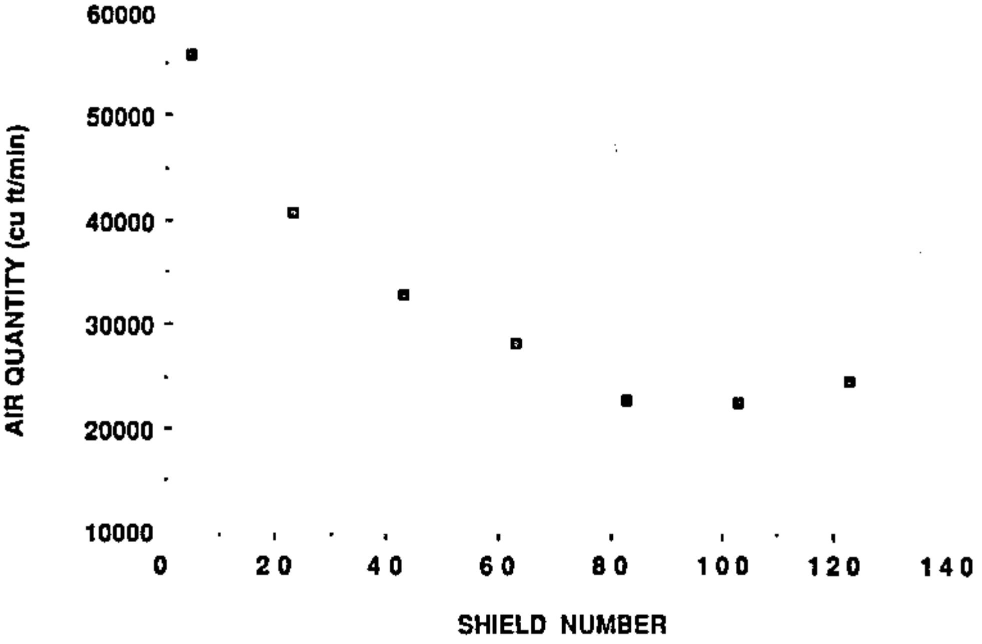


FIGURE 69. - Air quantity along longwall face (Mine C, Experiment 2).

A model is in the process of being developed with additional controlled mine experiments scheduled. Input parameters for the computer program include: air velocity, location of dust sources, size composition of dust sources, and boundary conditions. Potential applications of the model include description and prediction of dust concentration distributions along longwall face as a function of time and average dust concentrations at different places in the longwall face.

Knowledge Based Expert System for Planning Mine Ventilation Systems

The objective of this research is to develop a knowledge based expert system for aiding the planning and design of mine ventilation systems. It is recognized that mine ventilation system design is an engineering design problem involving not only numerical calculations to solve the pressure quantity problem, but also substantial judgement and expertise to analyze a problem situation and interpret the results of an algorithmic program. The expert systems approach facilitates a means of incorporating this qualitative knowledge in computer programs.

A logic flow diagram of a knowledge based system for mine ventilation planning is shown in Figure 70. The figure shows the interaction of the qualitative aspects of the problem through imput and output interfaces between the expert system and the design and analysis programs.

The thrust of this project is to embody the judgemental and experience based factors germane to mine ventilation system design in an interactive computer program. The highlighted portions of Figure 70 reflect the scope of work of this project. The work so far has focused on the development of an interactive (PC based) ventilation network simulator and a thorough evaluation of commercial expert systems shells currently available and suitable for the ventilation problem domain. Future work involves the development of the knowledge base and integration of the ventilation simulator with the expert system.

