The effects of ventilation controls and environmental cabs on diesel particulate matter concentrations in some limestone mines

J. D. Noll, L. Patts, & R. Grau
National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA

ABSTRACT: MSHA has promulgated a rule to limit the exposure of underground metal/nonmetal miners to diesel particulate matter (DPM). In May 2008, the final personal exposure limit will be lowered to 160 µg/m^3 total carbon. To comply with this rule, mine operators are implementing a variety of control technologies. In this study two types of control technologies (ventilation and cabs) which are being implemented in limestone mines were investigated. Two stone mines in this study use large diameter propeller fans for main mine ventilation and direct the air to the faces using auxiliary fans, stoppings, and long pillars while bypassing the old mine workings. NIOSH measured for sub-micrometer elemental carbon (EC) using SKC DPM cassettes (analyzed using NIOSH 5040) and a near real time instrument. With the present ventilation and the number and type of vehicles used, the concentration of EC from DPM at the working areas was at or below 400 µg/m^3 for both mines and about 166 µg/m^3 and 251 µg/m^3 at the returns. The real time data showed that the ventilation was reaching the working areas and effectively diluting the DPM. Environmental cabs were also used to reduce DPM exposures in three underground limestone mines. Using NIOSH method 5040 and near real time EC instrumentation, NIOSH sampled inside and outside of a loader cab at one of these limestone mines to determine the effectiveness of the cab. The cab was found to be over 90% effective in removing DPM as long as the cab system was properly maintained, and doors and windows were closed.

1 Introduction

Long-term exposure to elevated concentrations of diesel exhaust is a concern, because diesel particulate matter (DPM) is believed to be a possible carcinogen. [1-3] Exposure to elevated concentrations of diesel exhaust has also been linked to health effects such as eye and nose irritation, headaches, nausea, and asthma. [4-6] Because underground miners are exposed to some of the highest levels of diesel exhaust in the United States, the Mine Safety and Health Administration (MSHA) has promulgated rules to limit the exposure of metal/nonmetal underground miners to DPM. MSHA uses total carbon (TC) or elemental carbon (EC) as a surrogate because DPM could not be measured directly. The personal exposure limit is 350 µg/m^3 total carbon (269 µg/m^3 elemental carbon) for the 2007 interim limit and 160 µg/m^3 total carbon for a final limit effective in 2008.[7-8]

In order to comply with this rule, mines are implementing a variety of controls to reduce DPM concentrations. Some such controls are alternative fuels such as biodiesel, diesel particulate filters, ventilation, emission based maintenance, newer engines, environmental cabs, and some administrative controls. Mines are experiencing a variety of results when trying these different DPM reduction strategies. NIOSH is currently surveying a variety of metal/ nonmetal mines to document what methodologies mines are using to reduce the DPM. The compiled information may help the mining community reduce DPM exposure of the underground miners.

This paper concentrates on surveys conducted at two stone mines that were using ventilation and enclosed cabs to reduce DPM exposure. Two stone mines instituted a combination of unit and perimeter ventilation system and large diameter propeller fans to reduce contaminant concentrations.[9-10] Both mines were able to direct a substantial airflow to the face using long pillars or brattices. NIOSH measured the ventilation and DPM concentrations in several areas of these mines to determine the concentrations of DPM that were being achieved due to the combination of ventilation under existing operating conditions.

These stone mines also used enclosed cabs to reduce DPM exposure. Cabs have been shown to be very effective (over 90%) in removing different contaminants when properly working.[11-13] Cabs have also been reported to leak without proper maintenance and can provide different effectiveness depending upon factors such as type of contaminant, pressurization, cleanliness of cab, etc.[11-13] It is important, therefore, to investigate how these enclosed cab systems on working mining vehicles remove DPM. In order to determine how effective cabs in some mines can be, NIOSH investigated the effectiveness of an enclosed cab on a loader in reducing DPM. NIOSH conducted this investigation at a third limestone mine.

