Considerations for Estimating Remote Operator Dust Exposure Using Fixed-Point Samples on Continuous Mining Sections

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ABSTRACT

Respirable dust studies were conducted at several underground coal mining operations to evaluate and compare the dust measurements of fixed-point machine-mounted samples on a continuous miner and personal samples of the remote miner operator. Fixed-point sampling was conducted at the right rear corner of the continuous miner which corresponded to the traditional location of the operator's cab. Although it has been documented that higher concentrations of dust are present at the machine-mounted position, this work sought to determined whether a relationship exists between the concentrations at the fixed-point position and the dust levels experienced at the remote operator position and whether this relationship could be applied on a industry-wide basis. To achieve this objective, gravimetric samplers were used to collect respirable dust data on continuous miner sections. These samplers were placed at a fixed position at the cab location of the continuous mining machine and on or near the remote miner operator during the 1 shift/day sampling periods. Dust sampling took place at mines with a variety of geographic locations and in-mine conditions.

The dust concentration data collected at each site and for each sampling period were reduced to ratios of fixed-point to operator concentration. The ratios were calculated to determine similarities, differences, and/or variability at the two positions. The data show that dust concentrations at the remote operator position were always lower than dust concentrations measured at the fixed-point continuous miner location. However, the ratios of fixed-point to remote operator dust levels showed little consistency from shift to shift or from operation to operation. The fact that these ratios are so variable may introduce some uncertainty into attempting to correlate dust exposures of the remote operator to dust levels measured on the continuous mining machine.

KEYWORDS

Coal Mining, Continuous Mining, Dust Control, Dust Exposure, Personal Exposure, Dust Sampling, Personal Sampling, and Fixed-point Sampling

INTRODUCTION

Personal and fixed-point sampling are two types of environmental monitoring used in underground coal mining. Personal sampling offers improved correlation with exposures referenced to biological indicators, better representation of variations in worker exposure, and improved estimation of worker exposure. Personal sampling also may be used to evaluate exposure-response and effectiveness of exposure standards. Personal sampling is necessary to accurately determine the effectiveness of dust avoidance technology (NIOSH, 1995).

Fixed-point sampling involves the placement of the dust samplers either at a fixed-point on a piece of equipment or at a fixed location underground. Fixed-point sampling is preferable for either detecting sources of dust or evaluating the effectiveness of dust control measures. However, NIOSH recommends personal sampling to determine worker exposure to mine dust (Kissell and Jankowski, 1993).

The following studies compared exposures measured with personal and fixed-point samplers. While personal sampling (i.e., sampling on or at the operator position) remained consistent in these studies, the position of the fixed-point sampler in the section varied. In a study by Tomb-Ondrey (1978), fixed-point samplers were located outby the continuous miner section at the shuttle car dumping point and a study by Hadden, *et. al.*, (1977) took place on a longwall face. In these two studies in underground coal mine environments, exposures measured with personal samplers frequently were higher than exposures measured with fixed-point samplers. However, the location of the fixed-point samplers did not represent the point of highest dust concentration within the dust generation area. Another study conducted at continuous mining operations compared personal samples on the miner operator to fixed-point samples ahead of the operator (Kost and Saltsman, 1977). For this study, the operator was positioned in the cab location on the continuous miner. The results of this study showed that the fixed-point samplers collected more dust than the personal samplers. Additional studies placed the fixed-point samples at the hinge point of the boom on the same side as the operators cab (Foster-Miller, Inc., 1988a, 1988b). Personal samplers were located in the operator's cab. The results also showed that the fixed-point samplers were exposed to more dust than the personal samplers.

Although the aforementioned studies examined the relationship between fixed-point and personal sampling, these studies were conducted in operations that were not using remote control. In these studies, the continuous mining machine was operated from a position on the machine instead of from a position some distance outby the machine which is normal in remote operation. As of 1995, nearly 50% (Grau and Bauer, 1997) of coal mining operations were using remote control of the continuous mining machine. Thus, the information from these earlier studies is not applicable to many of the continuous mining operations today.

