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Coal in the United States

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Coal was first discovered in the United States in 1673 by Joliet and Marquette in Illinois. The first mining operations were begun in 1701 on the James River near Richmond, Va., but it was not until 1745 that bituminous coal was mined on a commercial basis.

The United States coal fields cover approximately 400,000 square miles or one-ninth of the total land area. Because of its utility and availability, coal has become a basic component of American industry—it generates more than half (51.8%) of the nations electricity; it is a necessary part of the vital iron and steel industries; and it is the basis of thousands of chemical by-products used by industrial and private consumers.

GEOLOGY AND CHEMISTRY

Geology

Most of the coal in the United States was formed during the Mississippian and Pennsylvanian geological epochs (Lower and Upper Carboniferous) about 250 million years ago. The coal found here is classed by four ranks: lignite, subbituminous, bituminous, and anthracite.

The fourth and lowest rank, lignite, is a soft, crumbly, brown-to-black coal that is somewhat more compact than peat. Lignite disintegrates rapidly in air and is liable to spontaneous combustion. It is mined on a limited basis.

Subbituminous coal, the third class, was formed under greater pressures than lignite. This caused additional loss of volatile constituents and a corresponding increase in the relative content of fixed carbon. Although subbituminous coal is black and looks a great deal like bituminous, it weathers and slacks rapidly when exposed to air and is subject to spontaneous combustion if not properly stored.

Bituminous coal, second-class rank, is the most abundant and the most widely used for industrial power, railroad, and heating purposes. There is an almost endless list of slightly different grades of bituminous.

Anthracite, first-class rank, the highest grade of coal, has a brilliant luster and a hard, uniform texture. It was formed under greater pressure than bituminous—pressures resulting from the folding of the earth's surface into great mountain ranges. In the United States, anthracite is mined only in northeastern Pennsylvania.

The United States Geological Survey* estimated that as of 1 January 1967, the remaining coal reserve of the United States was 1,559,875 million short tons. The total reserves of the various ranks of coal are listed in Table I. See Fig. 1 for a map of coal areas in the United States.

TABLE I
TOTAL OF THE VARIOUS RANKS OF COAL

Rank of coal	Millions of short tons in reserve
Bituminous	671,049
Subbituminous	428,210
Lignite	447,647
Anthracite	12,969
Total, all ranks	1,559,875

Chemistry

United States coal is analyzed on the basis of four items: (i) water (moisture); (ii) mineral impurity (ash) left when the coal is completely burned; (iii) volatile matter, consisting of the gases driven out when the coal is heated; and (iv) fixed carbon, which represents the coke-like residue that burns at greater temperatures after the volatile matter is driven off.

Because there are so very many varieties of bituminous coal in the United States, a typical chemical analysis is not meaningful. Table II was extracted from a Bureau of Mines chart and lists analyses of different ranks of coal.

* Aueritt, Paul. Coal Resources of the United States, January 1, 1967. Bulletin 1275, Geological Survey, 1969.

TABLE II

ANALYSES OF DIFFERENT RANKS OF COAL[a]

								Ultimate percent		
					Proximate percent					
Class by rank	State	County	Bed	Condition[b]	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Calor. value (B.T.U./lb)
1. Anthracite	Pa.	Lackawanna	Clark	1	4.3	5.1	81.0	9.6	0.8	12,880
2. High-volatile A bituminous coal	W. Va.	Marion	Pittsburgh	1	2.3	36.5	56.0	5.2	0.8	14,040
3. Subbituminous B coal	Wyo.	Sheridan	Monarch	1	22.2	33.2	40.3	4.3	0.5	9,610
4. Lignite	N.D.	McLean	(Unnamed)	1	36.8	27.8	29.5	5.9	0.9	7,000

[a] Source and analyses of coals selected to represent the various ranks of the Specifications for Classification of Coals by Rank adopted by the American Society for Testing and Materials. Prepared by W. A. Selvig, Bureau of Mines, U. S. Department of the Interior, Washington, D. C.

[b] Sample as received.

MINING METHODS

World production of coal totaled 3.08 billion tons in 1968. The United States supplied nearly 557 million tons of bituminous, anthracite, and lignite, or 18% of the world output in 1968.

Underground

Underground production of coal amounted to 344.1 million tons in 1968 or 63.1% of the United States production. Traditionally, underground coal is mined by the room-and-pillar mining system. In this mining method, main entries are driven into the coal seam and act as haulageways and aircourses. Side entries project into the seam from which coal is removed, forming "rooms."