2 Methods

2.1 Mine Survey

In several underground stone mines, ventilation and environmental cabs are used as a strategy to lower DPM exposure. NIOSH evaluated these strategies in three underground stone mines to document the successes and failures for information to the mining community. NIOSH measured the ventilation and noted the type of ventilation used in two stone mines. DPM measurements were made in several areas of the mines to determine what concentrations of DPM were achieved with this mine's ventilation package. NIOSH also investigated the effectiveness of an enclosed cab in a third limestone mine.

2.1.1 Ventilation

A vane anemometer was used to obtain ventilation measurements. Measurements were taken in several areas of the mine (return and some locations near the face). The anemometer was attached to an extendable rod and one minute entry cross sectional measurements were taken.

2.1.2 Area Samples

Area samples were taken at several locations in two stone mines to determine the DPM concentrations in these mines as well as the effects of the current ventilation systems. The EC monitor and three SKC DPM cassettes (standard setup method for EC and TC) were located in a basket on a tripod (see Figure 1), and were operated for six hours of a shift during a production shift of an underground stone mine.

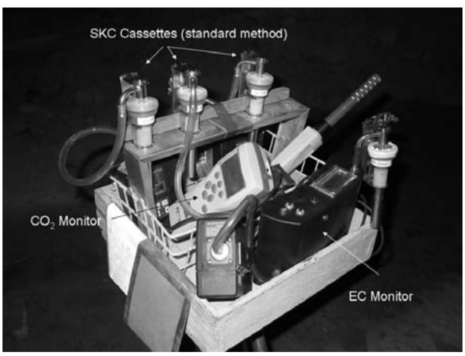

Figure 1: Apparatus for area sampling which includes an EC monitor for real time analysis, SKC DPM cassettes for NIOSH 5040 analysis.

A basket was setup at the intake of the mine (fresh air brought into the mine), the return (the exit of the intake air after passing through the whole mine), and at several locations at the working area where loaders were loading the limestone into haul trucks. Drilling, roof bolting, and scaling were also performed at the working areas. The EC monitors were downloaded each day and the EC concentration was calculated using a calibration curve. The EC monitor is a near real time instrument that measures elemental carbon in 5-15 minute averages depending upon concentration. The instrument is described in other publications.[15-16]

The quartz filters from the SKC DPM cassettes were analyzed for EC at the NIOSH Pittsburgh Research Laboratory using NIOSH 5040.[14] Area samples were taken in the mine for three days.

2.2 Enclosed Cab

These and other stone mines also use enclosed air conditioned cabs to reduce the miners' exposure to DPM. These cabs are air conditioned and filter (both a course filter and hepa filter are used) out the DPM to provide a cleaner atmosphere for the miner. In order to evaluate the efficiency of a cab to reduce DPM, two baskets each containing an EC monitor and three SKC DPM cassettes were prepared. One of the baskets was then strapped onto a loader (a Caterpillar 980F) outside the cab in Mine C. Another identical basket was placed inside the cab of the vehicle where the miner operates the vehicle. The loader was used to clean up areas in the mine and was run during normal production for this stone mine. After about 6 hours of sampling, the samples were removed from the vehicle. This sampling procedure was continued for five days at a stone mine.

The quartz filters from the SKC DPM cassettes were analyzed for EC at the NIOSH Pittsburgh Research Laboratory using NIOSH 5040.[14] The EC monitors were downloaded each day and the EC concentration was calculated using a calibration curve.

The reduction efficiency (the effectiveness of the cab to remove DPM) was calculated using the EC values from the NIOSH 5040 analysis using the following equation:

$$\mathrm{Re}\,duction\ \ efficiency \equiv \frac{(ECoutside - ECinside)}{ECoutside}\,x100$$

ECoutside – The EC concentration measured by NIOSH 5040 outside of the cab.
ECinside – The EC concentration measured by NIOSH 5040 inside of the cab.