One study did examine personal and fixed-point samples at an operation extracting deep cuts (greater than 6.1 m (20 ft)) with remote operation of the continuous miner (Divers, *et. al,* 1982). The fixed-point samplers were located at the cab position on the continuous miner while personal samplers were located at the remote operator position. In this study, the fixed-point dust levels were nearly thirty times greater than the personal dust levels. However, the mining operation studied by Divers used push-pull ventilation, a type not normally found in continuous mining applications.

Unlike on-board operation of the mining machine, remote control allows the machine operator much freedom to move about the face area. This may make the estimation of remote operator dust exposures using fixed-point sampling on the continuous mining machine difficult because the operator can move about the entry. Past experience has shown that dust levels can change dramatically depending upon the location of the remote operator. Colinet *et. al.*, (1996) found a significant decrease in dust exposure when the remote operator moved from a location 1.5 m (5 ft) inby the mouth of the exhaust curtain to a location 1.5 m (5 ft) outby the mouth of the curtain. Jayaraman *et. al.*, (1987) found that dust exposures were nearly 16 times higher when the remote operator stood on the "return" side of the intake curtain as compared to a location at the mouth of the intake curtain. With remote control of the continuous mining machine, the location of the operator can vary greatly and with it, the respirable dust exposure of that individual.

This manuscript summarizes the results of several studies conducted at underground coal mining operations using remote control of the continuous mining machine. Dust levels were measured at a fixed-point location on the continuous miner and at the remote operator location to determine if a relationship exists between the two locations and if so, if the relationship can be used to estimate operator exposures from fixed-point samples.

INSTRUMENTATION

Dust concentrations were measured using gravimetric samplers. These samplers used 10-mm nylon Dorr-Oliver cyclones as preseparators to deposit the respirable dust fraction onto pre-weighed 37-mm filters. Pre-weights and post-weights were measured to the nearest 0.001 mg using a Mettler M3 microbalance. Calibrated battery-powered pumps, operating at 2 l/min, were used to draw the dust through the cyclones and onto the filters. An array of two or three samplers was used at each sample location. The average mass increase on the filters was used to determine dust concentration at each location. It is important to note that this study utilized short term sampling ranging from 1 to 5 hrs and thus the results cannot be correlated with 8 hr compliance sampling.

The arrays of gravimetric samplers were positioned at various locations on the continuous miner section to monitor dust concentrations. The intake, return, miner operator, and the continuous miner cab location were monitored with the samplers. The intake and return arrays isolated the continuous miner from other dust sources. The intake array was hung from a roof bolt 30.5 to 45.7 cm (12 to 18 in) from the roof in the intake entry as close to the cut as possible. The return array was hung in the same manner as the intake samplers and positioned in the immediate return of the entry being mined. Another array of samplers was located at the right rear corner of the continuous mining machine at the approximate position of the operator's cab. This location was approximately 7.6 to 8.5 m (25 to 28 ft) from the cutting bits. The remote machine operator samplers were positioned nearby the operator and repositioned as the operator moved.

DESCRIPTION OF STUDY SITES

The five study sites surveyed during this investigation represent a wide variety of conditions. The operations were located both in the eastern and western U. S., had varying ventilation schemes (i.e., exhaust, blowing, curtain, and tubing), and mined both standard (6.1 m (20 ft)) and extended (>6.1 m (20 ft)) cuts. Continuous mining sections of the five operations were surveyed for respirable dust concentrations at several locations. However, for the purpose of this study, data analysis will focus on two locations: the miner operator, all of which used remote control, and a fixed-point location at the cab position of the continuous mining machine. Continuous mining machines at each of these operations were equipped with machine-mounted flooded bed scrubbers for control of respirable dust. Scrubber discharge on continuous miners was directed into return air on all study sections. Table 1 provides the para-meters of each of the 5 mines. As a courtesy to the operators that cooperated with this investigation, specific mine names will not be cited. Instead, the mines will be referred to as Mines A through E.

