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Respirable Dust Generation: Comparison of Continuous and Conventional Mining Methods When Excavating Rock in Coal Mines

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute	mg/st	milligram per short ton
ft	foot	min	minute
hp	horsepower	pct	percent
in	inch	st	short ton
mg/m^3	milligram per cubic meter		

RESPIRABLE DUST GENERATION: COMPARISON OF CONTINUOUS AND CONVENTIONAL MINING METHODS WHEN EXCAVATING ROCK IN COAL MINES

By John A. Organiscak[1]

ABSTRACT

The U.S. Bureau of Mines recently conducted an investigation into the amount of respirable and quartz dust generated while mining rock in coal mines by continuous and conventional methods. The study was made at two mines that use both continuous and conventional mining. Results show that continuous mining produces 1.2 to 3 times more respirable dust, and 6.7 to nearly 15 times more quartz dust than conventional mining.

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INTRODUCTION

Throughout the history of U.S. coal mining, mining has progressed from labor-intensive and hazardous operations to highly mechanized and safer methods. Some of the largest production gains came with the development of the continuous miner (CM). A CM replaces the cyclical operations of undercutting, face drilling, blasting, and loading with one operation. This simplification of operations has resulted in reductions in the labor requirements at the face, the number of entries required to mine efficiently, and place changes through deeper cutting, and increases in the safety and use of retreat pillar mining. Thus, continuous mining methods began to replace cyclical mining techniques in 1947, reaching a peak of 77 pct of all U.S. underground coal mining production in 1975 (fig. 1) (*1*),[2] while conventional mining production dropped from essentially 100 pct in 1947 to 19 pct in 1975. However, both continuous and conventional mining production have declined from 1975 to the present and are projected to continue declining because of the significant productivity gains of longwall mining.

In the early 1980's, quartz dust in underground coal mines could be monitored much more readily than before because of the development of the P7 infrared spectrophotometry technique to analyze compliance dust samples for quartz. When the percentage of quartz in the compliance dust sample exceeds 5 pct, the compliance standard is reduced from 2.0 mg/m^3 to 10 divided by quartz percent (example: 10 pct quartz in sample yields a reduced standard of 1.0 mg/m^3). Utilization of the P7 infrared technique has allowed compliance dust samples to be analyzed for quartz, increasing the number of continuous sections placed on reduced compliance dust standard (*2*).

The Bureau of Mines conducted several studies to identify the source of the quartz dust and found that the major contributor was the CM when cutting rock (roof, partings, or floor) (*3-6*); when a CM cuts rock, pick penetration is less, bit wear rate is increased, mined rock size is smaller than coal, and quartz dust becomes part of the finer particle fraction. Two-thirds of the mines with quartz problems operated in five or more entries, and these problems were associated with main- and submain-entry development. When mains and submains are developed, more reject (rock) is usually mined to improve travel clearance and cross-sectional areas for ventilation. These types of development plans are suitable for conventional mining, which can be considered as an alternative mining method.

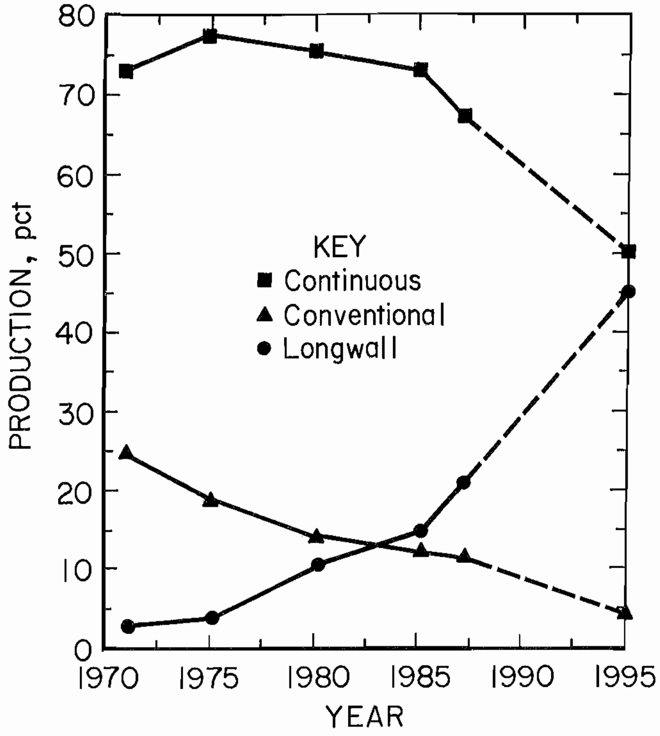

Figure 1.-Underground production by coal mining method. (Dashed lines represent projected production.)