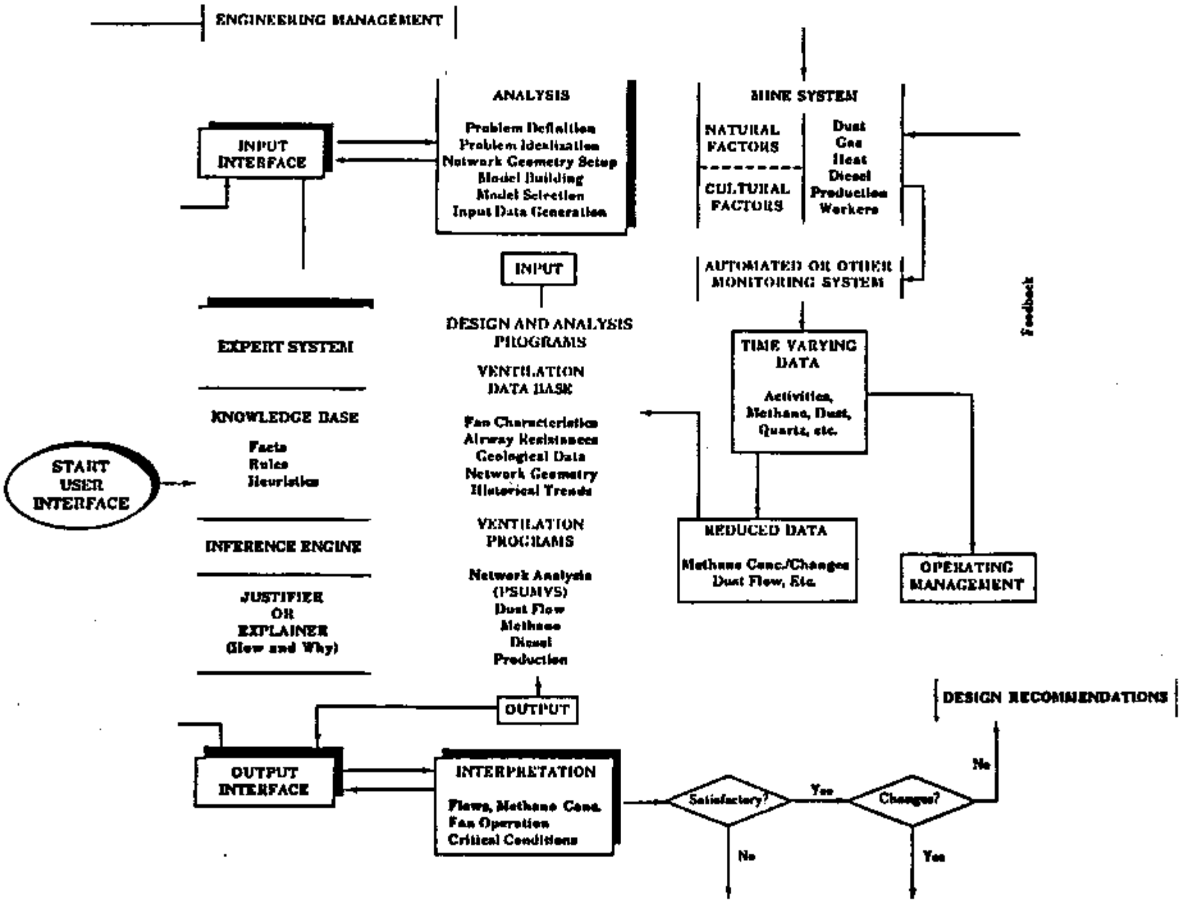


FIGURE 70. - A logic flow diagram of a knowledge based system for planning mine ventilation systems.

Control of Dust and Particulate Matter Generation

7

Control of Dust Generation

CONTROL OF DUST GENERATION

The main objective of this research is to identify the mechanisms of control of respirable dust generation in coal mines. Full understanding of the mechanics of crack propagation in coal is of fundamental importance in studies of the generation and control of respirable dust.

The main objectives of this fracture investigation are: 1) to determine reliable data on the fracture toughness of coal as a parameter controlling unstable crack propagation; 2) to determine fracture propagation velocity in coal providing data on the terminal velocity at which crack bifurcation occurs and fine fragments of coal material are generated; and 3) to apply the critical strain energy density criterion to model mixed mode crack propagation in coal.

The development of the protocol, laboratory procedure and equipment necessary to conduct an extensive mixed mode fracture toughness testing program has been completed. About 80 mixed mode fracture toughness tests, 10 good fracture velocity records and over 50 fracture surface examination with the SME are available. The details of the mixed mode fracture toughness testing are available in a paper titled, "Development of Mixed Mode Testing System for Geologic Materials" which is available from the center. The average fracture toughness and critical strain energy density values for the three seams investigated to date are included in the attached Figures 71, 72, 73.