Up to half of the coal is left in the form of pillars to support the roof.

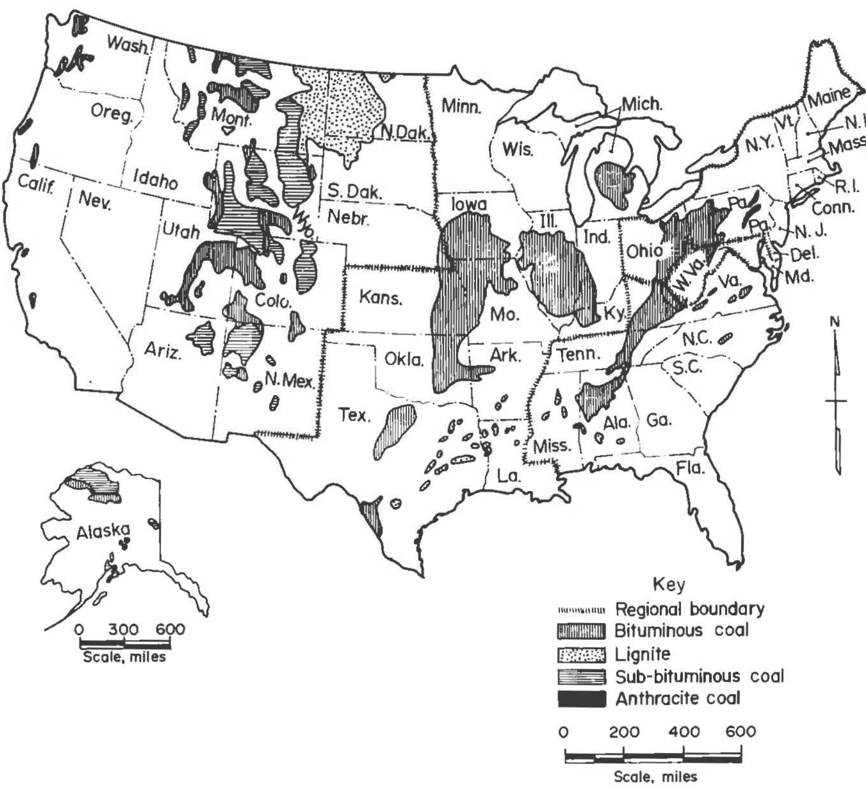

FIG. 1. Map of coal areas in the United States by class.

Conditions permitting, these pillars may be removed on retreat. Since the mid-1930's, coal mining has been mechanized to the point of almost eliminating the hand-loading system of yesteryear. Mechanical, or conventional, mining is characterized by separate machines for drilling, cutting, loading, and roof shoring. In recent years, continuous mining machines have been designed and developed which combine the cutting and loading. This advent of mechanization has revolutionized the mining industry and brought about a marked increase in productivity.

In longwall mining, the prevailing system in European coal mines, a planer or a plow extends along the entire work face (300–600 ft) and contains a coal conveyor. The plow or planer is pulled along the face and rips off coal.

This system has recently begun to gain acceptance in American mines. Coal tonnage mined in the United States by the longwall method increased threefold from 1966 to 1969, growing from 0.4% of all coal mined in 1966 to 1.2% in 1969. Even though these figures are small in an absolute sense, a trend of increasing use of longwall mining is apparent.

Strip Mining

Surface mining may be more economical than underground mining when the coal seam lies near the surface. In strip mining, the earth cover, or overburden, is removed by large power shovels. The exposed coal is then removed and loaded by smaller power shovels. Mining operations usually follow the coal seam until such time as the ratio of overburden to coal makes production uneconomical.

In 1968 production from surface mining amounted to 201.1 million tons, 33.9% of the total United States coal production. The fantastic growth of strip mining was made possible by the development of large-capacity equipment and new blasting agents. Strip mining has the advantages over underground mining of a greater output per man and a resulting lower cost per ton.

Augering

Auger mining, only recently developed, is gaining rapid acceptance. In 1968, it produced 15.3 million tons, or 3% of the total United States production.

When strip mines encounter an overburden too thick for economical removal, they sometimes revert to augering. These strip mines leave seams of coal exposed along what is commonly called a highwall. Large augers bore horizontal holes from the highwall into the seam, much as a carpenter's auger bores holes into wood. The coal is removed from inside the seam through a tube and screw.

