Development of a Fixed-Site Machine-Mounted Respirable Sampler for Underground Coal Mines

Andrew J. Gero, Paul S. Parobeck, and Thomas F. Tomb

Mine Safety and Health Administration, P.O. Box 18233, Cochrans Mill Road, Pittsburgh, Pennsylvania 15236

In May, 1991, the U.S. Secretary of Labor directed the Assistant Secretary for Mine Safety and Health to conduct a thorough review of the program to control respirable coal mine dust in the nation's mining operations. In response to that directive, the Assistant Secretary established the Coal Mine Respirable Dust Task Group, whose purpose was to study and recommend improvements to the program to control respirable coal mine dust. The Task Group concluded that new technology for continuous monitoring of the mine environment, and of the parameters used to control dust, offer the potential to improve the Mine Safety and Health Administration's dust enforcement program. The primary long-term recommendation made by the Task Group was that an accelerated research program be initiated to evaluate existing state-of-the-art technologies with the potential to be used in a fixed-site underground coal mine dust monitor. The instrument would provide continuous information to the miner and mine operator on the status of dust resulting from the mining process. To accommodate the recommendation, the Mine Safety and Health Administration and the Bureau of Mines instituted a joint-venture program for the development of such a monitor. In the meantime, the Mine Safety and Health Administration has undertaken a program to assemble and evaluate the application of a fixed-site monitor capable of continuous sampling, using current sampling technology, on a continuous-mining operation. The Mine Safety and Health Administration's program consists of assembling three coal mine personal sampler units into a package and programming them to sample the mine environment sequentially during each working shift (first, second, and third). The sample collected for each respective shift is cumulative for up to 7 days. The samples are analyzed to determine the average multiday respirable dust concentration. The data were analyzed to determine long-term sample variability, as well as intershift variability. This article presents the details of the design of the continuous monitor, its application, and a discussion of the data collected. GERO, A.J.; PAROBECK, P.S.; TOMB, T.F.: DEVELOPMENT OF A FIXED-SITE MACHINE-MOUNTED RESPIRABLE SAMPLER FOR UNDERGROUND COAL MINES. APPL. OCCUP. ENVIRON. HYG. 11(7):630–636; 1996.

In May, 1991, the Secretary of Labor directed the Mine Safety and Health Administration (MSHA) to conduct a thorough review of the program to control respirable coal mine dust and to develop recommendations for how the program could be improved. The impetus for the request was the announcement on April 4, 1991, of the issuance of approximately 4,700 citations to over 500 companies for alleged tampering with respirable coal mine dust samples. In response to the Secretary's directive, the Assistant Secretary for Mine Safety and Health established an interagency task group (the Coal Mine Respirable Task Group) to conduct the review and develop the recommendations. Although the tampering issue prompted the formation of the task group, the areas studied extended far beyond that issue and include, among other things, the development of new or improved monitoring technology.

In June, 1992, the task group published its report.[1] The principal recommendation for long-term improvement of the program is the establishment of "an accelerated research program to evaluate state-of-the-art technologies having the potential to be used in the development of a fixed-site underground coal mine dust monitor. . . . The ultimate goal is to have an instrument that . . . will provide continuous information to the miner and mine operator on the status of dust resulting from the mining process as well as information on the status of compliance with respect to the applicable respirable dust standard." As a result of this recommendation, MSHA requested the Bureau of Mines to develop a continuous respirable dust monitor that can be mounted on a mining machine or operate at a fixed site in a mine. As a result of this request, the Bureau of Mines and MSHA entered into a joint-venture program for the evaluation of different techniques that could continuously monitor the coal mine atmosphere and provide "real-time" information to the miner and mine operator about the concentration of coal mine dust. The expected time-frame for completion of the joint-venture program is 1½ to 5 years (tentatively projected to be completed by the middle of 1996). In the meantime, MSHA has undertaken a study to evaluate the application of a fixed-site monitor, using current sampling technology, on a continuous-mining operation.

The objectives of the study were to determine whether a machine-mounted respirable dust monitor could be developed and utilized to measure continuously the concentration of dust in the environment. Specific issues addressed include: mounting a continuous monitor in a proper location on a continuous-mining machine; problems that could arise concerning the durability of the monitor on the mining machine, such as whether it could be knocked off the mining machine or otherwise damaged; and obtaining preliminary data to help determine how MSHA could best use the monitor as part of its enforcement program.