FIGURE 71.

Dynamic Modulus Summary

Specimen and Orientation	Number of Tests	Young's Modulus (GPa) Ave., Std. Dev. and Relative Error	Poisson's Ratio Ave., Std. Dev. and Relative Error
Plaster of Paris	21	7.72 ±1.42 ±18%	.252 ±.056 ±22%
Pittsburgh Short Trans.	21	2.45 ±0.57 ±23%	.406 ±.022 ±5%
Pittsburgh Arrester	15	2.52 ±0.56 ±22%	.382 ±.048 ±13%
Pittsburgh Divider	26	2.47 ±0.39 ±16%	.394 ±.031 ±8%
Pittsburgh Total	62	2.47 ±0.49 ±20%	.395 ±.034 ±9%
Anthracite Short Trans.	20	4.27 ±0.92 ±22%	.326 ±.040 ±12%
Anthracite Arrester	5	4.43 ±1.11 ±25%	.339 ±.026 ±8%
Anthracite Divider	14	6.04 ±2.22 ±37%	.320 ±.037 ±12%
Anthracite Total	39	4.93 ±1.72 ±35%	.325 ±.037 ±11%
Lower Kitt. Short Trans.	9	4.59 ±1.40 ±30%	.283 ±.097 ±34%
Lower Kitt. Arrester	8	4.82 ±1.88 ±39%	.360 ±.043 ±12%
Lower Kitt. Divider	7	8.46 ±3.20 ±38%	.334 ±.072 ±22%
Lower Kitt. Total	24	5.80 ±2.73 ±47%	.323 ±.079 ±24%

FIGURE 72.

Critical Fracture Toughness and Strain Energy Density Summary
Orientation Effects

Specimen and Orientation	Number of Tests	Critical Fracture Toughness (MPa m) Ave., Std. Dev. and Relative Error	Critical Strain Energy Density (N/m) Ave., Std. Dev. and Relative Error
Plaster of Paris	21	.2232 ±.0300 ±13%	2.049 ±.6590 ±32%
Pittsburgh Short Trans.	16	.0879 ±.0587 ±67%	.5422 ±.6743 ±124%
Pittsburgh Arrester	15	.1119 ±.0382 ±34%	.8193 ±.4482 ±55%
Pittsburgh Divider	23	.1431 ±.0523 ±37%	1.349 ±.9650 ±72%
Pittsburgh Total	54	.1181 ±.0553 ±47%	.9627 ±.8321 ±86%
Anthracite Short Trans.	18	.1761 ±.0861 ±49%	2.065 ±1.899 ±92%
Anthracite Arrester	6	.2327 ±.1162 ±50%	3.096 ±2.299 ±74%
Anthracite Divider	13	.1780 ±.0992 ±56%	1.494 ±1.256 ±84%
Anthracite Total	37	.1860 ±.0956 ±51%	2.032 ±1.805 ±89%
Lower Kitt. Short Trans.	9	.5113 ±.3013 ±59%	19.37 ±19.02 ±98%
Lower Kitt. Arrester	8	.8018 ±.4467 ±56%	32.75 ±35.70 ±109%
Lower Kitt. Divider	9	.8184 ±.5581 ±68%	20.29 ±20.98 ±103%
Lower Kitt. Total	26	.7070 ±.4536 ±64%	23.80 ±25.51 ±107%

FIGURE 73.