The depth to which augering is carried out depends to a large extent on the coal thickness, whether the seams roll or are flat, and if they are strong enough to stand after penetration and not foul the auger.

Punch mining is similar to auger mining in that it is considered a secondary system of mining of coal that normally would be lost owing to the uneconomical overburden ratio. Punch mining employs conventional or continuous mining equipment and underground mining methods to win the coal from the highwall left by the stripping operation.

RESPIRABLE DUST SAMPLING EQUIPMENT

In the United States, respirable dust is measured on a mass concentration basis by two types of respirable size gravimetric samplers: the personal sampler and the MRE instrument. These two-stage instruments continuously sample air from the worker's breathing zone during the full working shift. The atmosphere is drawn through the devices by portable battery-operated pumps powered by nickel–cadmium batteries. Both instruments are battery operated, portable, and instrinsically safe for use in United States coal mines.

The coal mine dust personal sampler was developed by the United States Bureau of Mines. The first stage, a 10-mm nylon cyclone, performs as an elutriator or size selector. Penetration conforms to a curve which is in close agreement with the criterion for dust deposition in the lungs reported by the United States Atomic Energy Commission. The second stage is a membrane filter that collects the respirable fraction of the dust. The dust collected is weighed to the nearest 0.1 mg, and concentrations are expressed in milligrams per cubic meter of air sampled.

The second instrument used to collect respirable dust samples is an instrument developed at the Mining Research Establishment of the National Coal Board at Isleworth, Great Britain. Air is drawn at the rate of 2.5 liters/minute through a four-plate horizontal elutriator, and the penetrating respirable fraction of the dust is collected on a 55-mm-diameter polyvinyl chloride membrane filter. Penetration characteristics of the elutriator (see Fig. 2) agree with the size criteria specified at the Johannesburg Conference. Mass concentrations of samples collected by the MRE instruments are evaluated by weighing the dust retained on the filter to the nearest 0.1 mg. The dust concentration is reported as milligrams of respirable dust per cubic meter of air sampled.

Each instrument has its advantages and disadvantages. The horizontal

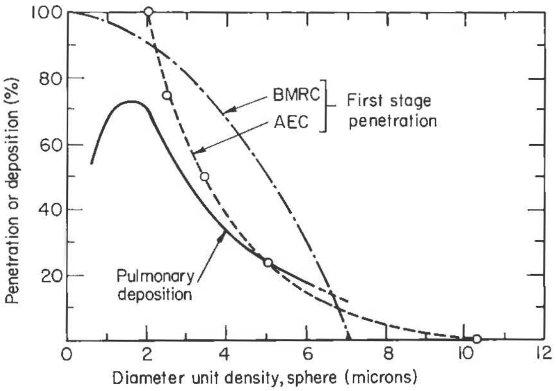

FIG. 2. Specifications for size selective performance.

elutriator-type sampler is bulky, cannot be attached to a miner to determine his dust exposure during the working shift, and is relatively sensitive to horizontal positioning. Its advantages are the consistencies of an empirical relationship between results obtained with this instrument and those obtained with the midget impinger collected under specified conditions.

The advantages of the personal cyclone sampler for gravimetric determination of respirable dust are: the device is light in weight and is portable; positioning of the sampler does not materially affect its operation; and the coarse fraction can be readily recovered for analysis. The disadvantages are that the design characteristics cannot be precalculated, the rate of airflow through the cyclone affects the collection efficiency, particle penetration through the cyclone is reported to decrease with concentration, and agglomeration and disaggregation can occur within the cyclone, causing the characteristics of the collected sample to differ from those of the dust cloud.

The penetration curve of the cyclone's respirable size fraction differs from that of the MRE instrument. However, the ratio of the concentrations collected in sampling under controlled test conditions and in actual coal mine tests appears to be nearly constant.

In addition to the previously mentioned gravimetric respirable dust samplers, which are required to fulfill sampling requirements under the Federal Coal Mine Health and Safety Act of 1969, the impinger-type instrument is used in coal mines for engineering investigations.

Although impingers are not used extensively outside this country, they have been in use in the United States since 1922 to collect samples for the determination of dust exposures. Most of the information correlating degree of dustiness with physiological effects has been obtained by use of the impinger and standardized light-field count methods.

