RESPIRABLE DUST IN BITUMINOUS COAL MINES IN THE U.S.

MURRAY JACOBSON

Pittsburgh Field Health Group, Bureau of Mines, U.S. Department of the Interior Pittsburgh, Pa., U.S.A.

Abstract — The Federal Bureau of Mines has conducted a comprehensive environmental dust survey in underground bituminous coal mines. The objectives of the study were to provide information relative to dust concentrations in mines as obtained by different sampling instruments, and to associate levels of dustiness with various mining operations and with specific occupations.

Included in this report are the concepts of respirable dust, the sampling devices used, the procedures followed and the data obtained.

Survey data were collected in operating sections of 29 different large coal mines; limited data were collected from representative small mines. The mean and range of dust concentrations relative to specific occupations and their distribution are presented. A linear relationship is derived between data collected by personal and by MRE samplers.

Partial analysis of the overall survey results indicates that respirable dust exposure can be reduced when water and ventilation are adequately controlled.

INTRODUCTION

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

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

Experimental findings indicate that all airborne dust inhaled does not enter the lungs; the dust of hygienic significance is that portion which reaches the terminal airways of the lungs; this fraction is generally referred to as respirable dust. Therefore, instruments used to evaluate the dust hazard in environmental atmospheres should simulate the respiratory tract in its selectivity for the respirable fraction of the dust particle.

Since understanding of the physiological mechanism associated with dust retention in the lungs is limited, the criterion for selecting dust sizes of hygienic significance is the generally accepted deposition curve for dust in the terminal airways of the lungs. The weight of dust extracted from the lungs of miners examined in autopsy shows good correlation with severity of pneumoconiosis based on X-ray categorization prior to death (NAGELSCHMIDT, 1965). Therefore, it is believed that the weight of dust in the respirable fraction is the parameter of primary interest for hygienic evaluation of dust exposure.

At present there are two criteria for the respirable fraction. The first, resulting from work performed within the U.S. Atomic Energy Commission (LIPPMAN & HARRIS, 1962), is defined by a sampling efficiency curve which is dependent upon the aerodynamic behaviour of the particles and which passes through the following points: effectively 100% efficiency at 2 μm and smaller, 50% efficiency at 3·5 μm, and zero efficiency for particles 10 μm and larger; all sizes refer to equivalent diameters.

The other criterion for the respirable fraction of dust, recommended and adopted by the Johannesburg Pneumoconiosis Conference (ORENSTEIN, 1960), is also defined by a sampling efficiency curve dependent on the aerodynamic behavior of the particles. This curve passes through the following points: effectively 100% efficiency at 1 μm and smaller, 50% efficiency at 5 μm, and zero efficiency for particles of 7 μm and larger; all sizes refer to equivalent diameters.

Equivalent diameter is the diameter of a spherical particle of unit density having the same falling velocity as the particle in question.

Comparison of the two recommended respirable size criteria with the pulmonary deposition curve is shown in Figure 1 (HATCH & GROSS, 1964). The purpose of both criteria is to approximate dust deposition in the nonciliated portions of the lung.

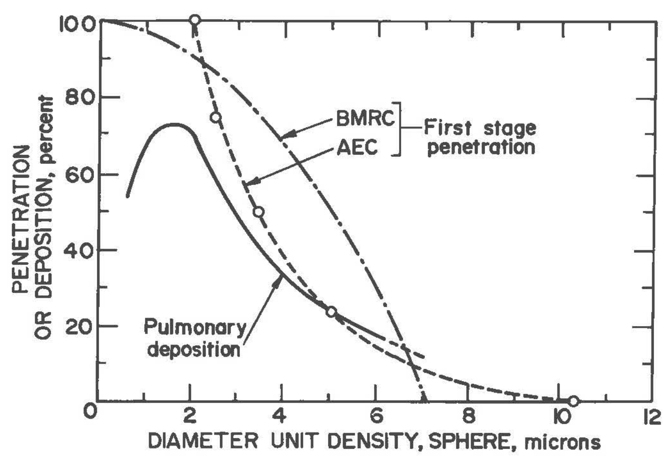

FIGURE 1. Comparison of the recommended respirable size criteria with pulmonary deposition curve

INSTRUMENTS

To effectively assess respirable dust concentrations encountered in the coal mine environment, two-stage sampling devices have been developed. Currently there are two types of respirable gravimetric sampling devices that can be used in the mines of the U.S.A.

