Evaluation of dust exposure to truck drivers following the lead haul truck

W.R. Reed and J.A. Organiscak
Mining engineers with NIOSH, Pittsburgh Research Laboratory, Pittsburgh, Pennsylvania

Abstract

Haul trucks have the potential to generate large amounts of respirable dust. This respirable dust has been shown to be a health hazard to personnel, especially if it has a high silica content. Lack of dust sampling data from haul trucks prompted the completion of a study to quantify respirable dust concentrations. These field studies were conducted measuring instantaneous respirable dust at stationary locations from passing haul trucks at a stone quarry and at a coal mine site. Fugitive dust levels from haul trucks were analyzed to characterize dust dispersion. This analysis indicates safe following distances for haul trucks and other heavy equipment to avoid overexposure of respirable dust from the lead haul truck.

Introduction

Almost all surface mining operations use mining haul trucks. These trucks are used to move material within or from the mining property. Past research, using the U.S. EPA's emissions factors for unpaved haul roads, has shown that haul trucks generate the majority of dust emissions from surface mining sites, approximately 78% to 97% of total dust emissions (Cole and Zapert, 1995; Amponsah-Dacosta and Annegarn, 1998; Reed et al., 2001). Observations of dust emissions from haul trucks show that if the dust emissions are uncontrolled, they can be a safety hazard by impairing the operator's visibility. Reducing the operator's visibility increases the probability for haul truck accidents. However, the greatest long-term health hazard of dust generated from hauling operations is due to inhalation of respirable dust, which contains dust particles whose median diameter is 4.0 μm and PM_{10}, which is the size fraction whose medium diameter is 10 μm (Soderholm, 1989; ISO, 1993; Lippmann, 1995; U.S. GPO, 2002).

Exposure to respirable dust has long been considered a health hazard at surface mining operations, especially if silica dust is present. Respirable dust containing silica has caused more than 250 deaths annually (MSHA, 1997). There is also the potential for 106,000 to 182,000 mine production, development and exploration workers to be exposed to respirable dust from surface mining operations (U.S. Census Bureau, 2001; NIOSH, 2002). The large range in the number of workers results from differences in the statistical databases from the U.S. Census Bureau and the Mine Safety or Health Administration (MSHA).

An evaluation of a recent MSHA database of respirable dust samples containing silica from 1996 through 2000 shows the exposure for truck drivers and road grader operators. At surface coal mines, approximately 10% of the dust samples taken exceeded the exposure limit for silica dust for truck drivers. For road grader operators, that rate was approximately 5% (Hale, 2002). For stone mining operations, the number of respirable dust samples taken that exceeded the exposure limit for silica dust was approximately 5% for truck drivers. The overexposure rate was approximately 29% for road grader operators (Hale, 2002). At nonmetal mines, the rates were approximately 5% and 14% for truck drivers and road grader operators, respectively (Hale, 2002), and the rates for metal mining operations were approximately 8% and 3% for truck drivers and road grader operators, respectively (Hale, 2002).

Although the health and safety concerns for dust overexposure focus on respirable dust, PM_{10} has also been shown to represent a health hazard. Many epidemiologic studies have been completed that show that PM_{10}, by itself, causes harm to humans. A 50 $\mu g/m^3$ increase in the 24-hour average PM_{10} concentration was statistically significant in increasing mortality rates by 2.5% to 8.5% (U.S. EPA, 1996). Long-term effects from PM_{10} are dependent on the exposure to PM_{10} over the life of the worker.

Of particular concern is the use of haul trucks outside of the mining industry. There are many off-road and over-the-road haul trucks that are used in the construction industry. Many of the over-the-road haul trucks enter quarry sites to obtain material to deliver it to construction sites, and these trucks generally use the mine site haul roads. Some of these quarry sites have a high traffic volume of over-the-road trucks. These operators can be exposed to high respirable silica dust concentrations during their time at the quarry site. Even though their time at the quarry site may be minimal, they may return several times during the day to the quarry for material thus, increasing their potential exposure to respirable silica dust.

The delivery locations are generally construction sites that also have the potential to expose the truck operators to high respirable dust concentrations, particularly at highway or road construction sites. Highway construction sites also use some of the same heavy equipment as surface mining operations. This equipment may be operated in close proximity to laborers, equipment operators and the general public. There may be a high probability for potential exposure of respirable dust to these personnel at these locations. However, data to substantiate this supposition is almost nonexistent.

There are several dust-control practices currently in use for haul trucks. These are reducing haul truck speed, watering haul roads, treating haul roads and maintaining equipment cabs. Reducing the haul truck speed is a simple control method. The reduction in dust is attributable to the lower amount of disturbance to the haul road at lower speeds.

Watering haul roads with a water truck once an hour has been shown, through past research, to have a control efficiency of 40% for total suspended particulates (TSP). If watering is increased to once every half hour, the control efficiency for TSP increases to 55% (Rosbury and Zimmer, 1983). The control efficiency was defined as a comparison of the controlled (watered) emission rate to the uncontrolled emission rate. The United States Environmental Protection Agency (U.S. EPA) reported several test results of watering haul roads. The results ranged from a control efficiency of 74% for TSP for the 3 to 4 hours following the application of water at a rate of 2.08 L/m^2 (0.46 gal per sq yd) to a control efficiency of 95% for TSP for 0.5 hours after the application of 0.59 L/m^2 (0.13 gal per sq yd) (U.S. EPA, 1998).