 1047-322X/96/1107-630$15.00/7 · PII S1047-322X(96)00057-0

Description of Mining Operation

Evaluation of the fixed-site sampler is being conducted in an underground coal mine. The sampler is mounted on a Joy 12CM twin-head continuous-mining machine used for development of a longwall section. Mining is in the Pittsburgh coal seam, which is approximately 6 feet thick. Total mining height is approximately 7 feet.

Coal mined at the face is loaded into shuttle cars and transported to the section dumping point, where it is loaded on a belt for transport out of the mine. Since the Joy mining machine incorporates an integral roof-bolting system, bolting takes place after each 4-foot cut of coal. In addition, a roof-bolting machine is used periodically to center pin the roof.

Dust is controlled in the section by ventilation and water. An exhaust ventilation system, supplemented by an auxiliary tubing system (16-inch ventilation tubing with a Joy 50-horsepower fan) is used to exhaust 5,000 to 12,000 cubic feet per minute from the face area. Dust generated during the mining operation is further controlled by 26 water sprays mounted on the cutting head of the mining machine. In addition, the conveyor of the mining machine has a spray system installed to prevent dust from boiling back over the operator. The water spray system operates at a water pressure of 150 pounds per square inch.

Rock dusting is conducted with the continuous-mining machine in place in the mined entry. This occurs after the mining machine has advanced 40 feet in the entry. Rock dusting is conducted for periods that typically last for 5 minutes, followed by a 10-minute waiting period before reentering the dusted area. During a typical operating shift, this procedure would occur three times.

Instrument Design

The sampler consists of a package of three coal mine dust personal sampler units (PSU) interfaced with a programmable controller that sequentially activates the units. The pumps, which have their battery packs removed, receive power from the mining machine through the controller, which is enclosed in an explosion-proof box mounted on the mining machine. Using its internal clock, the controller routes power to a selected pump during each working shift. The cyclones of the PSUs are mounted in a chamber, permitting sampling from a common inlet. The overall size of the package containing the PSUs is approximately 24 cm high, 16 cm deep, and 19 cm wide.

An intrinsically safe data logger is fastened to the sampler box and monitors current flow to each of the pumps, keeping track of the date and time of day using its own internal clock. The component layout in the sampler box is shown in Figure 1.

The original intent was to operate the sampler continuously, but, because of concerns regarding unattended operation and probable contamination during rock dusting (which is carried out with the mining machine at the face and personnel removed from the face), the system was modified so the controller passes power to the pumps only when power is supplied to the mining machine's cutting head. The data logger's automatic startup and shutdown are used so that it too operates only when the cutting head is powered.

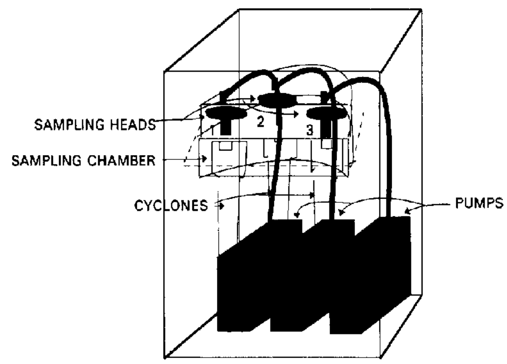

FIGURE 1. Component layout of sampler box.

Laboratory Experiments

Prior to mounting the sampler on a continuous-mining machine, preliminary testing was conducted in a laboratory dust chamber to compare samples collected by each PSU within the sampler to a sample collected by an external PSU. The initial testing was performed by collecting samples with all three PSUs simultaneously, but later tests were performed operating only one PSU at a time, more closely simulating the planned conditions of use in mines. Test duration was approximately 3 hours using a coal dust aerosol. The aerosol concentration was maintained at a high level (approximately 5 to 40 mg/m^3) in order to collect a sufficient amount of material during the test period for gravimetric analysis, as well as to validate the operation of the sampler with the dust loads anticipated over several shifts of sampling.