The Personal Respirable Dust Sampler (JACOBSON & LAMONICA, 1969) shown in Figure 2 is such a device. The first stage, a 10 millimeter nylon cyclone, performs as an elutriator whose penetration conforms to a curve which is in close agreement with the criterion reported by the U.S. Atomic Energy Commission. (This curve is obtained when the sampler is operated at 2 l/m). The second stage is a membrane filter that collects the respirable fraction of dust which passes through the cyclone. The dust collected is weighed to the nearest 0·1 mg, and concentrations are expressed as milligrams of dust per cubic meter of air sampled.

Another device, shown in Figure 3, is the Isleworth Gravimetric Dust Sampler or MRE (DUNMORE *et al.*, 1964) which was developed at the Mining Research Establishment of the National Coal Board at Isleworth, England. The first stage of the MRE, a four-plate horizontal elutriator, has penetration characteristics that conform to a curve that is in close agreement with the criterion recommended and adopted by the

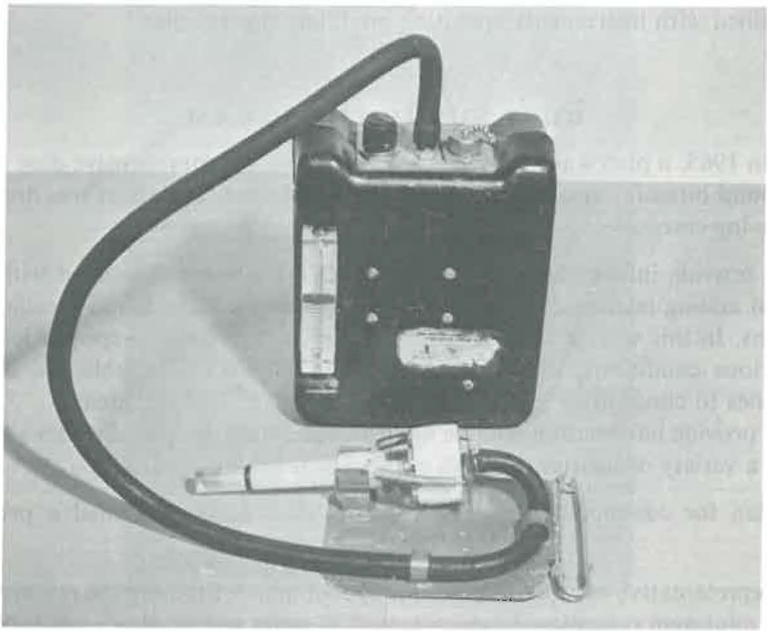

FIGURE 2. Personal respirable dust sampler.