Treating haul roads is generally completed through the application of chemicals and requires a significant amount of road maintenance. Control efficiencies were shown to be 95% for magnesium chloride and 70% for a petroleum derivative for controlling haul truck generated dust (Olson, 1987).

Maintaining equipment cabs in good operating conditions also reduces operator exposure to respirable dust. A study conducted on dozers and drills demonstrated that properly maintained cabs can attain dust reductions of 90% for drills and between 44% and 100% for dozers (Organiscak and Page, 1999). The variations of the dust reductions for dozers were attributed to reentrainment of internal cab dust (Organiscak and Page, 1999). An additional study completed on haul trucks, which involved the retrofitting of a cab with a filtration/pressure air conditioning system to produce positive pressure in the cab, showed that properly maintained cabs can produce a potential 52% reduction of respirable dust (Chekan and Colinet, 2003).

Field study

Due to a lack of data characterizing airborne dust generated from haul trucks, a field study that measured dust from haul trucks at surface mining operations was completed by Organiscak and Reed in the summer of 2002. The study was completed at two different sites: a surface stone quarry in Virginia and a coal preparation plant waste hauling operation in Pennsylvania. Both sites had a significant number of trucks that passed by the sampling instruments. Therefore, analysis for the potential exposure of haul truck drivers to respirable dust was completed, in addition to the haul truck dust characterization. It should be noted that the stone quarry site had more trucks following closer together than the coal preparation plant site.

This study utilized seven sampling stations located at varying distances from the haul road. However, the analysis of the respirable dust exposure of truck drivers required only the review of data from the two sampling stations that were adjacent to and on opposite sides of the road. The test section of the haul road was a straight unwatered section of road approximately 30 m (100 ft) in length. The test section for the Virginia site had a slight grade and was the main entrance road to the pit, while the Pennsylvania site was relatively flat and was the main haul road to the waste dump.

This study used MIE personal data RAMs, MSA Escort ELF personal sampling pumps, 10-mm Dorr-Oliver cyclones and BGI GK2.69 cyclones at each measurement location. Samples were collected on 37-mm filters. To measure respirable dust, Escort ELF personal sampling pumps were fitted with 10-mm Dorr-Oliver cyclones. The pumps were set to run at 1.7 L/min to collect the respirable dust sample (Bartley et al., 1994). The MIE personal data RAMs were used to collect instantaneous respirable dust concentration measurements. They recorded dust concentrations every two seconds. The MIE personal data RAMs were fitted with 10-mm Dorr-Oliver cyclones and were operated at 1.7 L/min. Because the PM$_{10}$ size fraction is similar to thoracic fraction of dust (Lippmann, 1995), BGI GK2.69 cyclones, which measure thoracic dust, were used to represent the PM$_{10}$ size fraction. Thoracic dust was measured using Escort ELF personal sampling pumps fitted with the BGI GK2.69 cyclones. The sampling pumps for the thoracic portion were operated at 1.6 L/min to collect the PM$_{10}$ sample (Maynard, 1999). Total dust concentrations were measured by attaching 37-mm filters directly to the Escort ELF personal sampling pumps, set to operate at 1.7 L/min. In addition, Cascade Impactors that contained six stages and were connected to Escort ELF personal sampling pumps operating at 2.0 L/min were used. This flow rate allowed for the measurement of dust concentrations for the cut-off size ranges of 21.3, 14.8, 9.8, 6.0, 3.5 and 1.55 μm (Andersen Instruments Inc., 2002).

The sampling stations (A and B) for this evaluation contained the previously mentioned respirable dust sampler, MIE Personal Data RAM respirable dust sampler, thoracic dust sampler, total dust sampler and Cascade Impactor. Weather data consisting of temperature, both dry and wet bulb, and barometric pressure were recorded hourly. A wind speed and direction station was placed nearby and recorded wind speeds and directions every 30 seconds. Dust measurements were collected for approximately 6 to 7 hours per day.

A time study was also conducted of the haul trucks using the haul road throughout the entire time period of the study. The haul truck time entering and exiting the test section of the road, type of haul truck and speed and direction of travel were recorded. The types of haul trucks at the Virginia stone quarry were mostly various tandem-axle over-the-road trucks, with some trailer trucks, capable of carrying 18-t (20-st) payloads. Additionally, some 45-t (50-st) off-road haul trucks were included in this study. Their average speed during the study was 7.0 m/s (15.6 mph). The Pennsylvania site operated 45- to 54-t (50- to 60-st) off-road trucks (Cat, Terex and Payhauler) that traveled at an average speed of 7.1 m/s (15.9 mph). The road conditions were similar at both sites, with average road surface material specific gravity, moisture content and silt content being 2.86, 0.16%, and 22.3%, respectively, for the Virginia stone quarry. The Pennsylvania site's average road surface material specific gravity, moisture content and silt content were 2.48, 0.62%, and 21.9%, respectively. The specific gravity, moisture content and silt content were determined according to ASTM standards.