In-mine Experiments

Two boxes, containing sampling heads and pumps, and two data loggers were prepared so they could be periodically exchanged and the filters and data logger information analyzed. The sampler box was mounted on the continuous-mining machine to the outside and front of the operator's cab (Figure 2), while the controller was placed in an explosion-proof box on the mining machine. The controller was programmed to switch active pumps at the shift change times of 8 a.m., 4 p.m., and midnight. The usual time for exchanging the sampler box and data logger was Monday morning at approximately 9:30 a.m. Each filter was used to collect aerosol for all times when mining was conducted during its shift through the week. As many as six shifts were sampled using the same filter.

Prior to placement on the mining machine, filters were preweighed to 0.001 mg on a Mettler MT5 microbalance and the data logger memory cleared. Pump flow rate was checked and, if necessary, adjusted. The box was assembled and sealed. After removal from the mine, filters were removed from the box and postweighed to 0.001 mg, the data logger memory read and the box cleaned. Production information for the section was obtained from the mine office.

Testing of the sampler in the mine began in December, 1993. Through July, 1994, 23 weeks of mining had been monitored. During several weeks, the equipment was being

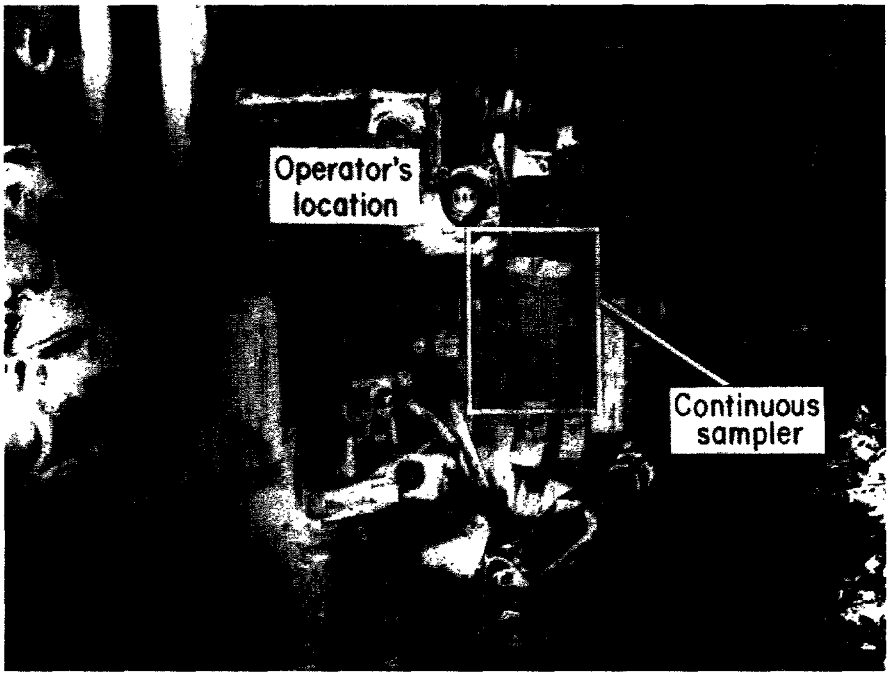

FIGURE 2. Sampler box.

moved between sections, and on occasion no mining was performed on the section during a week.

Data Analysis

Laboratory

A zero-intercept least squares linear regression model[2] was used to compare the quantity of dust collected by a sampler in the sampling chamber to the quantity collected by the PSU simultaneously sampling outside the chamber. Only data collected during tests when the samplers were individually operated were used.

In-Mine

The information stored by the data logger included the date, time of day, and the current being drawn by each pump. Data were only captured when power was supplied to the mining machine's cutting head. The date and time of day were used to calculate how many minutes the respective sampler had operated during the shift, and the current measurements provided verification that the pumps were operating normally. This information was used to determine the length of time mining was occurring on each shift on each day. Shift changes were determined from the time of day. It was observed that mining was almost always performed for more than 1 minute at a time. Therefore, any time the mining machine's cutting head was operated for less than 2 consecutive minutes was assumed to be for some purpose other than mining (such as cleaning of the bits) and not included in the time. The weight gain from the filters and the time each pump was operated during the week were used to calculate the respirable aerosol concentration during mining.