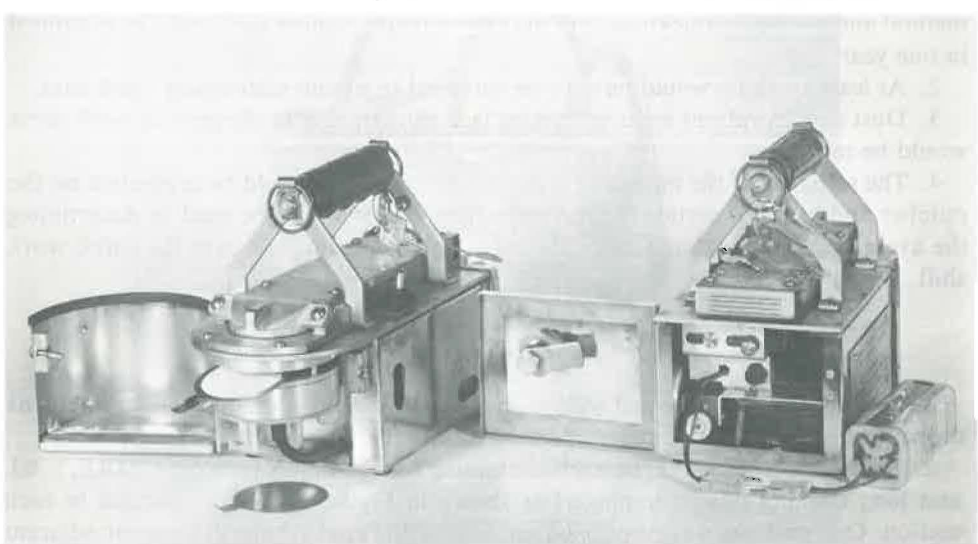

FIGURE 3. MRE or Isleworth gravimetric dust sampler.

Johannesburg Pneumoconiosis Conference. The membrane filter used as the second, or collecting, stage is treated in the same manner as the filters from the personal sampler. Concentrations are again expressed as mg/m^3.

The instruments and procedures described in this report have been tested during the studies conducted in underground mines. The instruments have all proven to be rugged enough to be used underground at the working face and have given results that indicate they can be employed in assessing environmental dust exposures of coal miners and contribute important information relative to correlating dust concentration obtained with instruments operating on different principles.

DUST SURVEY PROGRAM

Early in 1965, a plan was proposed for conducting a comprehensive dust survey of underground bituminous coal mines in the United States. The effort was divided into the following categories:

A. To provide information relative to levels of dustiness associated with various coal mining methods, ventilating conditions, types of coal, and specific occupations. In this way, a listing of levels of dustiness related to specific jobs, under various conditions, would be established. This would enable the Bureau of Mines to concentrate on reduction of this hazard in dusty areas.

B. To provide information relative to dust concentrations in coal mines as obtained by a variety of instruments and evaluation techniques.

The plan for conducting the environmental dust survey included a program in which:

1. A representative number of bituminous coal mines, fulfilling the requirements of having a minimum operational expectancy of 10 years and employing at least 20 men underground, in each of the five Health and Safety Coal Districts would be sampled. The mines surveyed in each district were selected according to productivity, mining method and coal seam thickness, and the approximate number that could be examined in one year.

2. At least 10 shifts would have to be surveyed to obtain statistically valid data.

3. Dust concentrations encountered by face workers and in the general work areas would be measured.

4. The selection of the operating sections to be sampled would be dependent on the number and types of sections in the mine. The results would be used in determining the average exposure of miners employed in specific operations over the entire work shift.

Field Test Procedures

1. Each miner of the selected section crew was equipped with a personal sampler as shown in Figure 4. This sampler operated during the entire shift.

2. Three sampling packages, each containing four samplers (personal, MRE, total, and long running midget impinger, as shown in Figure 5) were positioned in each section. One package was positioned on or near the coal-cutting equipment adjacent to the operator, the second package in the immediate vicinity of workers who were

indirectly involved with the coal getting operation, primarily the roof bolters, and the third was placed in the intake air to the section. All samplers operated the entire time the working crew was in the section.

3. Each sampling team consisted of 4 men, 3 working underground, and 1 on the

FIGURE 4. Personal sampler worn by miner.

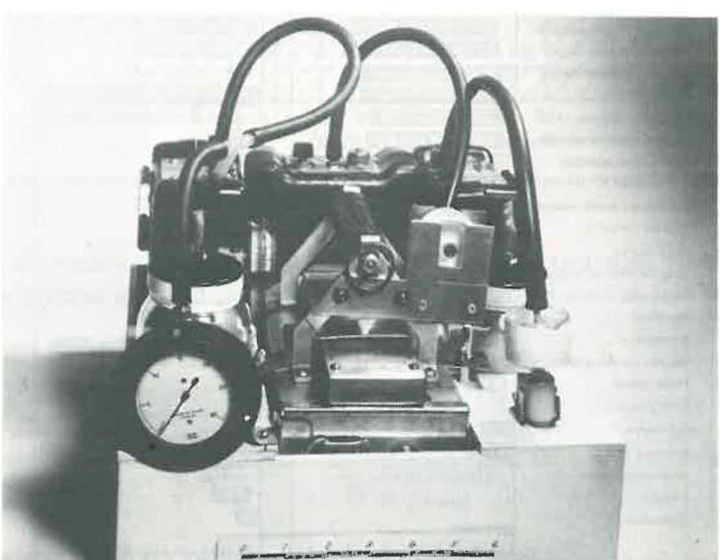

FIGURE 5. Instrument sampling package.