Results

Average particle size distributions of dust generated from haul trucks were calculated from cascade impactor sampler data from the two samplers located along the haul road from both sites. The average particle size distribution of the dust generated by haul trucks during this study is shown in Fig. 1. Figure 1 reveals that, on average, 14.5% of the airborne dust generated from haul trucks consists of material <10 µm and 3.5% is material <3.5 µm. The majority (85.5%) of the airborne dust consists of larger particles that do not pose a respirable threat to the truck operator, but may be a visibility hazard.

Instantaneous analysis of the airborne dust concentration data was completed for both sites. Figures 2 and 3 shows a typical average instantaneous respirable dust concentration curve for the airborne dust generated from haul trucks for Stations A and B, respectively.

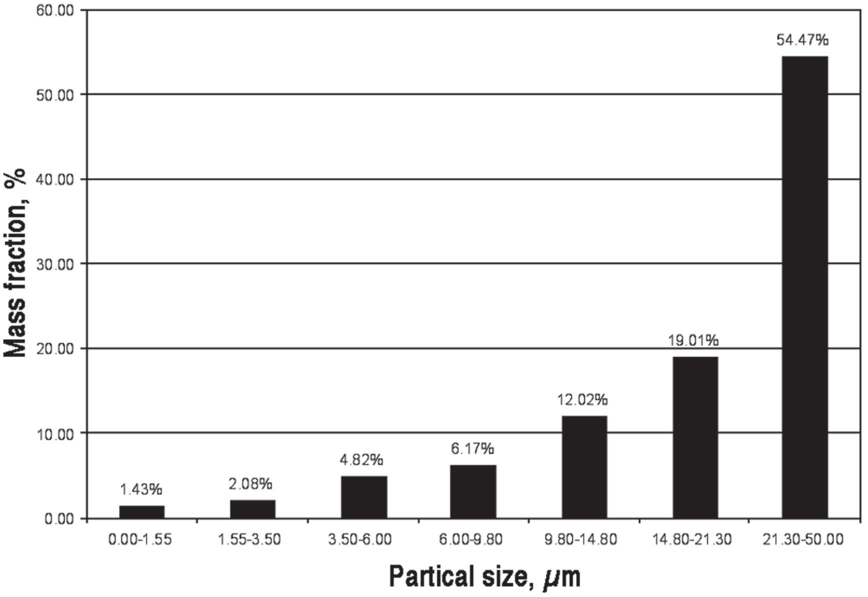

Figure 1 — Average size distribution for airborne dust generated by haul trucks for the entire sampling period.

Stations A and B were located adjacent to the haul road and on opposite sides. These graphs were constructed from data from the coal mine preparation plant study and show the average instantaneous respirable dust concentrations with their 95% confidence intervals. The confidence intervals were calculated using:

$$CI = \bar{x} \pm \left(1.96 \times \frac{s}{\sqrt{n}}\right) \qquad (1)$$

where

CI is the confidence interval,

$\bar{x}$ is the sample mean,

s is the sample standard deviation and

n is the number of data values.

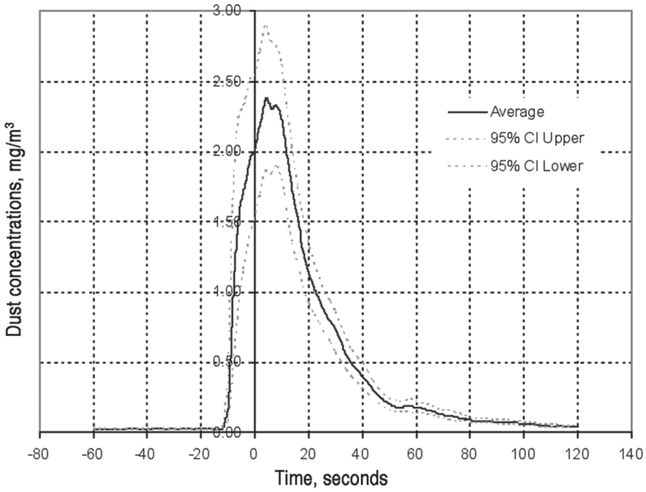

Figure 2 — Average instantaneous respirable dust concentrations for Station A of the coal preparation plant study.

The negative time intervals represent the time before the haul truck arrived at the sampling station, and the positive time intervals represent the time after the haul truck passed the sampling station. In addition, percentile plots were created from the data used to create Figs. 2 and 3. These plots present the statistics for the median and the 25th, 75th and 90th percentiles and are shown in Figs. 4 and 5.

Prior evaluations on the instantaneous dust data for the coal preparation plant showed a linear relationship existing between the respirable and thoracic dust (Reed, 2003; Organiscak and Reed, 2004). This relationship was represented as a ratio that was shown to be 3.93 respirable dust to thoracic dust (3.93 x respirable dust concentration = thoracic dust concentration). Graphs showing the instantaneous thoracic dust calculated from the instantaneous respirable dust graphs are presented in Figs. 6 and 7.

Instantaneous dust concentration data from the Virginia stone quarry were used to analyze dust concentrations with the time lag of a following haul truck. In this case, there were numerous trucks passing the sampling stations with the majority of the trucks following a lead truck. Box and whisker plots are presented of the stone quarry data in Figs. 8 and 9.