This study investigated the potential of utilizing the conventional mining method to reduce the amount of quartz dust generated. Previous research into the size of run-of-mine (ROM) coal clearly established that the product produced by the CM was finer than the product produced from conventional mining (*7*). These results implied that a similar relationship exists for respirable dust. Therefore, an investigation into this phenomenon was conducted at two mines, both utilizing each method. Each mine used the conventional section as a construction unit in main-entry development to mine more rock per foot of advance. A continuous versus conventional comparative study was made using data collected at both types of mining sections. This report describes the sampling strategy and presents the results of this study.

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[2] Italic numbers in parentheses refer to items in the list of references at the end of this report.

SAMPLING STRATEGY AND ANALYSES

The sampling strategy was structured to isolate and determine the amount of dust generated only during the mining process, excluding roof bolting. Undercutting, face drilling, blasting, and loading operations of conventional mining were compared with cutting and loading operations by a CM. The dust concentrations reflected average levels *only* during mining and cannot be used for compliance purposes. Also, dust concentrations measured in the return air of a cut are *not* representative of workers' actual dust exposure during mining. Data collected at each section included respirable dust samples (gravimetric and instantaneous), bulk samples of rock mined, ventilation quantities, cut dimensions, thickness of rock mined, thickness of coal mined, and time studies of each method during mining.

The instantaneous sampling was conducted with a real-time aerosol monitor (RAM-1) connected to a data logger. RAM sampling was conducted simultaneously with gravimetric sampling to determine a gravimetric-RAM ratio to be applied to instantaneous RAM averages of individual mining operations. The adjusted RAM concentrations reflected more absolute dust concentrations because they were calibrated to gravimetric measurements. Further analyses included quartz analysis of gravimetric dust samples and rock bulk samples, percentage contribution of conventional operations to dust generation, and normalization of airborne dust concentrations for ventilation, production, and mining time.

CONVENTIONAL VERSUS CONTINUOUS MINING AT MINE A

EXPERIMENT DESCRIPTION

Mining took place in the three Kittanning Seams. The continuous section mined the lower and middle Kittanning Seams, with one rock parting, for a combined mining height of 5.5 ft. The conventional section mined the lower, middle, and upper Kittanning Seams for a combined mining height of 7.5 ft. Both sections mined some roof rock. Table 1 shows the thickness and quartz content of the rock mined at both sections. Results showed that the quartz content in the rock was comparable between sections.

Face ventilation at both sections was by single-split, exhaust-curtain systems. The conventional section was a six-entry development plan that mined 10-ft-deep by 18-ft-wide cuts. The continuous section was a four-entry development plan that mined 20-ft-deep by 20-ft-wide cuts.

Table 1.—Rock mined at mine A

Section and rock sample	Thickness, in	Quartz, pct
Conventional:		
Parting 1	14	38.6
Parting 2	6	29.8
Roof	4	22.9
Continuous:		
Parting 1	12	34.0
Roof	6	26.7

Dust sampling at the conventional section was conducted only in the outmost intake entry to eliminate any upstream contamination from other concurrent conventional mining operations in the section (fig. 2*A*). To monitor intake air quality, two gravimetric samplers were located in the immediate intake of the entry, and four gravimetric samplers and one RAM were located in the immediate return behind the line brattice. Sampling was conducted for all the conventional equipment operations through four complete cut cycles.

Dust sampling at the continuous section was mobilized with the CM (fig. 2*B*). Four cuts were monitored. For measuring intake air quality, two gravimetric samplers were located in the last open crosscut; four gravimetric samplers and one RAM were located behind the entry return brattice.

Tables 2 and 3 show the results obtained at mine A, and figure 3 shows the percentage contribution of dust from individual conventional operations at mine A. Average dust concentrations per cut were compiled only from time-weighted averages of dust concentrations measured during mining activities. The amount of dust generated per cut was determined by normalizing dust concentrations for time, ventilation, and production.