surface. The duties of the team members working underground were to position the samplers in the designated locations, to periodically check and change the appropriate samplers to maintain them in proper operation condition, and to obtain pertinent mining and ventilation information relative to dust generation and removal. The team member on the surface weighed the gravimetric samples, calculated the concentrations, and prepared sampling equipment for the next working shift.

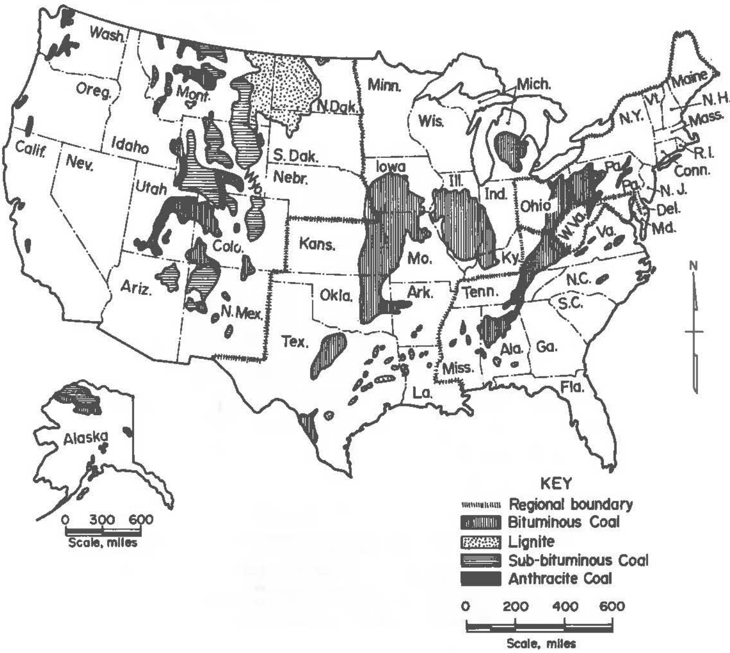

FIGURE 6. Coal deposits in the U.S. and boundaries of the Health and Safety Coal Districts.

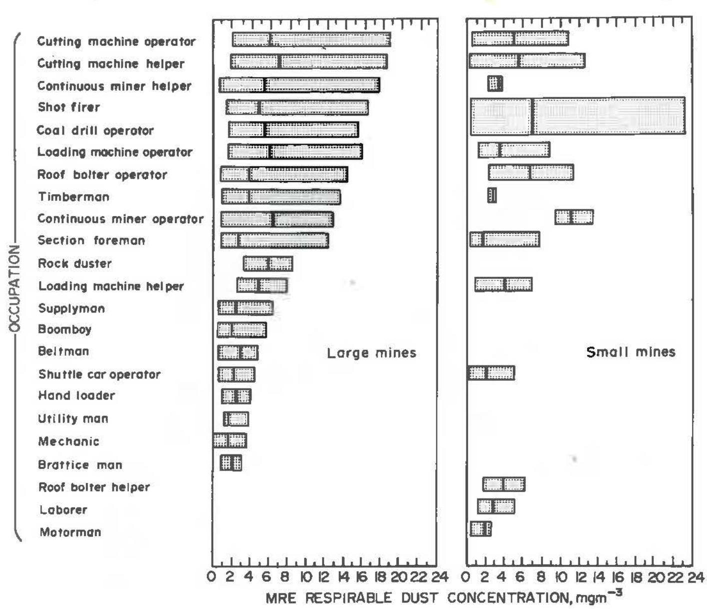

FIGURE 7. Range and average respirable dust concentration for specific occupations.