These results show the instantaneous airborne respirable dust concentration data versus time lag in seconds. These graphs present the instantaneous airborne respirable dust concentration for the following trucks at the point of passing the sampling stations, or time zero on Figs. 2 and 3. Figures 10

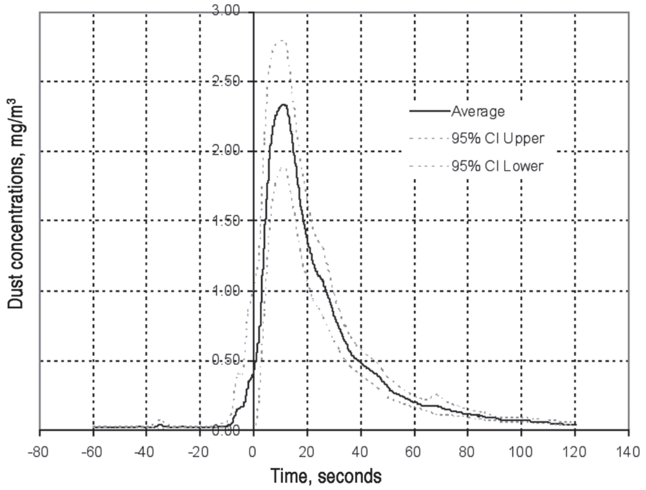

Figure 3 — Average instantaneous respirable dust concentrations for Station B of the coal preparation plant study.

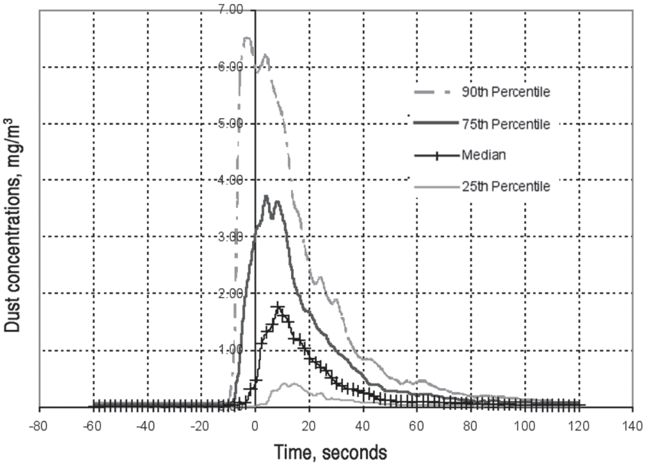

Figure 4 — Percentile graph of airborne respirable dust concentrations generated from haul trucks for Station A of the coal preparation plant study.

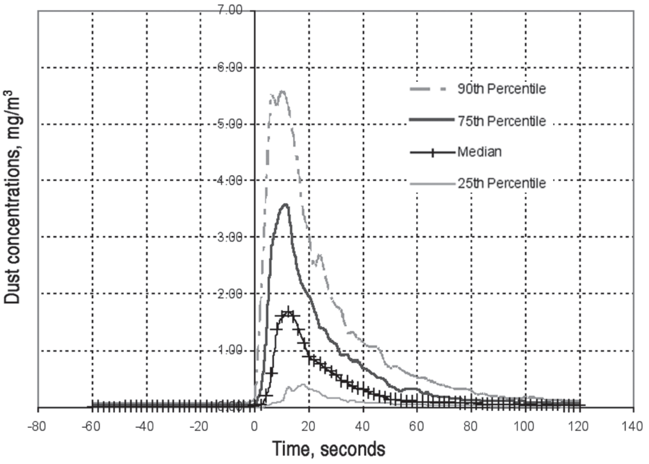

Figure 5 — Percentile graph of airborne respirable dust concentrations generated from haul trucks for Station B of the coal preparation plant study.

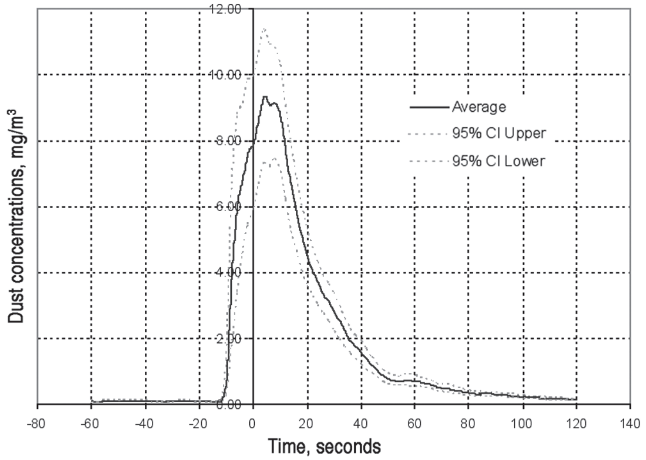

Figure 6 — Estimated average instantaneous thoracic dust concentrations for Station A of the coal preparation plant study.

and 11 show a "zoomed-in" version of the box and whisker plots shown in Figs. 8 and 9.