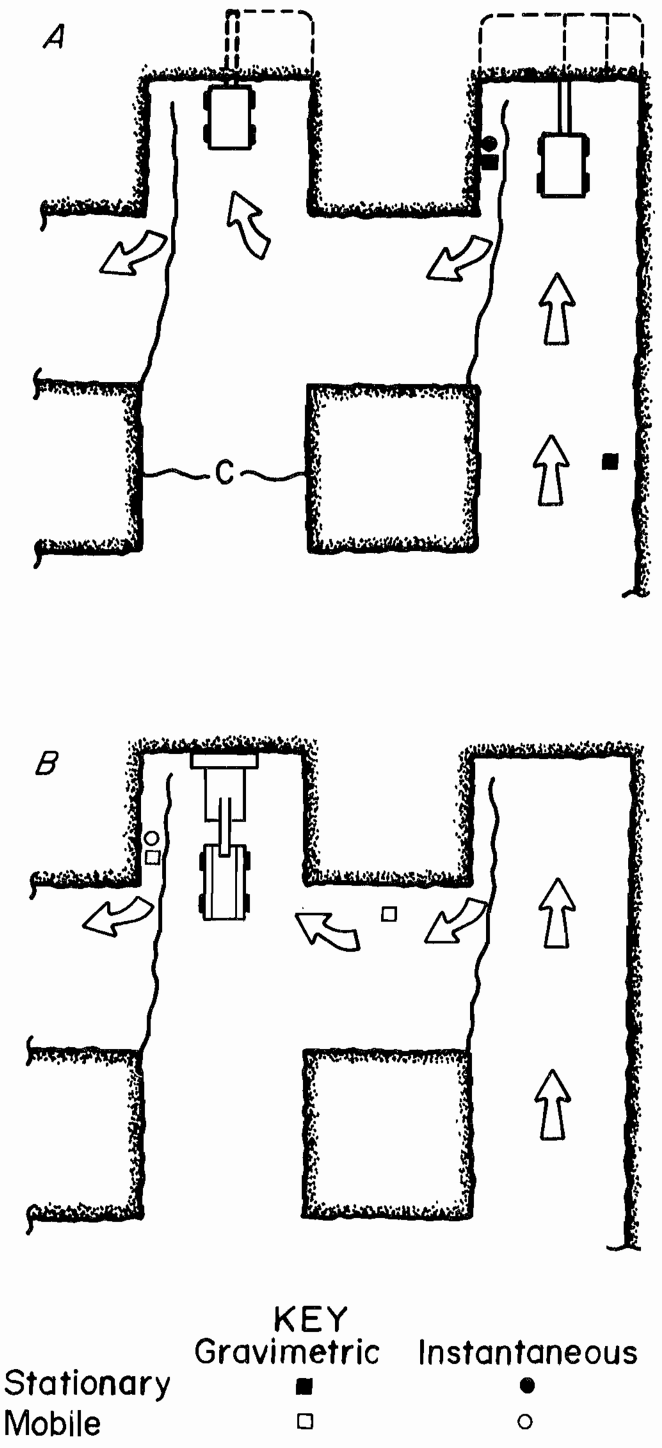

Figure 2.-Dust sampling strategy at mine A. *A*, **Conventional mining;** *B*, **continuous mining.**

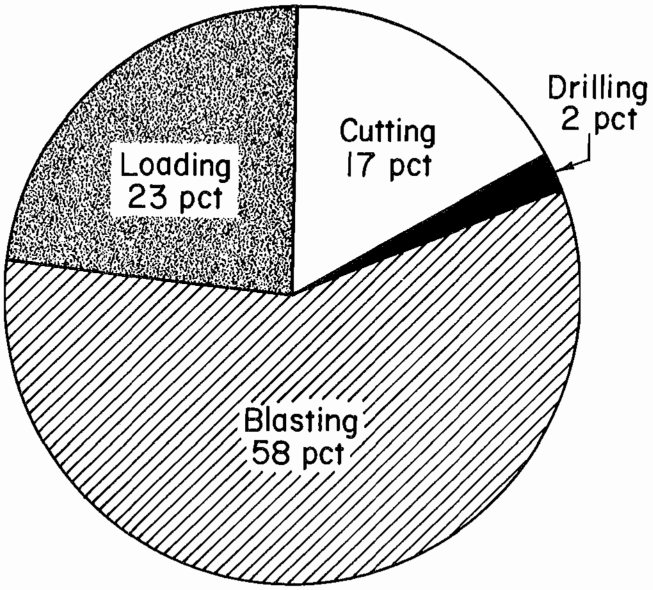

Figure 3.-Sources of conventional mining dust at mine A.