The Greenburg–Smith impinger was developed at the Bureau of Mines in cooperation with the U. S. Public Health Service in 1922. The midget impinger was designed in 1937 to overcome the objections to the use of the early impinger, which was bulky and heavy and had a high power dissipation rate. The newer device is a small-scale duplicate of the standard instrument in every respect except that it operates at an impinging velocity of 70 instead of 100 m/second and samples at a rate of 0.1 instead of 1 ft^3/minute. The development of the midget impinger greatly extended the practical convenience and usefulness of this method of dust sampling, because it provided the investigator with a light, small, hand-operated device for use in underground coal mines. Presently, intrinsically safe, battery-powered sampling pumps are available for operating midget impinger samplers.

MINE ENVIRONMENT

Dust Concentrations in Large Underground Coal Mines

In April 1968 the Bureau of Mines initiated a study of dust exposures in selected large underground bituminous coal mines. The objective of this comprehensive study was to obtain data on the respirable dust exposures of coal miners. These data would then be used for correlation with medical data obtained by the U. S. Public Health Service on the same coal miners. It was hoped that this study would provide information which would be useful in the development of a respirable dust standard and the determination of the effects of dust on the progression of pneumoconiosis.

The study was limited to mines that employed more than 20 men and had a producing life in excess of 10 years. All major bituminous coal fields were assessed. The study included a variety of production methods and mining systems, resulting in an overview of mining conditions indicative of those found in the bituminous-coal mining industry. During the study, no attempt was made to alter mining methods which would result in changing worker's dust exposures.

Nearly 2000 samples were evaluated to determine occupational respirable dust exposures in underground coal mines. Table III illustrates the mean dust concentrations found in the 29 mines that were studied.

The respirable dust exposures listed in Table III are indicative of concentrations found throughout the bituminous-coal mining industry at the time of this survey. It should be noted that these exposures are neither

TABLE III

MINE MEAN DUST CONCENTRATIONS BY OCCUPATION[a]

Occupation	No. of mines	No. of samples	Dust concentration (mg/m³) <1.6	1.61 2.4	2.41 2.9	>2.9	Low, high and mean concentration (mg/m³) Low	High	Mean	MRE equivalent
Continuous miner operator	21	178	2	2	4	13	0.02	21.44	4.08	7.7
Continuous miner helper	19	131	4	3	2	10	0.44	18.90	3.47	6.5
Cutting machine operator	15	98	1	6	2	6	0.71	15.42	3.69	6.9
Cutting machine helper	8	37	1	3	—	4	0.77	14.70	4.45	8.4
Coal drill operator	9	59	3	—	1	5	0.42	12.94	3.55	6.7
Loading machine operator	18	97	2	1	2	13	0.25	39.56	3.75	7.1
Loading machine helper	6	31	—	3	—	3	0.50	14.48	3.17	6.0
Roof bolter operator	25	296	6	9	6	4	0.09	38.50	2.46	4.6
Shuttle car operator	27	463	17	7	3	—	0.12	10.50	1.45	2.7
Beltman	7	32	2	3	1	1	0.42	4.97	1.85	3.5
Boomboy	6	20	5	—	—	1	0.23	5.88	1.30	2.4
Timberman	12	49	7	1	—	4	0.38	11.74	2.49	4.7
Shotfirer	12	83	5	2	2	3	0.62	56.97	3.15	5.9
Supplyman	8	24	5	1	1	1	0.05	9.36	1.59	3.0
Mechanic	19	142	17	2	—	—	0.06	5.43	1.10	2.1
Section Foreman	28	236	19	4	2	3	0.14	14.51	1.69	3.2
Percent of Total	—	—	40	19	11	30	—	—	—	—

[a] Sample taken with the personal sampler.

presumed nor implied to be representative of dust concentrations in the mines prior to this survey.

An analysis of the data indicates that (i) a significant number of occupations has respirable dust exposures in excess of the proposed legislative limits, (ii) the lightest dust exposures were recorded on the cutting machine helper, (iii) water and face ventilation were the only measures used to control airborne dust, and (iv) ventilating air entering working places in some cases contained a considerable amount of dust.