4. The approximate number of samples per section shift, by category, was as follows:

Personal respirable dust samples	10
Area respirable dust samples	3
Area MRE samples	3
Area total dust samples	3
Area midget impinger samples	6
Total	25

5. All gravimetric samples were weighed on the surface at the mine site. The midget impinger samples were analysed at the Pittsburgh Station of the Bureau of Mines.

6. Composite gravimetric samples were analysed at the Pittsburgh Station for their ash, quartz, and iron contents.

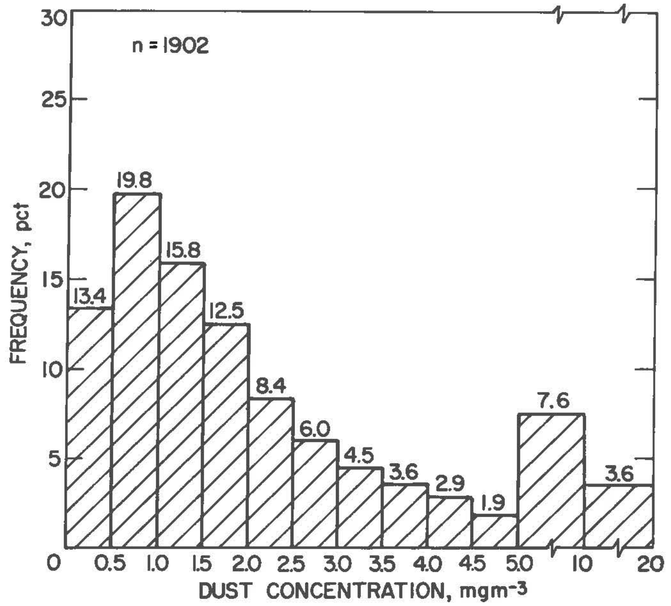

FIGURE 8. Frequency distribution of respirable dust concentrations in operating coal mines.

The initial phase of this comprehensive program included data from 29 mines meeting the criteria specified earlier. These mines are distributed as follows:

No. of Mines	Health and Safety Coal Districts
9	A (Northeast)
8	B (West Virginia)
7	C (Southeast)
4	D (Central)
1	E (West)

A map showing the distribution of coal in the United States and the boundaries of the Health and Safety Coal Districts is shown in Figure 6.

Survey Results

The range and mean dust concentration for specific occupations in the mines are summarized in Figure 7.

The frequency distribution of the respirable dust concentrations determined by full

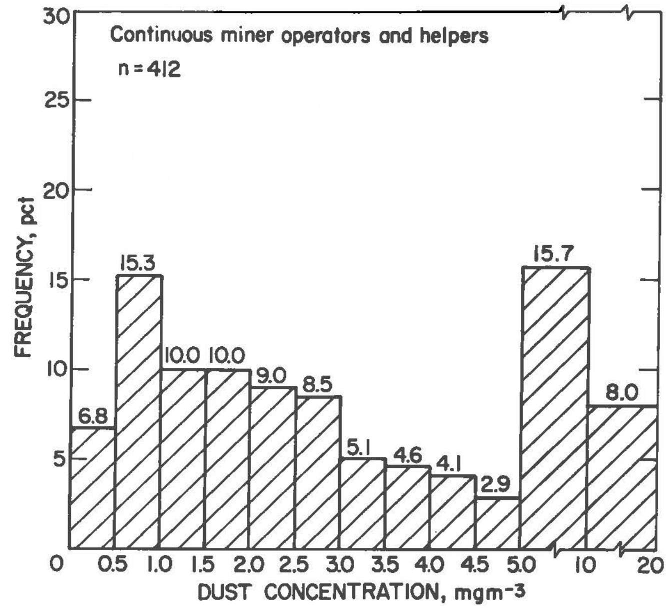

FIGURE 9. Frequency distribution of respirable dust concentrations encountered by Continuous Miner operators and helpers.