RESULTS

Both the amount of respirable dust and the quartz content of the dust generated at the continuous section were significantly greater than at the conventional section. Return dust concentrations at the conventional section averaged 2.91 mg/m^3 during mining, while return dust concentrations at the continuous section averaged 25.89 mg/m^3. The percentage of quartz in the respirable dust at the continuous section was approximately 2.5 times more than at the conventional section.

Although mining parameters at both sections were different, the conditions were very similar. The conventional section mined an additional seam and a parting, but no significant difference was apparent between the quartz content in the rock mined and the percentage of reject per cut at the two sections. The weighted averages of quartz content in the rock mined at the conventional and continuous sections were 33.8 and 31.6 pct, respectively. The percentages of reject per cut (by weight of rock mined) at

Table 2.—Conventional mining dust generation, mine A

	Cut 1	Cut 2	Cut 3	Cut 4
Dust concentration .... mg/m^3 ..	2.41	2.34	3.29	3.60
Quartz .... pct ..	2.9	2.9	2.2	2.2
Total sampling time .... min ..	42	49	64	71
Face ventilation .... cfm ..	1,880	3,220	4,660	4,660
Mined product (ROM) .... st ..	68	68	68	68
Rock mined .... st ..	28	28	28	28
Specific dust .... mg/st ..	79.2	154	407	494
Specific quartz dust .... mg/st ..	5.58	10.8	21.8	26.4

NOTE.—Average specific dust = 284 mg/st.
Average specific quartz dust = 16.1 mg/st.

Table 3.—Continuous mining dust generation, mine A

	Cut 1	Cut 2	Cut 3	Cut 4
Dust concentration .... mg/m^3 ..	22.46	22.76	22.37	35.97
Quartz .... pct ..	10.1	10.1	10.1	6.5
Total sampling time .... min ..	24	59	55	48
Face ventilation .... cfm ..	3,780	2,710	4,590	2,930
Mined product (ROM) .... st ..	56	112	112	112
Rock mined .... st ..	24	47	47	47
Specific dust .... mg/st ..	1,030	920	1,428	1,280
Specific quartz dust .... mg/st ..	243	221	344	198

NOTE.—Average specific dust = 1,164 mg/st.
Average specific quartz dust = 252 mg/st.

the conventional and continuous sections were 41 and 42 pct, respectively. Dust data were further analyzed (normalized) to negate the effects of different mining parameters (production and ventilation) on dust concentrations.

Specific dust and specific quartz dust amounts at both sections showed that the rotary cutting action of a CM generates significantly more dust than the conventional process of mining coal. *Continuous mining produced 3 times more respirable dust than conventional mining, and nearly 15 times more quartz dust.* These results indicate that conventional mining generates less dust, and this advantage over rotary cutting improves when mining rock.

Dust contributions from individual conventional mining processes show that blasting generated the majority of the dust during the cut (58 pct) (fig. 3). Dust contributions of cutting (17 pct) and loading (23 pct) were similar. Good water application at these operations was implemented. The loader had hollow-cone water-spray coverage on the loading pan and gathering arms. The cutting machine used a wet bar with water sprays directed at the kerf. Face drilling contributed negligible amounts of dust (2 pct) and utilized wet cutting at the bit. This section also maintained good exhaust-brattice lines for all the entries and sustained airflow at all faces.

The continuous section used a conventional boom-mounted water-spray system directed at the mining head. Airflow was comparable with that of the conventional section, but noticeable dust rollback reached the CM operator (*8*). When the CM was cutting rock, the dust levels in the return increased and occasionally went off the scale (25 mg/m^3).