3 Results and Discussion

3.1 Ventilation

3.1.1 Mine A

Table 1 shows the ventilation measured at mines A and B. Mine A used a perimeter ventilation method as shown in Figure 2. The ventilation system consisted of two exhausting propeller fans and brattice curtain stoppings to course the ventilation air across the active faces while bypassing the bulk of the old mine workings. An auxiliary fan was placed in the fresh air stream to draw air to the faces. Airflow of 310 m^3/s (660,000 cfm) (D) was measured to be exhausting from the two main mine propeller fans. Additional air measurements were taken 365-m (1,200 ft) from the main mine fans and totaled 270 m^3/s (570,000 cfm) (A-C). Since a brattice curtain line was used, face distances further from the fan would have decreased the available airflow. Previous tests[9-10] found about 33% of total airflow was available 975-m (3,200-ft) from the face at this mine.

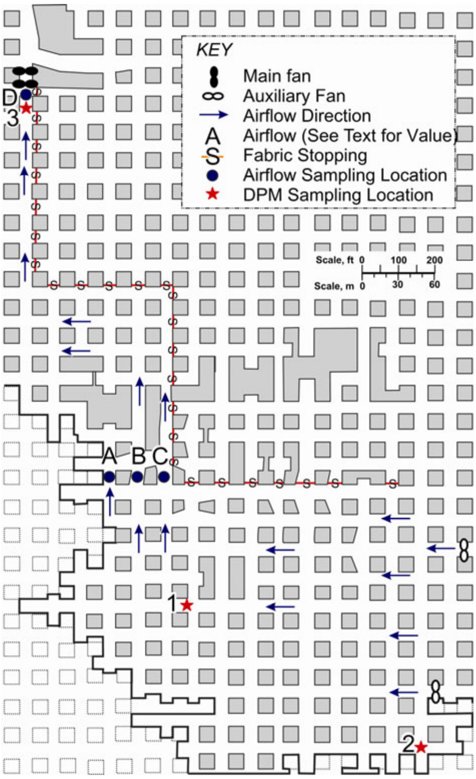

Figure 2: Ventilation and diesel particulate matter sampling points for Mine A.

Table 1: Ventilation Results		
Mine	**Location**	**Ventilation (cfm)**
Mine A	Return Portal	660,000
Mine A	Main Entry C	326,000
Mine A	Main Entry B	129,000
Mine A	Main Entry A	114,000
Mine B	Total Exhaust	554,000
Mine B	Location A	316,000
Mine B	Location B	209,000

3.1.2 Mine B

A notable difference in this mine from Mine A was that the main airflow was coursed and directed by a series of long stone pillars which separate the intake airways from the return airways. The mine was also phasing into unit mining. Research by NIOSH has shown that the use of long stone pillars instead of brattice curtain will maintain the total ventilation efficiency over a longer distance.[10] Long stone pillars eliminate the construction and maintenance costs associated with brattice curtain stoppings. Long stone pillars also eliminate leakage, resulting in both an increase in total mine, and delivery ventilation efficiencies. Using long stone pillars can be a key factor in maintaining adequate ventilation airflows at increasing distances from the fan to the active production faces where ventilation is most critical. The unit ventilation method is based upon a preexisting airflow system to block off an area for development. Units of pillars are created that are surrounded by in-place stone stoppings.

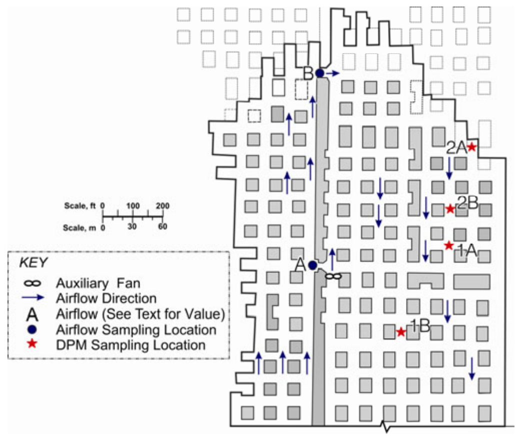

Figure 3: Ventilation and diesel particulate matter sampling points for Mine B

Mine B had a long pillar line with six cross cuts along the 850-m (2,800 ft) of length. The crosscuts nearest the fan have been sealed with piled stone and brattices although leakage has not been completely eliminated. Of the 280 m^3/s (590,000 cfm) entering the mine, about 250 m^3/s (525,000 cfm) (A, B) ventilated the working sections and was measured passing through the last two openings in the stone pillar as seen in Figure 3. This air ventilated the unit mining section and subsequently was sampled for DPM.