The box and whisker plots show the data grouped in percentiles. The horizontal line inside the box represents the median of the data. The lower end of the box is the 25th percentile line. All data below this line represents <25% of the data. Data above this line represents >25% of the data. The upper end of the box is the 75th percentile line. Similar to the 25th percentile line, all data below this line represents <75% of the data. Data above this line represents >75% of the data. The lower "whisker" represents the 10th percentile and the upper "whisker" represents the 90th percentile.

Discussion of results

The measured particle size distributions from the haul truck study (14.5% <10 μm and 3.5% <3.5 μm) are much less than previously determined airborne particle size distributions for road and soil dust of 52.3% <10 μm and 10.7% <2.5 μm (Chow and Watson, 1998). The mass fractions of 14.5% <10 μm and 3.5% <3.5 μm are more representative of airborne dust from haul trucks, than the mass fractions from previous research. A review of the procedure used to determine the prior mass fractions (52.3% <10 μm and 10.7% <2.5 μm) showed that bulk road samples were taken from the unpaved road and resuspension of the dust was completed in the laboratory (Ahuja et al., 1989; Houck et al., 1989). In this field study, the sampling stations were located right on the edge of the haul road and measured the airborne dust directly from the haul trucks. Therefore, the prior mass fractions of 52.3% <10 μm and 10.7% <2.5 μm portray the potential mass fractions for airborne road dust, while the mass fractions of 14.5% <10 μm and 3.5% <3.5 μm depict a more representative description of the mass fractions of road dust that emanate from haul trucks.

Examination of the instantaneous respirable dust data shown in Figs. 2 and 3 show that the peak dust concentration occurs within 20 seconds after the truck has passed the sampling stations. Figure 2 shows the dust concentrations starting to peak before the truck arrives at the sampling station. This effect is caused by varying wind directions. Sometimes wind directions originate from the same directions that the trucks originate. This can cause the dust concentrations to precede the truck. The average peaks, within the time frame of 20 seconds, are generally within 2.0 to 2.5 mg/m^3, showing that a driver following a truck can be potentially exposed to dust concentrations above the legal limit of 2.0 mg/m^3, although these are instantaneous concentrations and not eight-hour time-weighted-average concentrations. However, exposures can sometimes be significantly higher for the following truck driver, as seen by the percentile graphs of Figs. 4 and 5.

The percentile graphs show where the data lie in the spectrum of the data collection. It can be seen that, at the peaks, half of the respirable dust concentrations are above 1.76 mg/m^3 for Station A and 1.70 mg/m^3 for Station B. Twenty-five percent of the data lie between the median and the 75th percentile curves shown on Figs. 4 and 5. This shows that 25% of the peaks occur within the region of 1.76 to 3.71 mg/m^3 for Station A and 1.70 to 3.55 mg/m^3 for station B. It can also be seen that 25% of the peaks are greater than 3.71 mg/m^3 for Station A and 3.55 mg/m^3 for Station B. It can be concluded from these graphs that the following truck driver can be exposed to respirable dust concentrations greater than 3.55 mg/m^3 for approximately 25% of the time the driver is following the lead haul trucks.

Graphs of average instantaneous thoracic dust concentrations were created, as shown in Figs. 6 and 7. These graphs were created from the average instantaneous respirable dust concentration graphs of Figs. 2 and 3 by using the 3.93 respirable-thoracic ratio calculated in previous research (Reed, 2003). These two graphs show that the estimated average peak of thoracic dust is approximately 9.36 mg/m^3 for Station A and 9.16 mg/m^3 for Station B and that the following truck driver can be exposed to these high concentrations within a time frame of zero to 20 seconds behind a haul truck. Again, these concentrations are instantaneous concentrations rather than the 24-hour time-weighted-average concentrations.

The evaluation of the data from the stone quarry in Virginia was completed in a different manner. Due to the high traffic volume, instantaneous dust concentration curves representing dust generation from individual haul trucks could not be reliably evaluated because of the interference from other trucks. In this case, the haul truck emissions were examined using dust concentrations versus time lag. Box and whisker plots were created as shown in Figs. 8 and 9. Figures 8 and 9 show that the instantaneous respirable dust concentrations for Station A are lower than the concentrations for Station B. This is due to the fact that the wind directions were predominately towards Station B. Therefore, Station B would record a higher amount of respirable dust than Station A.

It can be seen from the plots in Figs. 8 and 9 that the instantaneous respirable dust concentrations are lower than the instantaneous respirable dust concentrations from the coal preparation plant study. Part of the explanation for this phenomenon is that these plots show the instantaneous dust concentrations as the following truck passes by the sampling station. It is seen from Figs. 2 and 3 that the maximum average respirable dust concentrations generally occur within a time frame of 5 to 15 seconds behind the truck. Many of the following truck concentrations in Figs. 8 and 9 did not occur at the maximum instantaneous concentration. Another explanation is that almost all the trucks at the stone quarry were over-the-road haul trucks, not off-road mine trucks as in the coal preparation plant study. It was seen from visual observation that the off-road mine trucks generated more dust than the over-the-road haul trucks. Although, this cannot be quantified, as separation of the truck type was not completed.