Critical Fracture Toughness and Strain Energy Density Summary
Loading Rate Effects

Specimen and Loading Rate	Number of Tests	Critical Fracture Toughness (MPa m) Ave., Std. Dev. and Relative Error	Critical Strain Energy Density (N/m) Ave., Std. Dev. and Relative Error
Plaster of Paris-Slow	7	.2203 ±.0237 ±11%	1.958 ±.6080 ±31%
Plaster of Paris-Middle	7	.2031 ±.0240 ±12%	1.922 ±.4820 ±25%
Plaster of Paris-Fast	7	.2463 ±.0275 ±11%	2.268 ±.8740 ±39%
Plaster of Paris-Total	21	.2232 ±.0300 ±13%	2.049 ±.6590 ±32%
Pittsburgh Slow	19	.1033 ±.0503 ±49%	.8118 ±.9381 ±116%
Pittsburgh Middle	16	.1198 ±.0526 ±44%	.9384 ±.6660 ±71%
Pittsburgh Fast	19	.1314 ±.0610 ±46%	1.134 ±.8566 ±76%
Pittsburgh Total	54	.1181 ±.0553 ±47%	.9627 ±.8321 ±86%
Anthracite Slow	11	.1855 ±.0990 ±53%	1.876 ±1.863 ±99%
Anthracite Middle	13	.2057 ±.0899 ±44%	2.297 ±1.579 ±69%
Anthracite Fast	13	.1666 ±.1018 ±61%	1.897 ±2.066 ±109%
Anthracite Total	37	.1860 ±.0956 ±51%	2.032 ±1.805 ±89%
Lower Kitt. Slow	8	.6222 ±.3331 ±54%	18.11 ±16.06 ±89%
Lower Kitt. Middle	9	.6038 ±.3994 ±66%	19.47 ±19.88 ±102%
Lower Kitt. Fast	9	.8856 ±.5756 ±65%	33.21 ±35.49 ±107%
Lower Kitt. Total	26	.7070 ±.4536 ±64%	23.80 ±25.51 ±107%

Other respirable dust generation investigations involve three major areas: (1) indentation tests, (2) rotary coal cutting tests and (3) an analytical study to examine the dust effects of plunging a tool into a coal block.

In the first part both quasi-static and dynamic indentation tests were conducted. From the quasi-static tests on rock and coal, it was found that failure of the specimen at zero and low confining pressures was in extension mode. But at high confining pressures the failure mode changed to tension and shear for rock while it remained the same for coal. However, failure of coal specimen preceded with a high degree of crushing and the confining pressure and wedge angle increased. This crush zone is a major source of respirable dust. In the dynamic tests the distribution of energy in the crush zone of a laterally confined specimen was studied. Parametric study suggests that by applying optimum energy by a sharper tip angled bit which has a narrow and smooth configuration, coal can be cut efficiently and respirable dust can be reduced significantly.

A rotary coal cutting device was fabricated and instrumented to monitor and vary the simulated mining machine operating parameters and in-situ conditions. Parametric experimental studies were conducted and a relationship was established between the size distribution and the fracture surface for bit type, bit spacing, depth of cut, equivalent in-situ confining pressures and cleat orientation. A statistical model was developed to predict the force requirements, specific energy and size distribution. It was concluded that the key to achieve efficient coal fragmentation and reduce respirable dust generation is to limit the degree of bit-coal interaction by choosing the optimum machine operating parameters predicted by the statistical model for seam specific in-situ conditions.

Investigations of the fundamental bit-coal interaction which is believed to be the major source of respirable dust generation resulted in the conclusion that research on secondary dust generation was also necessary. Therefore, the subject of regrinding is the focus of the present research. Modification of the test facilities to carry out the necessary experiments has been completed.

The analytical study involved two stages. They are: 1) to investigate the damage effects of plunging a tool into a coal block and 2) to characterize the damage zone in a coal block around a tool bit due to rotary cutting. In the first stage a parametric study was conducted by dropping different tools from different heights and weights. In the second stage the damage zone was characterized with a single bit configuration using different values of, attack angles, and depths of penetration and normal and tangential loads on the tool under plane strain conditions. Results indicated that the volume of damage zone increased in a nonlinear manner as the ratio of the loads was increased from 0 to 10. However, the increase in damage volume corresponding to an increase in the ratio of the loads from 3 to 10 was only about 20 percent.

8

Technology Transfer

Technology Transfer

In sum, significant benefits to mine worker health have resulted and should continue to result from the synergistic scientific, engineering, and medical research in respirable dust. As always, an important objective is the rapid dissemination of the results of this research to industry. Video tapes and the Technology News series published by the United States Bureau of Mines (USBM) have been a very effective means of technology transfer. Individual no-cost subscriptions to the Technological News series are available from the Bureau of Mines, Branch of Technology Transfer, 2401 E St., N.W. Washington, DC, 20241.