In both mines, good ventilation was reaching the face indicated by the air flow after passing through the face areas. A substantial part of the airflow was still measured even after passing through the face area (locations A-C in mine A and locations A-B in mine B).

3.2 Vehicles Used in The Mine

Mining equipment utilizing both new and old engines was used in both mines A and B. Over 12 vehicles were working in the mines at one time (loaders, haul trucks, drillers, scaler, water truck, etc.).

3.3 DPM Concentrations

Diesel particulate matter (DPM) could not be measured directly due to sensitivity of the method (gravimetric) and interferences (mineral dust, cigarette smoke, etc.). Total carbon was susceptable to potential interferences (cigarette smoke, vapor phase OC, etc.) Therefore, elemental carbon (EC) was used as a surrogate to measure DPM since elemental carbon is not prone to interferences. It is also used by MSHA to determine total carbon concentrations for the interim PEL,[8] and in a previous study, EC was shown to have a linear relationship between DPM and TC from DPM in several metal/nonmetal mines.[17]

Elemental carbon (EC) results measured via NIOSH 5040 are shown in Table 2. The results show the average concentration for about 6 hours of sampling per day for three days. EC concentration can vary from day to day depending upon the number of vehicles operated and production levels. Three days of sampling were performed to permit averaging of some of the fluctuations caused by daily production changes.

Table 2: NIOSH 5040 Results

Mine	Location	EC (g/m3)
Mine A	Intake*	10
Mine A	Return*	251
Mine A	Face 1 *	180
Mine A	Face 2 *	216
Mine B	Intake*	4
Mine B	Return*	166
Mine B	Face 1A	94
Mine B	Face 1B[t]	198
Mine B	Face 2A	91
Mine B	Face 2B[t]	171

*average of three days
[t] average of two days

As seen in Table 2, the NIOSH 5040 results show that in Mine A, the average EC concentrations were about 251 $\mu g/m^3$ at the return and in Mine B the average EC concentration was about 166 $\mu g/m^3$ at the return.

The NIOSH 5040 results derived from the area samples obtained in Mine A and B do not provide a good evaluation of the DPM concentration at the working area because the vehicles were only working in the area where the samples were collected for part of the day. The near real time EC data from the EC monitors collected during the time the vehicles were operating would more closely represent the DPM concentrations expected at a working face than do the NIOSH 5040 results.

Figures 4 and 5 are examples of near real time data at the working areas. As can be seen by Figure 4, for this working area in Mine A, the miners were not working directly at the face where these samplers were until 13:00. The concentration of EC before the vehicles were operating at this face was about 200 $\mu g/m^3$. The concentration increased to about 400 $\mu g/m^3$ with an average of about 350 $\mu g/m^3$ when the vehicles were operating near the samplers. One would then expect the concentrations of EC to be around 350 $\mu g/m^3$ where some of the miners are working in Mine A.

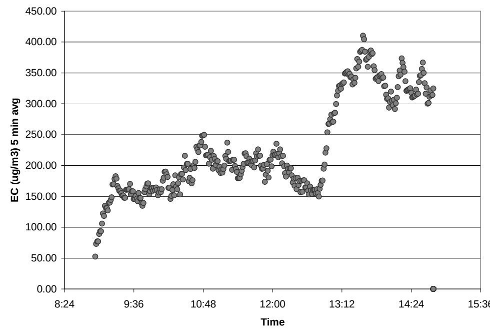

Figure 4: Near real time EC concentration for area samples at the working area of mine A. This showed the highest concentration achieved in the three days of sampling.