Table 1. Parameters for each mining operation.

Mine ID	Location	Cut Type	Ventilation		Control technique
A	east	standard	exhaust	tubing	scrubber
B	east	extended	blowing	curtain	scrubber
C	west	extended	exhaust	curtain	scrubber
D	east	extended	blowing	curtain	scrubber
E	west	extended	exhaust	tubing	scrubber

POSITIONAL DUST CONCENTRATION

Sampling data described here was collected from continuous mining sections over a duration of 2 to 5 shifts. Figure 1 illustrates the location of the sampling instruments at a typical site. The typical sampling protocol involved collecting dust samples in the intake and return entries and at the operator and fixed-point positions during one shift for at least three coal extraction sequences (cuts). Cut sequences were similar at each site, usually consisting of 4 steps or lifts per cut. However, Mine C used 5 lifts to extract an extended 40 ft cut. Figure 2 shows the cut sequencing for the two methods used during this study.

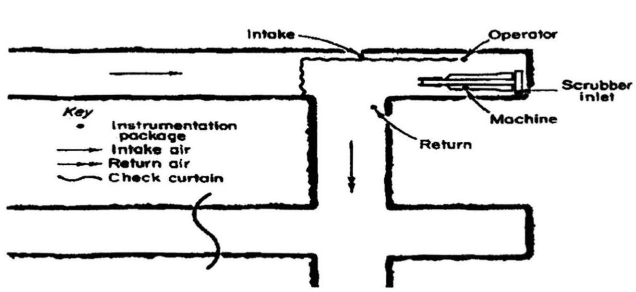

Figure 1. Sampling locations on a typical continuous miner section.

Respirable dust concentration data collected at the operator and fixed-point positions are shown in Table 2. Overall, dust concentrations ranged from 0.51 to 6.15 mg/m^3 and 1.48 to 7.86 mg/m^3 for the operator and fixed-point, respectively. The fixed-point position had a higher average concentration than the remote operator position and high variability was present among the samples. These findings confirm previous work presented in Kost and Saltsman (1977) and Divers *et. al.*, (1982).

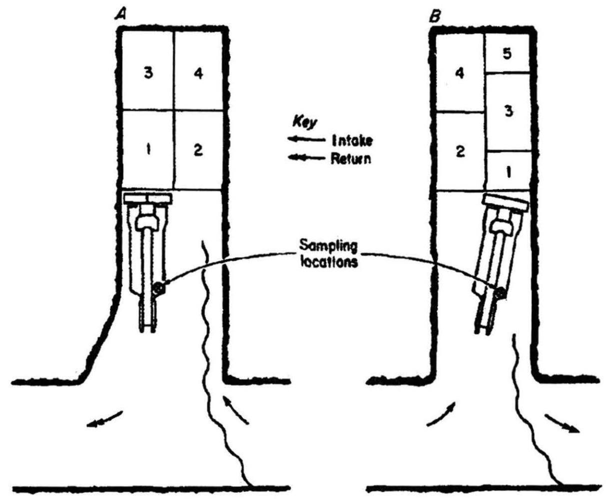

Figure 2. A - Four cut sequencing. B - Five cut sequencing.

Dust levels measured at the remote operator location were plotted against those levels measured at the fixed-point sampling location on the continuous mining machine (Figure 3). Each data point represents one shift of sampling conducted at an underground operation.

Table 2. Study site dust concentrations.