CONVENTIONAL VERSUS CONTINUOUS MINING AT MINE B

EXPERIMENT DESCRIPTION

Mine B operated in the Mary Lee Seam. Both sections mined two partings in the 65-in seam. Table 4 shows the thickness and quartz content of the rock mined at both sections. Quartz content in the rock was almost identical at both sections; the face ventilation was by single-split, blowing-curtain systems. The continuous section was a nine-entry development supersection that mined 20-ft-wide by 40-ft-deep cuts with the assistance of a remote control

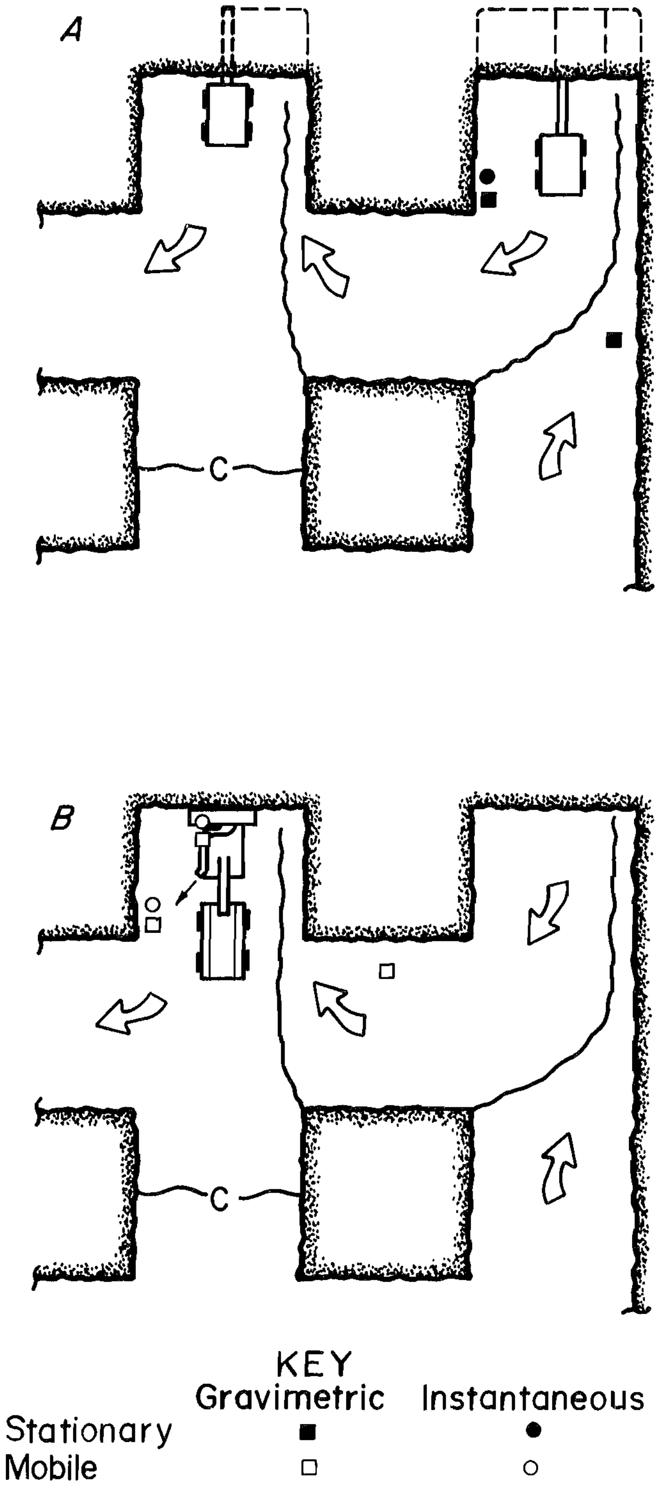

Figure 4.-Dust sampling strategy at mine B. *A*, Conventional mining; *B*, continuous mining.

Table 4.—Rock mined at mine B

Section and rock sample	Thickness, in	Quartz, pct
Conventional:		
Bottom parting	15	33.3
Top parting	4	28.3
Continuous:		
Bottom parting	14	33.3
Top parting	4	29.0

and a machine-mounted fibrous bed scrubber. Two CM's alternated operation. Dust sampling was conducted at the CM that was located on the intake side of the section to minimize intake dust contamination. The conventional section was a six-entry development plan that mined 10-ft-deep by 20-ft-wide cuts.