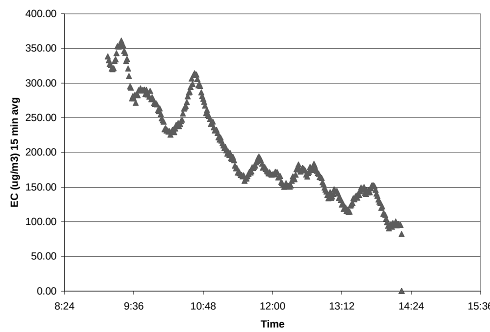

Figure 5: Near real time EC concentration for area samples at the working area of mine B. This showed the highest concentration achieved in the three days of sampling.

After examining the near real time data for all of the days and areas sampled, the highest concentration seen in Mine A was about 400 $\mu g/m^3$ and 350 $\mu g/m^3$ for mine B at the face. The highest average concentration when the vehicles were working in the area of the samplers was about 350 $\mu g/m^3$ for mine A and about 250 $\mu g/m^3$ for mine B.

Mine A was achieving EC concentrations around 251 $\mu g/m^3$ in the return and at or below 400 $\mu g/m^3$ at the working area with the ventilation package and number and type of vehicles used. Mine B was achieving EC concentrations around 166 $\mu g/m^3$ at the return and at or below 350 $\mu g/m^3$ at the working areas with the ventilation package and number and type of vehicles used. The concentrations of DPM achieved with similar ventilation packages can differ depending upon the vehicles used (number and type).

The mine air in these mines was not below the final personal exposure limit (PEL) (160 $\mu g/m^3$ TC which would be represented by 123 $\mu g/m^3$ EC if one were to use the MSHA interim 1.3 TC/EC conversion factor – the conversion unit for the final limit has not been determined yet), but can still be beneficial in achieving the PEL. Higher ventilation will provide a mine more options of controls because not as much of a reduction would be needed to reduce the DPM down to the PEL. For example, biodiesel with a higher percentage of ultra low sulfur fuel could be used instead of 100% biodiesel or a diesel particulate filter. One could also use enclosed cabs and control the time that miners are outside the cabs (the better the ventilation, the longer a miner could be out of the cab before going above the PEL). At these mines, a miner could be in the atmosphere at the face for about 2.5 hours before reaching the PEL and could be exposed about 4-6 hours in other parts of the mine before reaching the PEL. Such improved ventilation could also give the benefit of lowering the concentration of other possible irritants in the air.

3.4 Enclosed Cabs

As seen in the section above with the engines and ventilation package employed in these two mines, the mine air was not below the final PEL. Because the final PEL was not achieved at these mines, stone mines also used enclosed cabs to protect the miners. This has been shown to be an effective strategy in eliminating exposure of workers to contaminants when the cab is maintained well.[11-13] In one stone mine (Mine C), miners in enclosed cabs were exposed to concentrations of DPM higher than the final limit (below interim limit). With the efficiencies reported in other studies, the concentrations measured in the enclosed cabs at this mine were unexpected. Therefore, NIOSH investigated the efficiency of these cabs to reduce DPM concentrations. NIOSH 5040 samples and EC monitors were placed inside and outside of a cab at Mine C.

As seen in Figure 6, the reduction efficiency of the cab measured using NIOSH 5040 results was between 40-93% depending on the day and driver. One would not expect the reduction of DPM to vary this much from day to day just due to leakage or bad performance of the cab when nothing was done to the cab or vehicle, the sampling environment did not change drastically, and no trend was in the data (getting better or worse in each day). The real time data seems to indicate a possible reason for the variation. The real time data shows DPM peaks throughout the shift on days which display a lower reduction efficiency. This would indicate that the cab window and/or door was being opened periodically throughout the shift.

This effect can be visualized when examining at a day with 73% cab efficiency compared to a day with 93% cab efficiency. The biggest difference between these days was only the driver.