Mine ID	Shift Sampled	Face Airflow (cfm)	Production (tons)	Fixed-Point Dust Concentration (mg/m^3)	Remote Operator Dust Concentration (mg/m^3)	Ratio: Fixed-Point to Remote Operator
A	1	24600	178	3.32	1.90	1.75
	2	27400	144	2.25	1.40	1.61
B	1	5700	300	7.86	6.15	1.28
	2	5700	430	5.62	4.02	1.40
	3	5700	390	4.50	1.23	3.66
C	1	11700	1020	3.95	0.76	5.20
	2	14800	680	2.72	0.60	4.53
	3	15000	860	3.03	1.23	2.46
	4	14100	680	5.27	0.71	7.42
	5	10700	1020	2.22	0.51	4.35

D	1	7400	1180	1.96	1.23	1.59
	2	6400	920	2.27	0.55	4.13
	3	5000	1500	1.48	0.84	1.76
E	1	12400	270	7.16	1.35	5.30
	2	12300	980	5.29	2.23	2.37
	3	12000	290	2.49	1.29	1.93
	4	12300	640	3.62	2.55	1.42

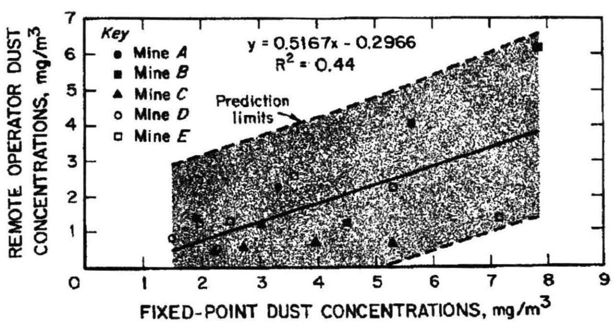

Figure 3. Regression line and prediction limits of Mines A-E.

Previous researchers (Kost and Saltsman, 1977) speculated that a site specific models relating fixed-point and remote operator dust levels for individual operations would not be representative of industry-wide exposures at these two positions. For this reason, no attempt was made to develop separate relationships for each individual operation. Instead, a single model for all study sites was considered as the best means for estimating remote operator dust exposure using fixed-point dust levels.

Simple linear regression was used to develop a model for estimating personal dust exposure of the remote miner operator using measurements at the fixed-point sampling location. This regressed line is shown in Figure 3. Analysis of variance showed that the dust level at the fixed-point location and dust levels measured at the remote operator location were significantly related at a 95% confidence level. However, this linear model had a coefficient of determination (R^2) of 44%. This result suggests that the linear model in Figure 3, although positively correlating fixed-point to operator dust levels, did not provide a strong relationship between fixed-point and operator exposures and that there is little predictive capability between the two locations.

Also included in figure 3 are the 95% prediction intervals (Walpole and Myers, 1972). These intervals specify the limits of predicted remote operator dust exposures for various fixed-point dust levels. The upper and lower prediction intervals are broad due to the wide variation found in remote operator dust exposures. For fixed-point dust levels at of 5 mg/m^3, remote operator dust exposures will be estimated to within ±2.3 mg/m^3 (with 95% confidence) of the predicted dust concentration. Even at fixed-point dust levels less than 5 mg/m^3, considerable variation exists for dust exposures predicted at the remote operator location. However, because dust exposures are lower-bounded at zero (dust concentration samples cannot be below zero), fixed-point dust levels less than 5 mg/m^3 lead to less spread in predicted operator dust levels. A fixed-point reading of 3 mg/m^3 will lead to a predicted operator exposure between 0 and 3.5 mg/m^3 with 95% confidence. However, as fixed-point concentrations increase above 5 mg/m^3, the spread of the prediction intervals also increases.

Finally, the data show that predicted operator dust exposures may exceed 2 mg/m^3 regardless of fixed-point dust levels. For instance, if fixed-point dust levels are 1.5 mg/m^3, then the 95% predicted operator exposure can vary from zero to 2.6 mg/m^3. Although this data range may fit statistically, it does not fit the nature of the data from this study. Fixed-point sampling at the continuous miner cab position is closer to the dust source than that of the operator's and thus under normal operating conditions, should show a higher respirable dust concentration. Divers, *et. al.*, (1982), show that dust levels at the fixed-point location were always greater than dust levels at the remote operator location. The studies conducted at operations A through E also confirm this finding.