Dust sampling at the conventional section was conducted in the outmost intake entry to eliminate any upstream contamination from other concurrent mining operations in the section (fig. 4*A*). Two gravimetric samplers were located in the immediate intake behind the line brattice; four gravimetric samplers and one RAM were located in the entry outby the face for measuring return air. Sampling was conducted during conventional operations over four complete cuts.

CM sampling equipment was moved as the cutting machine advanced. Two gravimeters were located in the immediate intake behind the line brattice; four gravimetric samplers and one RAM were located 2 ft outby one scrubber intake and outby the scrubber exhaust (fig. 4*B*). A straight 40-ft cut and a 20-ft-long crosscut were sampled.

Tables 5 and 6 show the results obtained at mine B, and figure 5 shows the percentage contribution of dust from individual conventional operations at mine B. Average dust concentrations per cut were compiled only from time-weighted averages of dust concentrations measured during mining activities. The amount of dust generated per cut was determined by normalizing dust concentrations for time, ventilation, and production.

RESULTS

Dust concentrations at both sections showed no significant differences. Return dust concentrations at the conventional section averaged 3.70 mg/m^3 for all operations. At the continuous section, concentrations just outby the scrubber intake and the scrubber exhaust were 4.39 and 3.51 mg/m^3, respectively. It was impractical to sample inby the scrubber intake, so the amount of dust actually generated by the CM was probably higher than the amount measured just outby the scrubber intake. However, the percentage of quartz in respirable dust at the continuous section was approximately three times more than that in the conventional section.

Table 5.—Conventional mining dust generation, mine B

	Cut 1	Cut 2	Cut 3	Cut 4
Dust concentration .... mg/m^3 ..	3.96	4.81	3.38	2.63
Quartz .... pct ..	1.7	1.7	.7	.7
Total sampling time .... min ..	61	49	38	42
Face ventilation .... cfm ..	4,740	4,740	5,980	5,980
Mined product (ROM) .... st ..	56	56	56	56
Rock mined .... st ..	25	25	25	25
Specific dust .... mg/st ..	578	564	390	335
Specific quartz dust .... mg/st ..	22.0	21.5	6.11	5.26

NOTE.—Average specific dust = 466 mg/st.
Average specific quartz dust = 13.7 mg/st.

Table 6.—Continuous mining dust generation, mine B

	Scrubber intake		Scrubber return	
	Cut 1	Cut 2	Cut 1	Cut 2
Dust concentration .... mg/m^3 ..	4.58	4.19	3.44	3.58
Quartz .... pct ..	4.3	4.8	5.9	4.3
Total sampling time .... min ..	81	70	81	70
Face ventilation .... cfm ..	16,940	16,940	16,940	16,940
Mined product (ROM) .... st ..	224	112	224	112
Rock mined .... st ..	100	50	100	50
Specific dust .... mg/st ..	795	1,257	597	1,074
Specific quartz dust .... mg/st ..	76.6	135	78.9	103

NOTE.—Average specific dust = 1,026 mg/st at scrubber intake and 836 mg/st at scrubber return.
Average specific quartz dust = 106 mg/st at scrubber intake and 91.0 mg/st at scrubber return.

Coal seam conditions were identical at both sections. The mining height and number of partings mined were the same. The weighted averages of the quartz content in the rock mined at the conventional and continuous sections were 32.2 and 32.3 pct, respectively. Reject per cut (by weight of rock mined) at both sections was 45 pct. The most prominent difference between these two sections was ventilation. The continuous section had two times more air than the conventional section. Dust data were further analyzed (normalized) to negate the effects of different mining parameters (production and ventilation) on dust concentrations.

Specific dust and specific quartz amounts at both sections indicate that the CM with a scrubber still generates more airborne dust per ton than conventional mining. *Continuous mining produced 1.2 times more respirable dust, and 6.7 times more quartz dust (measured just outby the scrubber intake) than conventional mining.* Even on the exhaust side of the scrubber, the specific dust was almost double, and the specific quartz dust was 5.6 times greater at the continuous section than at the conventional section. Again, this strongly suggests that, for limiting dust generation, there is an advantage using conventional mining when cutting rock.