The box and whisker plots do support the premise that the maximum dust exposure of the haul trucks occurs within the time frame of zero to 20 seconds behind the lead haul truck (max. occurs at the 10 to 20 second time period). In addition, Figs. 10 and 11 show a close-up view of Figs. 8 and 9, respectively. Figure 11 shows that the following truck driver can be exposed to instantaneous respirable dust concentrations in the range of 0.75 to 2.75 mg/m^3, excluding the outliers for approximately 15% of the time that they follow 10 to 20 seconds behind a haul truck. Additionally, 10% of this time the respirable dust concentrations can exceed 2.75 mg/m^3.

Using this information, an additional control technique can be implemented to help protect truck drivers from overexposure. This technique consists of monitoring the locations of the haul trucks. By instituting traffic-control procedures to require haul trucks to maintain more than 10 to 20 seconds of separation, there should be a resultant reduction in dust exposure to the haul truck operator.

In many cases, such as in large open pits with many load-out locations, implementing such a policy may not be economically feasible. It may also not be feasible for road grader operators to avoid the trucks in their duty of removing material from the haul roads. In these cases, the cabs and air condition-

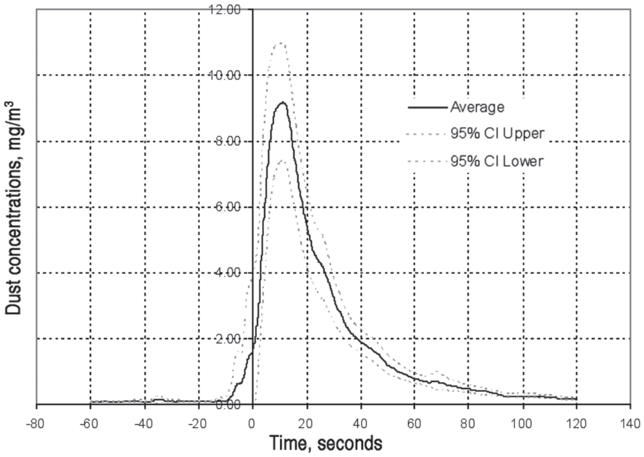

Figure 7 — Estimated average instantaneous thoracic dust concentrations for Station B of the coal preparation plant study.

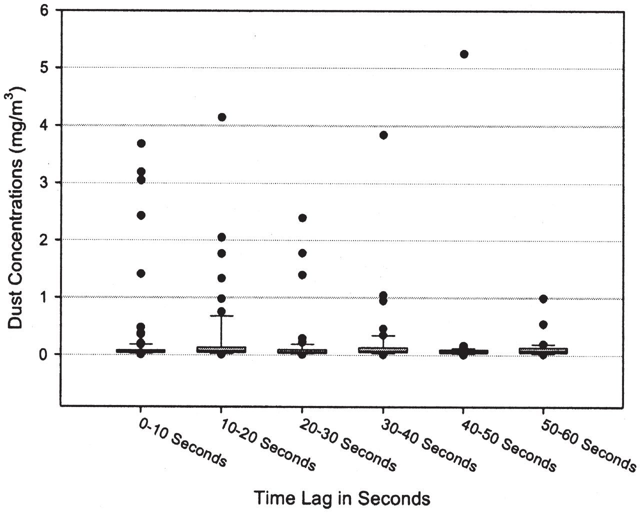

Figure 8 — Airborne respirable dust concentrations at Station A for various haul truck time lag intervals from the stone quarry study.

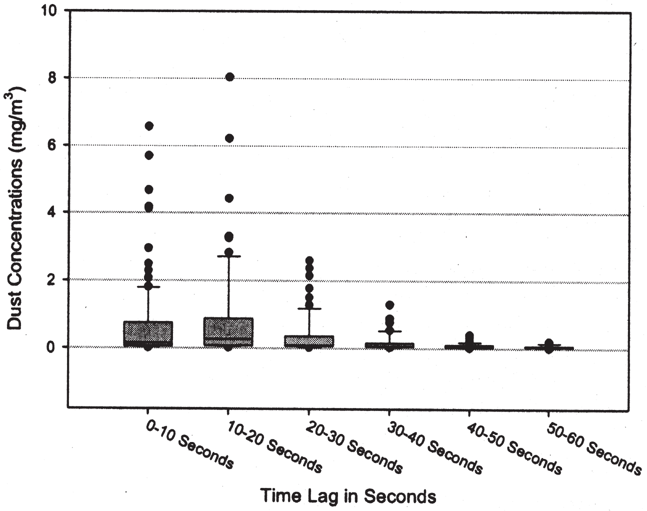

Figure 9 — Airborne respirable dust concentrations at Station B for various haul truck time lag intervals from the stone quarry study.

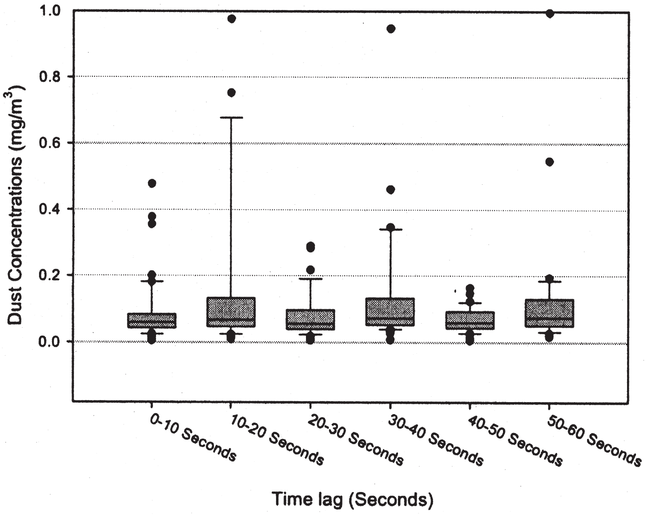

Figure 10 — Instantaneous respirable dust concentrations from 0.0 to 1.0 mg/m^3 with time lag for Station A of the stone quarry study.