The respirable dust standard in the Federal Coal Mine Health and Safety Act of 1969 is for dust containing less than 5% SiO_2 (quartz). Table IV shows results of analysis from quartz from samples taken during

TABLE IV
QUARTZ PERCENTAGE IN MINE ATMOSPHERES

	Quartz (SiO_2)	
Mine	Respirable	Gross
A-1	1.6	—
A-2	1.3	1.4
A-3	.9	1.2
A-4	.4	.4
A-5	1.1	.6
A-6	1.5	1.0
A-7	1.0	2.3
A-8	—	—
A-9	—	—
B-1	1.1	.8
B-2	.8	—
B-3	2.9	2.1
B-4	2.4	2.1
B-5	.9	1.1
B-6	—	—
B-7	—	—
C-1	2.2	1.7
C-2	1.8	1.2
C-3	3.1	2.4
C-4	1.3	.9
C-5	2.3	1.5
C-6	2.2	1.5
C-7	—	—
C-8	—	—
D-1	2.0	1.9
D-2	—	—
D-3	—	—
D-4	—	—
E-1	1.0	.5

this study. In all mines studied, the quartz content was below 5%, with an average of 1.5%.

Dust Concentrations in Small Underground Coal Mines

In September 1969 the Bureau of Mines conducted a study to determine respirable dust exposures in 12 small bituminous coal mines. The objective of this study was similar to that of the study conducted in large mines. The criteria for selection of mines were employment under six men and production of less than 100 tons/shift.

An analysis of this study produced the following conclusions:

1. Slightly over 50% of the miners monitored were subjected to exposures of less than 3.0 mg/m^3, and nearly 80% were subjected to exposures of less than 4.5 mg/m^3. All measurements were taken with personal samplers and were converted to MRE equivalents.
2. In most cases, excessive respirable dust concentrations resulted from lack of face ventilation.
3. All investigators reported that respirable dust levels could be markedly reduced by employing face ventilation techniques.
4. Higher dust concentrations were recorded on miners working at distances well beyond their source of fresh ventilating air.

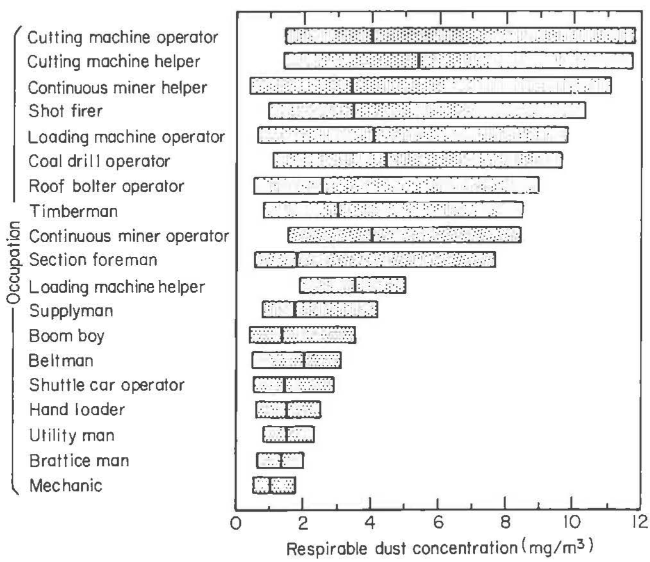

FIG. 3. Mean and range of full shift dust exposures relative to specific occupations in bituminous coal mines.

5. The graph in Fig. 3 shows dust exposures relative to specific occupations, measured with the personal sampler. The graph in Fig. 4 is a comparison of the dust exposures (converted to MRE values) from large and small mines.

Dust Concentrations in Aboveground Mining Facilities

In the summer of 1970, the Bureau of Mines conducted a study to determine respirable dust exposures in 39 strip mines, auger mines, and preparation plants. The facilities chosen were representative of the industry in size and methods of operation.

An analysis of this study produced the following conclusions:

1. Eighty-eight percent of all workers had exposures of less than 2 mg/m^3. All measurements were taken with personal samplers and were converted to MRE equivalents.