TABLE 1. Sample Weights (mg) Collected by Samplers Outside and Inside the Sampling Chamber During Laboratory Evaluation of the Continuous Monitor

External PSU	Internal Sampling Head 1	External PSU	Internal Sampling Head 2	External PSU	Internal Sampling Head 3
4.357	4.420	1.939	1.846	11.137	11.172
13.746	12.016	11.771	8.780	11.853	11.173
5.776	5.251	5.527	3.138	5.682	5.759
3.773	3.836	3.822	3.284	3.880	3.634
7.204	6.930	14.039	10.763	11.981	11.812
8.438	7.008	11.297	10.271	8.083	6.871

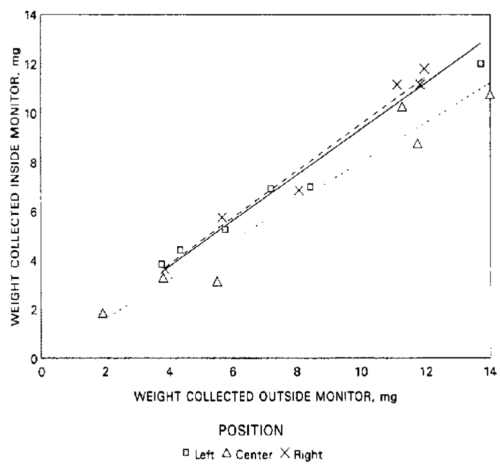

FIGURE 3. Comparison of sample weights collected outside and inside the continuous monitor-laboratory tests.

The number of days on which mining was conducted on the different shifts was determined from production information. This approach was used rather than information from the data logger because there were several times when mining machine operation was recorded (typically for approximately 20 minutes) but no production was reported. It was assumed that maintenance or cleanup was being conducted at these times. An average aerosol concentration for the shifts where production was reported was calculated assuming miners were present through the full shift (480 minutes).

For the shift during which the box was exchanged, shift and tonnage were apportioned based on mining time while the box was in operation. In addition, average production and time spent mining on each shift were calculated for each week of operation. Average concentration values normalized to production data were also calculated. The variability of these quantities from shift to shift and from week to week were characterized.

Results

Laboratory

The results of the laboratory tests are shown in Table 1 and Figure 3. They indicate that losses occur at all three sampling locations within the chamber, with the greatest loss at the center position, which is recessed further from the box inlet. On average, losses at this location were approximately 20 percent, while losses at the other two locations approximated 5 percent. There was considerable variability in the data at all three locations, indicating that the design of the inlet needs to be optimized. The degree of variability prevented the calculation of "correction" factors to give values equivalent to the PSU results.

In-Mine

The average concentrations determined from filter analysis and data logger information, and production data, are summarized in Table 2. Figures 4 and 5 show the average concentrations for each week obtained on each shift, based on run time and 480-minute shift time, respectively. The concentration based on the 480-minute shift is the concentration that would approximate the machine operator's full-shift exposure. The calculated 480-minute average concentrations ranged from less than 0.1 mg/m^3 to 0.5 mg/m^3. Figures 6 and 7 show the equivalent concentration data normalized to production. Normalizing for production was done to determine if the weekly variability in concentrations would be reduced. Figure 8 shows week-to-week variability, expressed as the coefficient of variation, for each work shift, while Figures 9 and 10 show the variability between shifts for each week. As shown in these figures, there is frequently considerable variation in concentration between shifts during a week, or within a shift from week to week. The concentration based on run-time varied between shifts by more than 80 percent during one week, and by more than 40 percent during several other weeks. The variability of each shift across weeks was nearly 50 percent for all three shifts for both the run-time concentration and the 480-minute shift concentration, with the midnight shift having the greatest variability. When the concentration is normalized to production the variability, contrary to what was expected, is even greater, whether across weeks during each shift or across shifts during each week.

Figure 11 shows a trend plot of the weekly mass obtained for all shifts against the weekly production. Although there is variability in the data, this plot shows a reasonable relationship between the mass of dust collected and the quantity of material produced on this mining operation. The increased variability observed when the data are normalized to production indicates the dust concentration measured by the sampler is not solely dependent on dust produced by the mining process.

One of the major concerns considered in developing the fixed-site sampler was ruggedness of the unit from both hardware (ruggedness of electrical components) and operational (capable of withstanding the day-to-day mining process) standpoints. For this evaluation, withstanding the rigors of the operation was of primary concern, since the sampler contained no sophisticated electrical components. While the units used in this evaluation were found to be extremely durable and reliable, several incidents did occur that caused sampling to be interrupted. On one occasion, the sampler suffered damage when the mining machine was turning a corner. The cowl protecting the sampling entrance was crushed and the hinges of the door severely damaged. On another occasion, one of the cables connecting the control box and the data logger was torn loose. In addition, on three occasions, one of the wires providing power to the sampling pumps became disconnected.