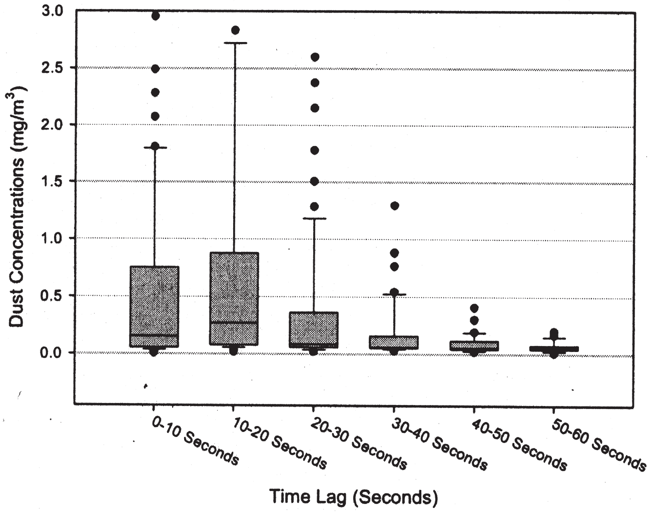

Figure 11 — Instantaneous respirable dust concentrations from 0.0 to 3.0 mg/m^3 with time lag for Station B of the stone quarry study.

ing systems should be properly maintained so that in instances where trucks are following one another, the cabs have a proper seal. However, many cases, such as quarries, over-the-road trucks usually enter the site in groups. It would be easy enough to install traffic procedures such that trucks enter the loading area at 20 to 30 second time intervals, instead of back-to-back, which frequently occurs. One possible method could involve the use of a traffic light that monitors the traffic nearby the weighing station. Once a truck passes the light, the light turns red stopping traffic until 20 to 30 seconds have passed. The light then changes to green allowing the next truck to proceed. This could also help alleviate the backup of trucks at the load-out point, which can also be a source of dust exposure.

Summary and conclusions

In summary, from respirable and PM_{10} dust sampling conducted during the study, it was found that airborne dust generated by haul trucks consists of, on average, 14.5% <10 μm and 3.5% <3.5 μm.

At the coal preparation plant in Pennsylvania, the instantaneous respirable concentration levels ranged anywhere from 0.001 to 21.50 mg/m^3 within 5 to 15 seconds after the 45- to 54-t (50- to 60-st) off-road haul trucks traveling at 7.1 m/s (15.9 mph) had passed. However, the average peak instantaneous respirable concentration level was approximately 2.35 mg/m^3 within the same time period. The percentile graphs showed that a truck driver might be exposed to respirable dust concentration levels above 3.55 mg/m^3 for 25% of the time that the driver is following 5 to 15 seconds behind other trucks.

At the Virginia stone quarry, the instantaneous respirable concentration levels ranged from 0.01 to 8.03 mg/m^3 within 0 to 20 seconds after the haul trucks had passed. Most of these were over-the-road tandem axle trucks, with some trailer trucks capable of 18-t (20-st) payloads, traveling at 7.0 m/s (15.6 mph). The high traffic volume at this site precluded the calculation of an average peak respirable concentration level. However, the box and whisker graphs showed that a truck driver might be exposed to respirable dust concentration levels within a range of 0.75 to 2.75 mg/m^3 for 15% of the time that the driver is following 10 to 20 seconds behind other trucks. Additionally, the respirable concentration levels can exceed 2.75 mg/m^3 for 10% of this time.

From the results of this study, an additional control technique is proposed — one that monitors the locations of haul trucks with respect to one another. A review of Figs. 2, 3, 8 and 9 shows that the critical time period of following a truck is from 0 to 20 seconds, with maximum exposure occurring between 4 and 15 seconds. Implementing a policy to ensure that trucks do not follow within 20 seconds of another truck can result in a 41% to 52% reduction in airborne respirable dust exposure to the following truck.

By reviewing the effects of haul truck generated dust on following equipment, another method of dust control by using traffic procedures can be implemented. This knowledge will help in the understanding of dust exposure for haul truck operators and give mine operators additional insight as to how to effectively reduce it.

References

Ahuja, M.S., Paskind, J., Houck, J.E., and Chow, J.C., 1988, "Design of a study for the chemical and size characterization of particulate matter emissions from selected sources in California," *Transactions: Receptor Models in Air Resources Management*, Watson, J.G., ed., Air & Waste Management Association, San Francisco, California, Feb., pp. 322-333.

Amponsah-Decosta, F., and Annegarn, H.J., 1998, "Assessment of fugitive dust emissions from an opencast coal mine," *Journal of the Mine Ventilation Society of South Africa*, Vol. 51, No. 1, Jan.-March, pp. 5-11.