Dust contributions of the individual conventional mining processes show that loading generates most of the dust (70 pct) (fig. 5). Water sprays were present on the loader, but spray coverage, orientation, and pressures were not optimal. The cutter machine used a wet bar with additional sprays directed at the kerf, which contributed 19 pct of the dust. Blasting contributed only 10 pct, because ventilation, which was considered to be excellent, kept concentrations and duration low. The face drill utilized wet drilling and contributed negligible dust (1 pct). This section maintained good blowing brattice line for all the entries and sustained airflow at all faces.

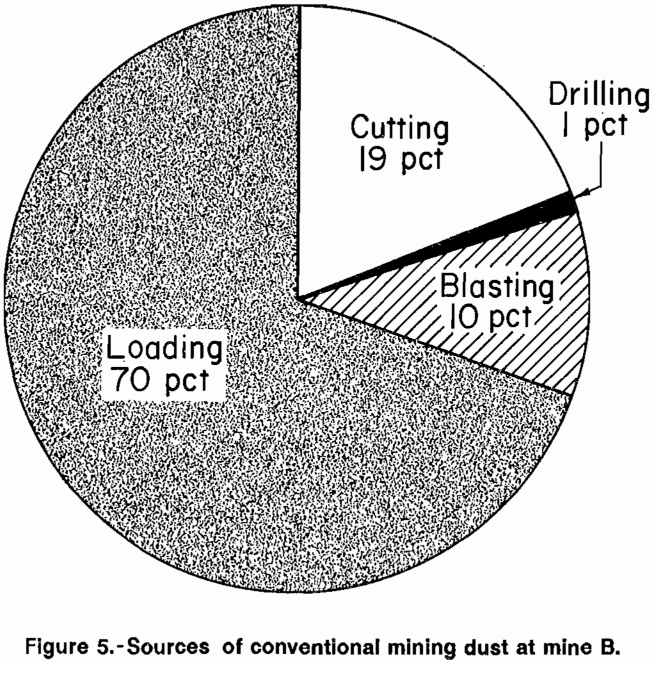

Figure 5.-Sources of conventional mining dust at mine B.

The continuous section utilized a 6,000-cfm (30-hp) fibrous-flood bed scrubber with blowing ventilation for dust control. Air quantity to the face was almost 17,000 cfm. The scrubber's effectiveness can be seen from the dust level results outby the scrubber exhaust (fig. 6). Even though the scrubber obtained good results during the box cut on the off-curtain side, the ventilation overpowered the scrubber during the slab cut on the curtain side and reduced its capture efficiency.

CONCLUSIONS

Continuous mining generates more respirable dust and quartz dust than conventional mining. In this study, it was shown that continuous mining produces 1.2 to 3 times more respirable dust, and 6.7 to nearly 15 times more quartz dust than conventional mining. This difference is attributed to diverse types of extraction methods. The CM mills the coal and rock, which produces more fines. Blasting fractures the coal and rock into larger sizes and produces less fines and dust; i.e., it is a more efficient extraction process. The amount of dust generated using conventional mining when excavating rock decreases notably. These results confirm past experience, which showed that rotary-cutting efficiency diminishes when cutting rock, and chemical agents (explosives) provide a better means of excavating hard materials (rock).

These results should not be construed to mean that all mines should use conventional mining for dust control, only that conventional mining produces less dust. Workers' dust exposure in continuous sections can be effectively controlled through implementation of available dust-control technology (*9*). Although conventional mining produces less dust, neglecting basic dust-control technology (ventilation, water application) can expose conventional mining workers to dust levels greater than the Federal compliance level, because dust levels are cumulative from multiple face operations.

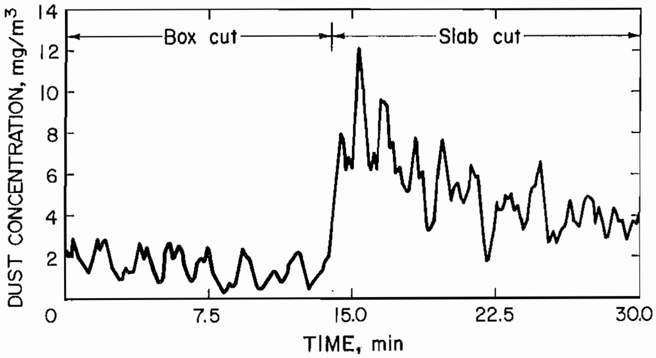

Figure 6.-Dust concentrations outby the scrubber exhaust.

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