Damage to the sampler and interfacing cables was due in part to the fact that the position where the sampler was located was not ideal. Although the sampler was relatively small, locating it to measure the dust in the mining machine operator's breathing zone was difficult, especially without impeding his view and without placing the sampler in jeopardy from damage. Consequently, the location selected left the instrument in a vulnerable position. The process of selecting an appropriate location for the sampler brought to light the problems that may be encountered when retrofitting a device of this type to various types of mining equipment.

TABLE 2. Results of In-Mine Tests

	Day				Midnight				Afternoon			
Week	Mass (mg)	Time (min)	Prod (tons)	Shifts	Mass (mg)	Time (min)	Prod (tons)	Shifts	Mass (mg)	Time (min)	Prod (tons)	Shifts
1	0.979	733	2506	5	1.282	651	3491	6	1.745	527	2332	5
2	0.583	306	1338	2.2	0.596	437	1758	3	0.306	266	1264	2
3	1.094	809	3159	5.7	0.826	648	2741	5	1.232	444	1715	4
4	0.999	812	2925	5	1.237	601	1993	5	2.263	939	3470	6
5	1.606	602	2190	4.8	1.261	671	2503	5	1.179	590	2116	5
6	0.786	487	1229	4.1	0.636	508	1796	4	0.869	519	1285	4
7	0.720	481	1301	4	0.972	577	1604	4	1.187	356	1307	3
8	0.558	510	1462	3.9	0.809	718	1873	5	1.013	631	1607	4
9	0.93	792	1790	4.7	0.859	743	2707	4	0.593	586	1692	4
10	0.215	180	465.3	1	0.138	335	704	2	0.438	404	1060.7	3
11	0.254	386	1166.6	2.1	0.366	570	1614	4			1001	2
12	0.361	735	1859.7	4.1	1.555	490	1468.1	4	0.693	594	1656.2	3
13	0.721	575	1403.1	3.9	0.458	882	2414.4	6	0.751	596	1877.8	5
14	0.429	243	715.4	2.1	0.375	339	1181.8	2	0.519	248	783.9	2
15	0.591	501	1410	2.8	0.427	493	1645	3	0.643	515	1650	4
16	1.074	690	1856	4			2017	4	1.111	471	1351	3
17	0.261	197	651	2	0.347	247	669	2	0.241	311	693	2
18	0.976	389	1052	2.2	0.754	557	1593	4	0.762	531	1561	3
19	0.587	534	1417	4	0.643	572	1274	4	0.996	457	1401	3
20	0.341	215	387	0.8	2.85	112	284	1	0.778	500	1229	3
21			725	2	0.061	98	224	1	0.288	166	441	1
22	0.021	19	58.8	0.5	0.824	332	893	2	0.124	97		
23	0.584	191	677.2	2.5	0.426	207	564	2	0.411	231	637	2
Mean	0.667	472.3	1380.2	3.2	0.688	490.4	1609.2	3.6	0.825	453.6	1460.5	3.3
SD	0.370	234.6	790.8	1.5	0.395	207.2	831.6	1.5	0.507	187.0	651.8	1.2
CV	55.5	49.7	57.3	46.2	57.4	42.3	51.7	41.2	61.5	41.2	44.6	37.64

Future work

It is intended that, during further in-mine testing, PSUs will be placed near the sampling box and on the continuous-miner operator to provide comparative samples. The PSUs will be changed daily. Data obtained with this work will provide a comparison between the average concentrations measured with the continuous sampler and the combined personal sam-

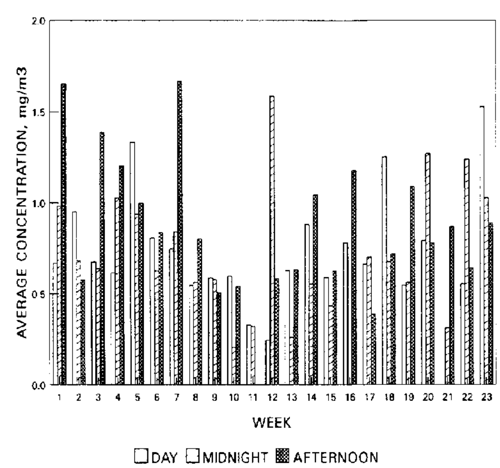

FIGURE 4. Average weekly shift concentration based on run time.