2. In most cases, excessive respirable dust concentrations were found

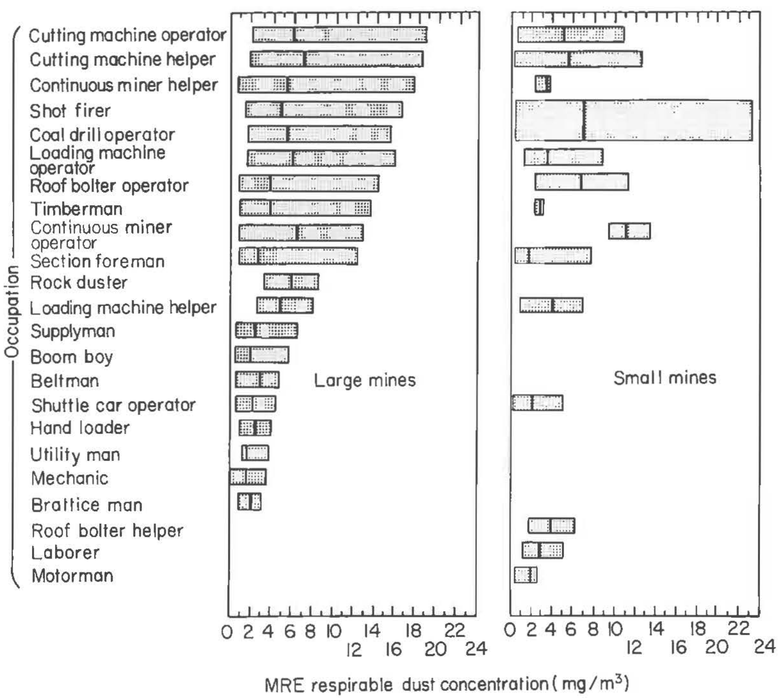

FIG. 4. Range and average respirable dust concentration for specific occupations (MRE).

among the laborer or repairman occupations where the excessive exposure resulted from exposure while in a confining area.

3. Exposures at strip and auger mines are presumably less in winter months when vehicle windows are closed.

Table V indicates that the mean and median exposures at aboveground facilities were much less than the exposures underground.

TABLE V
SUMMARY OF THIRTY-NINE SURFACE STUDIES

Type of facility	No. of samples	% < 1 mg/m³	% < 2 mg/m³	% < 3 mg/m³	Mean	Median
Auger	50	68	86	90	1.1	0.7
Preparation plant	516	57	84	93	1.3	0.9
Strip	416	79	93	97	0.8	0.6
	982	67	88	94	1.1	0.7

Control of Respirable Dust

In general, control measures used which reduce respirable dust are limited to water and ventilation. Water infused into the coal seam has produced limited results. In 1957 the Bureau of Mines reported that water infusion did not materially reduce respirable dust. Some reduction was later reported in continuous mining, but the reduction was insufficient to meet legislated requirements.

Water sprays are employed extensively throughout the coal mining industry to abate concentrations of total airborne dust, as well as respirable dust. Spraying systems are used on the coal mining machines as well as at loading points and coal transfer points. To reduce respirable dust, water sprays must produce a very fine mist to be effective on particles 1 micron or less in size. Producing the necessary quantity of small droplets of water in the form of a mist which is required to allay respirable dust has not been completely successful.

After data from previous studies were initially assessed, it became increasingly apparent that the single most important parameter affecting the abatement of respirable dust was ventilation. In an effort to further refine the effect of ventilation, the Bureau launched a short-term technical study in mines on the control of respirable coal mine dust by ventilation. Results of these tests clearly indicated that under certain conditions, face-generated dust could be effectively confined, captured, and conducted to return airways. Figure 5 illustrates test results of face-generated concen-

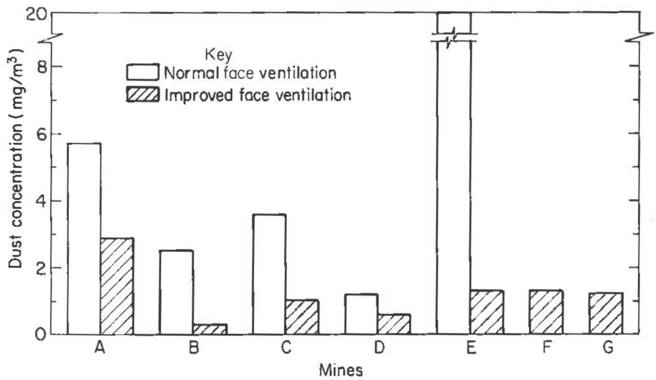

FIG. 5. Face-generated respirable dust concentration at continuous mining machine.

trations of respirable dust at continuous mining machines recorded during this study. Thus, in some situations the technology exists which can greatly reduce harmful concentrations of respirable dust. However, adapting this technology to existing mining equipment and underground conditions will, in some cases, prove difficult. For instance, in coal seams where the total mining height is less than 48 in., it is difficult to provide the space required to make this technology applicable. Also in retreat or pillar mining, there may be a problem in maintaining the velocity of air required to establish control. Finally, and as a direct result of this study, it was determined that the amount of respirable dust entering the section may contribute to high dust concentrations.

PULMONARY REACTIONS TO COAL DUST

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