As seen in Figure 7, on the day with 73% efficiency, inside the cab for test 1, a peak of higher EC exposure for one part of the shift and then a higher exposure at the end of the sampling period are shown. The peak would indicate a window or door opening and then closing. The higher concentration at the end of the shift could be from the miner opening the window slightly and leaving it open for

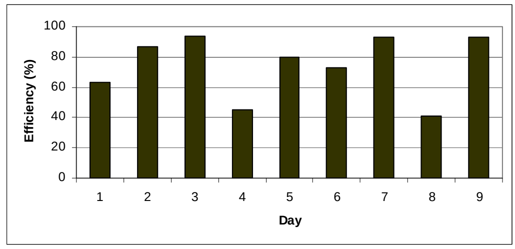

Figure 6: Efficiency of the cab of a loader using the NIOSH 5040 data.

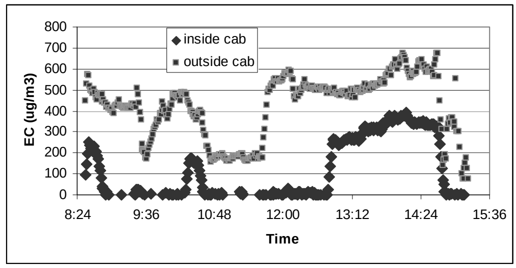

Figure 7: The real time data comparing inside and outside of the cab on the day with 73% efficiency.

the rest of the sampling period. If the EC exposure was due to a leak or penetration through the filtration system, one would expect the EC concentration to follow a trend and not expect to have a peak.

As can be seen in Figure 8, unlike in test 1, the window or door does not seem to have been opened during the shift for test 2. It appears that after the first initial opening that the cab was closed for most of the day. The reduction efficiency from test 2 is probably closer to the expected efficiency of the cab.

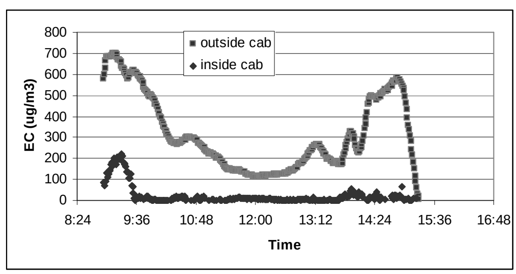

Figure 8: The real time data comparing inside and outside of the cab on the day with 93% efficiency.

This cab should reduce DPM by over 90% when operating correctly and kept sealed. Work practices might be able to help minimize the opening of the windows and doors.

4 Conclusion

For the mines surveyed in this study, the ventilation controls used in conjunction with the number and type of engines operated in these two mines did not produce DPM concentrations below the final PEL. The controls used did lower the concentration enough to possibly give the mine more options in controlling the DPM exposures such as the time miners outside of an enclosed cab are working in certain areas of the mine. Enclosed cabs were also used in these mines to limit the exposure of the underground miners. In one mine, an enclosed cab was found to be over 90% efficient in reducing DPM as long as the windows and doors were kept closed. The opening of windows seemed to cause a substantial increase in DPM exposure. Other studies have shown that along with keeping doors and windows closed good maintenance of the cabs is necessary for achieving good cab performance. Not all miners can be in enclosed cabs. For the miners outside of cabs, a different control needs to be used to reduce their DPM exposure such limiting the amount of time they work outside of a cab, restricting the areas where they work, lowering the DPM concentrations in areas of the mine through maintenance, improved ventilation, the use of diesel particulate filters, alternative fuels, or a combination of these engineering controls.

This is some preliminary data. NIOSH is presently investigating various enclosed cabs to obtain a better understanding of how effective cabs are. Surveys are also continuing to investigate other types of DPM controls.

References

Birch, M. E. *NIOSH Manual of Analytical Methods (NMAM)*, 2004, ed. O'Connor P.F., Third Supplement to *NMAM*, 4th Edition. Cincinnati, OH: Department of Health and Human Services, Public Health Service, Center for Disease Control and Prevention, National Institute for Occupational Safety and Health. DHHS(NIOSH) Publication No. 2003-154.