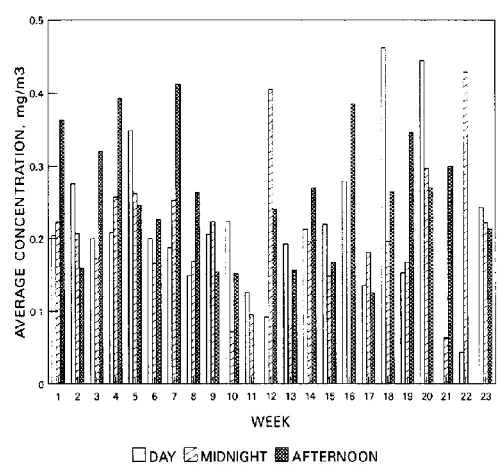

FIGURE 5. Average weekly shift concentration based on a 480-minute shift.

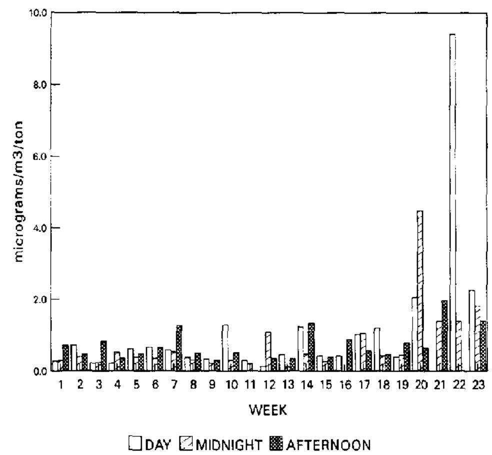

FIGURE 6. Average weekly shift concentration based on run time and normalized to production.

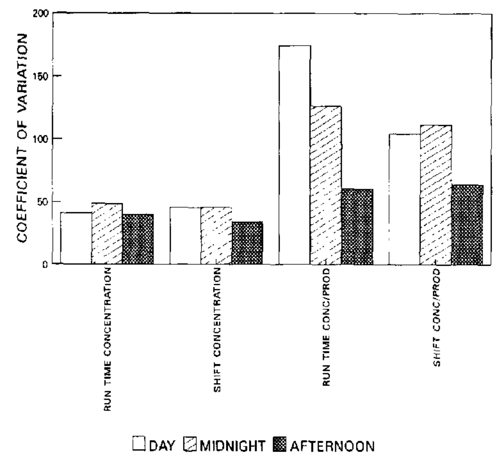

FIGURE 8. Coefficients of variation of each shift across weeks.

pling concentrations obtained during the same period, giving an indication of the reproducibility of measurement with the continuous sampler.

Summary

MSHA initiated a program to evaluate the application of a fixed-site sampler for continuously measuring the respirable dust concentration in underground mine environments. The objectives of the evaluation were to assess the feasibility of mounting a device on a mining machine and continuously monitoring the respirable dust concentration on a weekly shift basis, to obtain data on the required ruggedness of such a unit, and to gather and evaluate data to help determine how MSHA could best use such a device in its enforcement programs.

Three approved coal mine dust personal sampling units were assembled into a package, mounted on a continuous-mining machine, and interfaced with the machine's power. The package was used to monitor weekly shift average respirable dust levels continuously. Data were gathered regarding machine operating time and production, and analyzed to determine the effect of these parameters on measured dust levels.