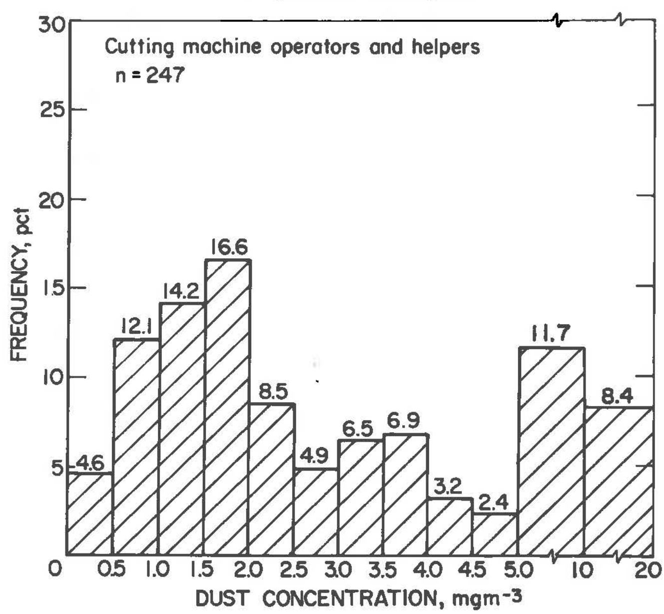

FIGURE 10. Frequency distribution of respirable dust concentrations encountered by machine operators and helpers.

shift personal sampling in operating coal mines is shown on Figure 8. The data describe a skewed distribution which approximates a log normal distribution.

The data shown on the preceding figure were further broken down into five major occupations. Frequency distributions of respirable dust concentrations for the specific occupations are shown on Figures 9, 10, 11, 12 and 13. The dust concentrations

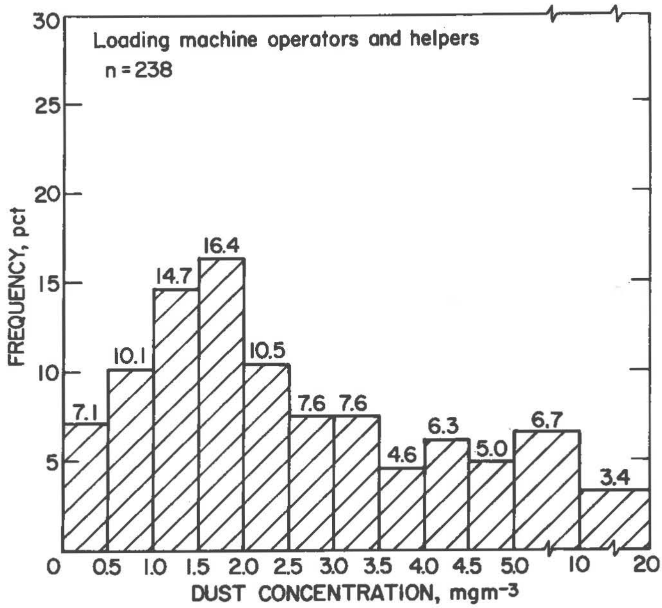

FIGURE 11. Frequency distribution of respirable dust concentrations encountered by loading-machine operators and helpers.

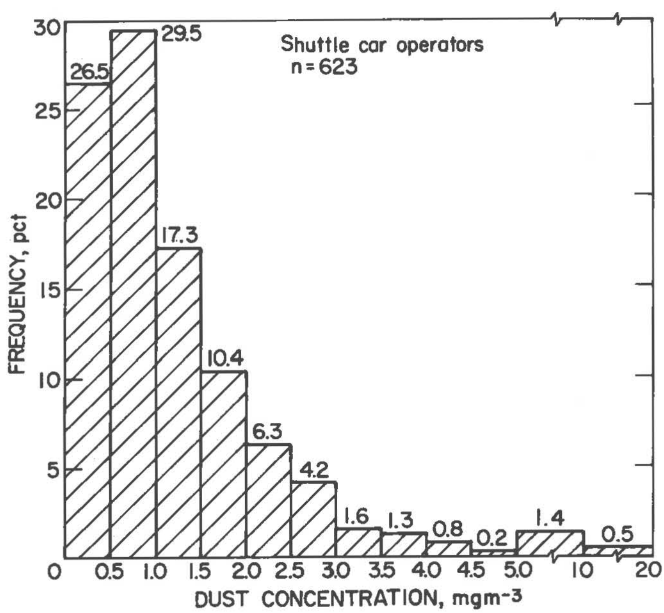

FIGURE 12. Frequency distribution of respirable dust concentrations encountered by shuttle car operators.

encountered by miners in the specific occupations appear to describe skewed distributions similar to that shown as typical for the total data.