Andersen Instruments Inc., 2002, "Series 290 Marple Personal Cascade Impactors, Operating Manual," Bulletin No. 290I.M.-3-82, Smyrna, Georgia.

Bartley, D.L., Chen, C.-C., Song, R., and Fischbach, T.J., 1994, "Respirable aerosol sampler performance testing," *American Industrial Hygiene Association Journal*, Vol. 55, No. 11, November, pp. 1036-1046.

Chekan, G.J., and Colinet, J.F., 2003, "Retrofit options for better dust control - cab filtration, pressurization systems prove effective in reducing silica dust exposures in older trucks," *Aggregates Manager*, Vol. 8, No. 9, December, pp. 9-12.

Chow, J.C., and Watson, J.G., 1998, "Guideline on Speciated Particulate Monitoring," Research Triangle Institute, NC, U.S. EPA, Office of Air Quality Planning and Standards, August.

Cole, C.F., and Zapert, J.G., 1995, "Air Quality Dispersion Model Validation at Three Stone Quarries," National Stone Association, Washington D.C., January.

Hale, J., 2002, "NIOSH's Division of Respiratory Disease Studies informational analysis of MSHA's dust sampling database."

Houck, J.E., Chow, J.C., and Ahuja, M.S., 1988, “The chemical and size characteristics of particulate material originating from geological sources in California,” *Transactions: Receptor Models in Air Resources Management*, Watson, J.G., ed., Air & Waste Management Association, San Francisco, CA, February 1988, pp. 322-333.

International Standards Organization (ISO), 1993, “Air Quality-Particle Size Fraction Definitions for Health-Related Sampling,” Draft Int. Standards ISO Technical Report, ISO/TR 7708-1983 (E), ISO, Geneva.

Lippmann, M., 1995, “Size-selective health hazard sampling” Chapter 5, *Air Sampling Instruments for Evaluation of Atmospheric Contaminants, 8th Edition*, Cohen, B.S., and Hering, S.V., eds., American Conference of Governmental Industrial Hygienists, ACGIH, Cincinnati, OH, pp. 81-119.

Maynard, A.D., 1999, “Measurement of aerosol penetration through six personal thoracic samplers under calm air conditions,” *Journal of Aerosol Science,* Vol. 30, No. 9, Elsevier Science, Ltd., Great Britain, pp. 1227-1242.

Mine Safety and Health Administration, 1997, “Labor Department Renews Push to Eliminate Silicosis,” MSHA News Release No. 97-1031, U. S. Department of Labor, Mine Safety and Health Administration, October.

National Institute for Occupational Safety and Health, 2002, “MSHA Data File Downloads,” Website: www.cdc.gov/niosh/mining/data/mshadata.html, U. S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health.

Olson, K.S., and Veith, D.L., 1987, “Fugitive dust control for haulage roads and tailings,” Bureau of Mines Report of Investigations 9069, U.S. Department of the Interior.

Organiscak, J.A., and Page, S.J., 1999, “Field assessment of control techniques and long-term dust variability for surface coal mine rock drills and bulldozers,” *International Journal of Surface Mining, Reclamation, & Environment*, Vol. 13, No. 4, pp. 165- 172.

Organiscak, J.A., and Reed, W.R., 2004, “Characteristics of fugitive dust generated from unpaved mine haulage roads,” *International Journal of Surface Mining, Reclamation, and Environment*, Vol. 18, No. 4, pp. 236-252.

Reed, W.R., 2003, “An Improved Model for Prediction of PM_{10} for Surface Mining Operations,” Ph.D. Thesis, Virginia Tech, Blacksburg, VA.

Reed, W.R., Westman, E.C., and Haycocks, C., 2001, “An improved model for estimating particulate emissions from surface mining operations in the eastern United States,” *Securing the Future, International Conference on Mining and the Environment, Proceedings*, The Swedish Mining Association, SkellefteÂ, Sweden, pp. 693-702.

Rosbury, K.D., and Zimmer, R.A., 1983, “Cost Effectiveness of dust control used on unpaved haul roads -Volume I. Results, analysis, and conclusions,” Bureau of Mines Open File Report 106-85 Vol. 1., U.S. Department of the Interior, December.

Soderholm, S.C., 1989, “Proposed international conventions for particle size-selective sampling,” *Annals of Occupational Hygiene*, Vol. 33, No. 3., pp. 301-320.

U.S. Census Bureau, 2001, “1997 Economic Census, Mining Subject Series,” U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau.

U.S. Environmental Protection Agency, 1996, “Executive summary,” *Air Quality Criteria for Particulate Matter*, Vol. I, U.S. EPA, Office of Research and Development, Washington, D.C., April.

U.S. Environmental Protection Agency, 1998, “*Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, fifth edition AP-42, Section 13.2.2 Unpaved Roads*, Research Triangle Park, NC, U.S.EPA, Office of Air Quality Planning and Standards, Emission Factor and Inventory Group, September.

U.S. Government Printing Office, 2002, *Code of Federal Regulations: Title 40, Volume 3, Chapter I, Part 53, Section 43*, Website: www.ecfr.access.gpo.gov/otcgi/cfr, June.