REMOTE OPERATOR POSITIONING

One factor suspected of contributing to the variability of dust exposure concentrations between the remote operator and the fixed-point positions may be attributed to the movement of the operator during the mining of a particular cut. Machine positioning and lack of visibility often require the operator to move away from a fresh air position and into areas of higher respirable dust concentrations. For example, on a blowing-curtain ventilation section, the operator can limit dust exposure by maintaining a position at the mouth of the curtain. This position would enable the operator to be continually exposed to fresh intake air. However, the extraction sequence within the cut will dictate the position of the machine and depending upon this position, the operator may be forced to leave the fresh air position. For instance, the machine will be extracting coal on both sides of the entry during the sump and slab extractions and, for extended cut operations, the machine will get progressively farther from the operator (up to 12.2 m (40 ft)) as mining advances. For visibility of the cutting head to be maintained during these different machine positions, the operator must move out of the fresh ventilating air to areas that experience higher levels of respirable dust (Figure 4).

Similar operator activity occurs on an exhaust curtain ventilation scheme. The operator's position shifts from one side of the entry to the other to improve visibility (Figure 5). As with the blowing system, the operator is likely to move into areas of higher dust concentration and thus a consistent dust exposure sample between operator and fixed point positions would not be experienced. These varying dust levels at the operator position, regardless of the ventilation scheme, will make it unlikely that the dust concentration experienced at the fixed-point and the operator positions will be consistently proportional.

Although the movement of the operator contributes to the variations in dust levels experienced at the operator location, it may not be the only factor that influences dust exposures. Other contributing factors could include variations in the ventilation patterns, airflow, distance of the miner from the curtain or tubing, movement of the mining machine within the cut, and scrubber efficiency.

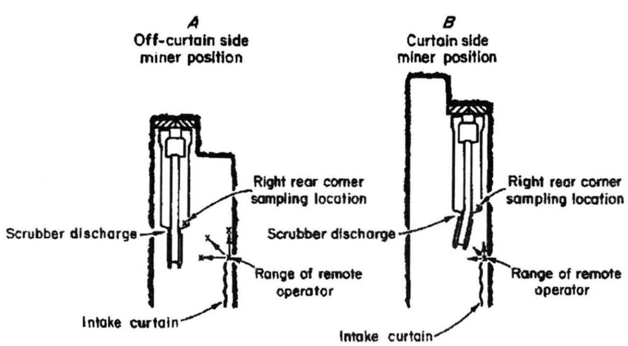

Figure 4. Operator positions at curtain and off-curtain sides of cut on a blowing ventilation scheme.

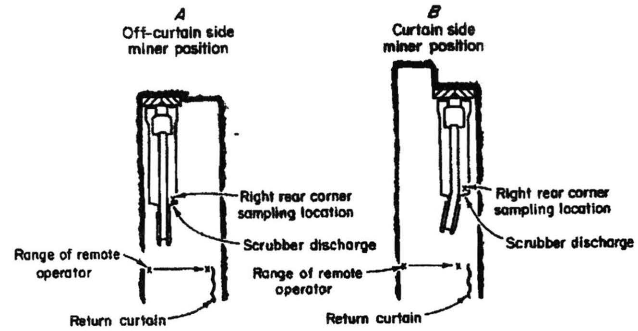

Figure 5. Operator positions at the curtain and off-curtain sides of cut on an exhausting ventilation scheme.

these data and a R^2 value of 44% produced by the regression model, the variability is too high to predict with any certainty the concentration at either site. Ratios of fixed-point to operator position of all data collected also show little consistency. Variability is also high when comparing ratios of individual mines. Data show that, for these mines, the high variability in the samples at each of the positions examined do not allow for an accurate prediction of dust concentration at these two positions. The variation of dust concentration at either of these positions appears to be impacted by the changing locations of the mining machine (Goodman and Listak, 1998) and the remote operator throughout the extraction process (Jayaraman, *et. al.*, 1987) as well as other previously stated factors.