Two respirable dust conferences have been jointly sponsored by the Center, USBM, NIOSH, and MSHA. The proceedings from these conferences are titled:

1. Coal Mine Dust Conference
   held in Morgantown, West Virginia
   on October 8-10, 1984 and

2. Respirable Dust in the Mineral Industries:
   Health Effects, Characterization and Control
   held in University Park, Pa.
   on October 14-16, 1986.

Copies of the proceedings from the first conference are available from the National Technical Information Service (NTIS):

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
NTIS # PB86-169380
Telephone Number: (703)487-4650

Copies of the second conference proceedings, ISBN: 0-936712-76-7 (publication #3010), are available from ACGIH by writing to

William D. Kelley
Executive Director, A.C.G.I.H.
6500 Glenway Avenue, Building D-F
Cincinnati, Ohio 45211
Telephone Number: (513)661-7881

During the period 1984-1987 more than sixty-four (64) papers and publications have been produced by the Center researchers. These publications have appeared in scientific journals and have been presented at national and international symposiums and meetings. A list of these papers, organized by topical headings, has been included in this publication.

The generic center maintains a reference center that serves as a clearinghouse for technical information for the generic area and supplies reports on generic center accomplishments.

9

Conclusion

CONCLUSION

Health standards in the U.S. are among the highest in the world. Achieving these standards have often had an impact on productivity, slowing output, and raising prices to levels that make it difficult to compete with many foreign industries. The answer to many of these problems lies in the development of new and advanced control techniques. This overview has identified some of the major respirable dust technological hurdles that have been overcome, and provided some insight into current and future approaches underway to remove these obstacles and to provide the United States with the most advanced state-of-the-art mining industry in the world from a respirable dust standpoint. The necessary developmental research is costly and time-consuming. The long-term, high-risk aspects of this effort are being addressed by the Bureau and the Generic Center on Respirable Dust, with support by industry. This should be recognized as one of the principal agents through which the great mineral potential of this Nation can be realized, and our international status as a mining power be assured without compromising the health and welfare of those who ensure it.

The problem of more stringent dust standards will continue to grow. To date, approximately 40 pct of the coal mining industry has been placed on more stringent dust standards due to quartz. Control techniques must be improved if mandated levels are to be met. As longwall production increases, dust levels will also increase. In light of the industry trend toward longwall mining, if no new control technology is available, the Federal dust standard will act as a constraint on future output per hour. The Bureau has recently completed a survey of 18 coal preparation plants; 50 pct of these operate at dust levels which exceed 2.0 mg/m^3; future work will be directed toward solutions in this area. The 2.0 mg standard for respirable dust is for dust particles which are below 10 µm in diameter. Recent studies have shown that dust in the range between 10 and 25 µm can cause obstructive airway disease. The Bureau is currently determining the extent of exposure to dust in this size range from various mining operations.

The Generic Center on Respirable Dust is conducting fundamental research which will afford each miner the opportunity to work underground during the period of his/her adult working life without incurring any disability from pneumoconiosis or any other occupational disease. Long-range dust/lung research objectives of the Center include: better methods for the early diagnosis of coal workers' pneumoconiosis, methods to modify the disease process, tests to identify toxic products, and tests to identify individuals with heightened susceptibility to pneumoconiosis. Engineering studies are concerned with reducing the respirable dust in the working environment.

In sum, significant benefits to mine worker health have resulted, and should continue to result, from the synergistic scientific, engineering, and medical research being conducted jointly by the Bureau and the Generic Mineral Technology Center for Respirable Dust.

Publications

PUBLICATIONS LIST

Every entry in the PUBLICATIONS LIST contains the following information:

(1) Last name of the first listed author with the number of authors in parenthesis if the article had multiple authors.

(2) A short description phrase, generally the title of the paper.

(3) The year in which the paper was published or presented

(4) The location of the paper in The Respirable Dust Center published volume.

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