Cecala, A.; Organiscak, J.; Zimmer, J.; Heitbrink, W.; Moyer, E.; Schmitz, M.; Ahrenholtz, E.; Coppock, C.; Andrews, E. 2005, „Reducing Enclosed Cab Drill Operator's Respirable Dust Exposure with Effective Filtration and Pressurization Techniques" *Journal of Occupational and Environmental Hygiene*, 2, 54-63.

Grau, III R.H., Krog, R.B. & Robertson, S.B. 2006. Maximizing the ventilation of large-opening mines. Proceedings of the 11th U.S./North American Mine Ventilation Symp. University Park, PA, June 5–7, 2006. Leiden, Netherlands: Taylor & Francis/Balkerma, 53-59.

Grau, III R.H., Robertson S.B., Krog R.B., Chekan G.J. & Mucho T.P. 2004. Raising the bar of ventilation for large-opening stone mines. In: Ganguli R, Bandopadhyay S, (eds.), Mine ventilation: Proceedings of the 10th U.S./North American Mine Ventilation Symposium, Anchorage, AK, May 16–19, 2004. Leiden, Netherlands: Balkema, 349–355.

Heitbrink, W.; Moyer, E.; Jensen, P.; Watkins, D.; Martin, S. 2003, "Environmental Agricultural Tractor Cab Filter Efficiency and Field Evaluation" *AIHA Journal*, 64, 394-400.

IARC, 1989, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, International Agency for Research on Cancer (IARC), Lyon, France, World Health Organization, p 458.

Janisko, S.; Noll, J. D., 2008. Near Real Time Monitoring of Diesel Particulate Matter in Underground Mines, in *Proceedings of the 12th U.S./North American Mine Ventilation Symposium 2008*, submitted.

Kahn, G.; Orris, P; Weeks, 1988, "Acute overexposure to diesel exhaust: report of 13 cases," J. *Am. J. Ind. Med*., 13, 405-406.

Mine Safety and Health Administration. (January 19, 2001) 30 CFR Part 57 Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners; Final Rule. *Fed. Reg*. vol. 66, No. 13, 5706.

Mine Safety and Health Administration. (May 18, 2006) 30 CFR Part 57 Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners; Final Rule. *Fed. Reg*. vol. 71, No. 96, 28924.

Moyer, E.; Heitbrink, W.; Jensen, P. 2005, „Test for the Integrity of Environmental Tractor Cab Filtration Systems"*Journal of Occupational and Environmental Hygiene*, 2, 516-523.

NIOSH, 1988, *Carcinogenic Effects of Exposure to Diesel Exhaust. Current Intelligence Bulletin No. 50*. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Pub., No. 88-116.

Noll, J. D.; Janisko, S., 2007. Using Laser Absorption Techniques to Monitor Diesel Particulate Matter Exposure in Underground Stone Mines, in *Proceedings of SPIE*, vol 6759.

Rundell, B, et al. 1996, "Effects on symptoms and lung function in humans experimentally exposed to diesel exhaust," *Occup. Environ. Med*., 53, 658-662.

U.S. Environmental Protection Agency (EPA), 2002, *Health Assessment Document for Diesel Engine Exhaust*, Prepared by the National Center for Environmental Assessment, Washington, DC, for the Office of Transportation and Air Quality; *EPA/600/8-90/057F*. Available from: National Technical Information Service, Springfield, VA; PB2002-107661.

Wade, JF, III; Newman, LS. 1993, "Diesel asthma: reactive airways disease following overexposure to locomotive exhaust," *J. Occup. Med*., 35, 149-154.J. D. Noll; A. D. Bugarski; L. D. Patts; S. E. Mischler; L. McWilliams 2007 „ Relationship between Elemental Carbon, Total Carbon, and Diesel Particulate Matter in Several Underground Metal/Non-metal Mines" *Environ. Sci. & Technol*., Vol. 41, No. 3:, 710-716.