The data accumulated during the survey are being analysed by ADP procedures to determine the correlation between dust concentrations and engineering parameters such as ventilation, height of seam, type of coal and mining method. No positive

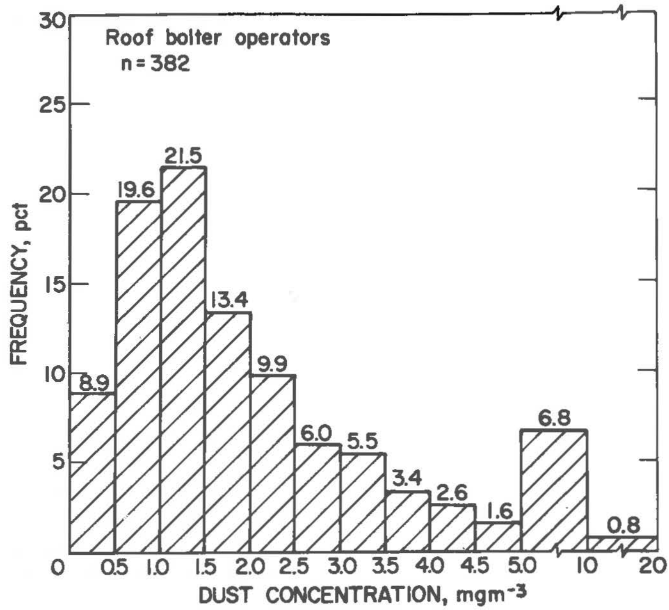

FIGURE 13. Frequency distribution of respirable dust concentrations encountered by roof bolter operators.

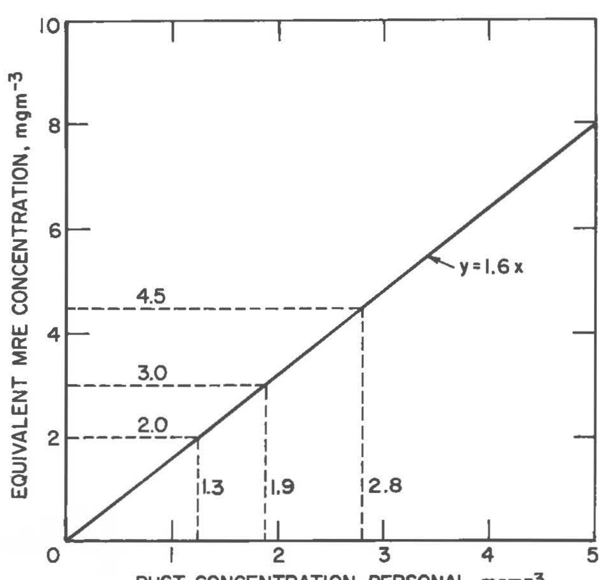

FIGURE 14. Relationship between Personal Sampler gravimetric data and data collected with the MRE

relationships have been derived for individual parameters. Further treatment of data is being pursued using more sophisticated statistical procedures.

A linear relationship derived between personal gravimetric sampling data and data collected with the MRE is shown on Figure 14.

The importance of the relationship between data collected by personal and MRE respirable dust samplers must be emphasized. The dust standards given in the Federal Coal Mine Health and Safety Act of 1969 are specified in terms of mg/m^3 as sampled by the MRE; this empirical relationship permits the using of the personal sampler and reporting in terms of equivalent MRE values.

REFERENCES

DUNMORE, J. H., HAMILTON, R. J. & SMITH, D. S. G. (1964). An instrument for the sampling of respirable dust for subsequent gravimetric assessment. *J. scient. Instrum.* **51**, 669–672.

HATCH, T. F. & GROSS, P. (1964). *Pulmonary deposition and retention of inhaled aerosols.* New York, Academic Press. p. 149.