CONCLUSIONS

This study examined the relationship between the respirable dust exposures at two positions on continuous miner sections in underground coal mines. Respirable dust samples were collected at five mine sites having a variety of geographical locations and in-mine conditions. A fixed-point position on the continuous miner and the remote operator position were sampled for their respective dust concentrations. Past studies have shown that, when comparing dust concentrations at these two positions, respirable dust concentration is lower at the remote operator position. The data from this study further supports those results. In addition, the data were analyzed and compared to determine if a concentrations measured at the fixed-point position could predict exposure at the remote operator location.

The data obtained from this study were analyzed collectively to determine if a relationship exists between the two positions on an industry-wide basis. Linear regression shows that the concentrations at the two positions are positively correlated. The R^2 statistic indicates that the fitted curve explains 44% of the variability at the operator. Based on

REFERENCES

Colinet, J. F. and R. A. Jankowski, 1996. "Dust Control Considerations for Deep-Cut Mining When Utilizing Exhaust Ventilation and a Scrubber," Report of Investigations 9615, U.S. Bureau of Mines, 12 pp.

Divers E, N. I. Jayaraman, and J. Custer, 1982. "Evaluation of a Combined Face Ventilation System Used With a Remotely Operated Mining Machine," U. S. Bureau of Mines, IC 8899, 7 pp.

Foster-Miller, Inc., 1988a, "Identification and Control Strategies to Control Quartz Dust," U.S. Bureau of Mines Contract H0348030, April, 146 pp.

Foster-Miller, Inc., 1988b, " Concepts to Control Quartz Dust Exposure of the Continuous Miner Operator and Helper," U.S. Bureau of Mines Contract H0348031, December, 174 pp.

Goodman, G.V.R., and J. M. Listak, 1998, "Variations in Dust Levels with Continuous Miner Position," SME Annual Meeting. Orlando, FL., Mar. 9-11.

Grau, R.H. III., and E.R. Bauer, 1997, "Ground Control Worker Safety During Extended Cut Mining," Proc. of 16th International Conference on Ground Control in

Mining, West Virginia Univ., Morgantown, WV, August 5-7, pp. 283-288.

Jayaraman, N. I., R. A. Jankowski, and D. Stritzel, 1987, "Improving Health, Safety, and Productivity Through the Use of Machine-Mounted Scrubbers," Proc. 95th Annual Meeting of Illinois Mining Institute, Mount Vernon, October, pp. 62-75.

Hadden, G. G., C. O. Jones, and H. L. Thorpe, 1977, "A Comparative Assessment of Dust Surveillance Procedures Including the Use of Personal and Fixed Position Sampling Instruments," Report No. TM/77/ 15 (EUR. P4 1), Edinburgh, Scotland, Inst. of Occup. Medicine.

Kissell, F. N. and R. A. Jankowski, 1993, "Fixed-Point and Personal Sampling of Respirable Dust for Coal Mine Face Workers," Proc. 6th U.S. Mine Ventilation Symposium, Salt Lake City, pp 281-284.

Kost, J. A., and R. D. Saltsman, 1977, "Evaluation of the Respirable Dust Area Sampling Concept as Related to the Continuous Miner Operator," BCR Report L-792, Bituminous Coal Research, Inc., January, 46 pp.

National Institute for Occupational Safety and Health , 1995, "Occupational Exposure to Respirable Coal Mine Dust -Criteria for a Recommended Standard," DHHS, Pub. No. 95-106, 336 pp.

Tomb, T. F., and R. S. Ondrey, 1976, "Determining the Feasibility of Area Sampling to Enforce Respirable Dust Standard in Underground Coal Mines," Mine Safety and Health Administration IR 1037.

Walpole, RE and R. E. Myers, 1972, "Probability and Statistics for Engineers and Scientists," MacMillan Publishing: New York, 506 pp.