The evaluation to date has demonstrated that a fixed-site sampler can be utilized to measure respirable dust levels on a continuous-mining operation continuously. It has also brought to the forefront important issues with respect to the use of the device, such as the difficulty of locating the sampling inlet of the monitor to obtain a representative sample, interpretation and use of data, questions regarding the need to retrofit the device to different types of machines, and ensuring the monitor

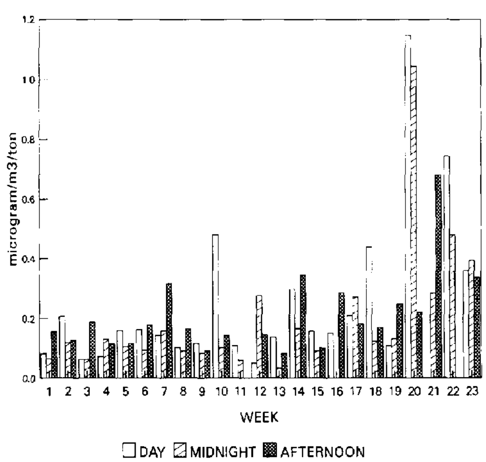

FIGURE 7. Average weekly shift concentration based on a 480-minute shift and normalized to production.

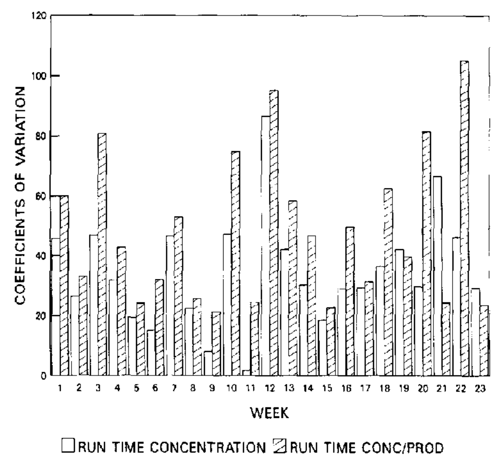

FIGURE 9. Coefficients of variation by week across shifts; concentration based on run time.

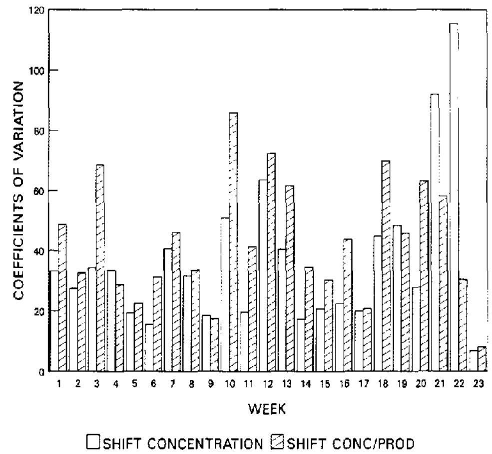

FIGURE 10. Coefficients of variation by week across shifts; concentration based on a 480-minute shift.

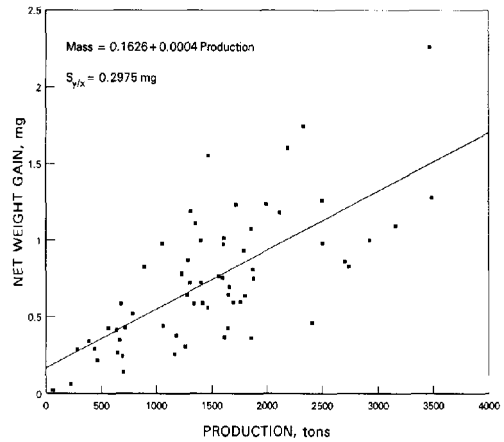

FIGURE 11. Comparison of the mass of dust collected to production.

is sufficiently rugged to survive the environment in which it is used.

Acknowledgments

The authors wish to acknowledge and thank personnel at Bailey Mine, Consol Pennsylvania Coal Company, Graysville, Pennsylvania, for their assistance with this study. The cooperation and special efforts made by Donald Yoders, Superintendent, and William Rosner, Master Mechanic, are appreciated. Without their assistance, the study could not have been successfully conducted.

The authors also wish to acknowledge the following MSHA personnel for their work on this project: Dean Skorski, Electrical Engineer, who was instrumental in the design of the electrical circuitry for the sampler, Raymond Gadomski, Industrial Hygienist, who conducted much of the in-mine experimental work, and Karen Suppers, Engineering Technician, who participated in both the design and in-mine testing of the sampler and performed the laboratory tests.

Disclaimer

References

1. U.S. Department of Labor, Mine Safety and Health Administration. Review of the Program to Control Respirable Coal Mine Dust in the United States. Report of the Coal Mine Respirable Dust Task Group. 60 pp. (1992).
2. Natrella, M.G.: Experimental Statistics. National Bureau of Standards Handbook 91 (1963).