JACOBSON, M. & LAMONICA, J. A. (1969). Personal respirable dust sampler. *Tech. Prog. Rep. U.S. Bur. Mines* (17).

LIPPMAN, M. & HARRIS, W. B. (1962). Size-selective samplers for estimating "respirable" dust concentrations. *Hlth. Phys.* **8**, 155–163.

NAGELSCHMIDT, G. (1965). The study of lung dust in pneumoconiosis. *Am. ind. Hyg. Ass. J.* **26**, 1–7.

ORENSTEIN, A. J. *Editor* (1960). *Proc. Pneumoconiosis Conf., Johannesbnrg, 1959.* London, J. & A. Churchill. p. 619.

DISCUSSION

H. I. McKENZIE: Do you consider that 2 mg/m^3 is an attainable figure in your mines?

Mr. JACOBSON: I have no available data indicating whether or not 2 mg/m^3 can be achieved. Results of work accomplished by the Bureau of Mines and data obtained during the mandatory sampling programme indicate that 3 mg/m^3 can be achieved.

The requirement to reach the standard of 2 mg/m^3 will be done — because it must be done.

R. E. G. RENDALL: Does your personal sampler incorporate a pulsation damper? If not, do you not think they are necessary?

Mr. JACOBSON: The instruments in use do not incorporate a pulsation damper. There is a possibility that such a device may be necessary.

We now use instruments that are somewhat different from the ones used during our original survey work. An investigation programme is being conducted in the laboratory and in the field to determine the need for pulsation dampers.

J. R. LYNCH: The theoretical relationship between the MRE and the cyclone was calculated to be 1·25 as opposed to the empirical relationship of 1·6. We know that the cyclone does not operate entirely according to theory and that pulsation does have an effect. It may be necessary in the future to include a pulsation dampener in the sampling instrument.

H. BREUER: What was the influence of the increase in mechanized mining in the United States coal mining industry during the past ten years on the respirable dust concentrations? This question is asked because Figure 10 (conventional mining) and Figure 9 (continuous mining) show no essential differences.

Mr. JACOBSON: These results were obtained over 18 months, we did not go back earlier. Although the continuous mining process will, in itself, generate more dust than the individual machine in conventional mining, there is an offset effect because of different ventilation requirements. We looked at the broad occupation, and we could not relate dust concentration to the amount of coal production during the shifts on coal faces. However, differences could show up on a further, more detailed, evaluation of conventional and continuous operations.

W. H. WALTON: The personal sampler approach to dust measurement is good, it enables a large number of samples to be taken and provides a good assessment of the risk. The cyclone is probably the most suitable size-selector in this case, but it is an empirical device which requires calibration against a "standard" selector such as the MRE. I am surprised that it was possible to use the same correlation factor for all circumstances, especially in view of the large spread of ratios of total to respirable dust, from 3 to 50. Were no systematic variations found under different mining conditions?

Mr. JACOBSON: There is a difference in the correlation between the two instruments when the concentration exceeds about 10 mg/m^3. This was found in bituminous coal mines; we have not looked at anthracite mines but the indications are that they will be very similar.

Our measurements are spread over the entire shift, including the time the men travel from the surface to the working place. There is not a constant distribution, as found in certain surface factories. We take the top rock, the coal, the bottom, and we add stone dust; thus the sample covers distributions that vary all the time. That might explain the constancy of our correlation.

S. E. DEVIR: Do you not consider using the Greenberg Smith impinger?

Mr. JACOBSON: The Coal Mines Health and Safety Act, 1969, states that you should use the MRE, with the four plate elutriator, as a standard.

INHALED PARTICLES
III

Proceedings of an International Symposium
organized by the British Occupational Hygiene Society
in London, 14–23 September, 1970

Edited by

W. H. WALTON

VOLUME II

UNWIN BROTHERS LIMITED
THE GRESHAM PRESS, OLD WOKING, SURREY, ENGLAND

First printed and published 1971
by
Unwin Brothers Limited, The Gresham Press, Old Woking, Surrey, England