Respirable quartz hazard associated with coal mine roof bolter dust

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ABSTRACT: This study examined the potential for coal mine roof bolter dust to be a source of a worker's exposure to respirable quartz. For the models of roof bolter studied, the dust from bolt hole drilling is collected by a dry vacuum exhaust system. The collected dust-laden air passes through a cyclone size-separator (pre-cleaner) and into a collector box containing two additional cyclones and a filter cartridge. The filtered air is then discharged through a muffler into the ambient mine air. The pre-cleaner is designed to remove oversize dust, with the pre-cleaner undersize dust passing to a collector box. The pre-cleaner periodically dumps collected dust onto the mine floor. To assess the hazard presented by the roof bolter dust, bulk samples of the pre-cleaner dust and collector box dust were obtained from roof bolters operating in Mine Safety and Health Administration Coal Districts 4, 5, 6, and 7. Forty-six samples of each dust type were collected from twenty-six mines. Dust size distributions were determined for each sample. The quartz content was also determined for forty samples. The fraction of pre-cleaner dust smaller than 10 micrometers ranged from 5.3% to 35.4%. Quartz content, by weight, of the pre-cleaner dust ranged from 9.8% to 53%. The collector box dust was significantly smaller in size with the fraction of dust below 10 micrometers ranging from 13% to 86.7%, its quartz content ranged from 1.0% to 79%. Airborne dust samples along with detailed observations of the bolter operation were collected at two of these mines to further evaluate potential for worker exposure. This study quantifies the high content of respirable quartz in the roof bolter pre-cleaner cyclone dump dust and the collector box dust.

1 Introduction

Miners are exposed to several occupationally related agents that have the potential to degrade health. These agents include physical forms such as noise, vibration, and temperature extremes; and chemical forms such as respirable dusts, diesel particulates, and asphyxiants. Underground coal miners can be subject to high concentrations of respirable dust from coal extraction and transportation activities, and this dust may contain quartz. Extended exposure to elevated levels of respirable coal mine dust may result in coal workers pneumoconiosis (CWP), and if the respirable dust contains quartz, the miner may develop silicosis. Both of these lung diseases are incurable, and silicosis may continue to worsen after exposure has ceased. Consequently, the best means to control these diseases is to prevent their occurrence.

Pneumoconiosis in coal miners, including cases of rapidly progressive disease, has been reported to be increasing among underground coal workers in the Southern Appalachian Region (SAR) (CDC, 2006; 2007). The SAR area is not strictly defined; it is generally described as southern West Virginia, the eastern third of Kentucky, and western Virginia. The area is largely encompassed by Mine Safety and Health Administration (MSHA) Coal Districts 4, 5, 6 and 7. The fraction of coal miners with rapidly progressive CWP in these MSHA districts based on recent surveillance is given in Table 1 (Antao, *et al.*, 2005). Counties with fewer than five miners evaluated, or less than 40% with rapid progression are not included.

As part of an on-going research effort into potential explanations for this increase, the National Institute for Occupational Safety and Health (NIOSH) examined the particle size distribution and quartz content of dust generated by the installation of roof bolts in a group of mines in these four MSHA Coal Districts. Forty-six bulk samples of roof bolting machine pre-cleaner cyclone dump dust and collector box dust were collected from twenty-six underground coal mines. Real-time and integrated airborne respirable dust concentrations were measured on three mining sections in two mines in District 6. The real-time airborne dust concentrations profiles were examined to identify any concentration changes that might be associated with pre-cleaner cyclone dust discharge events.

Roof bolting, as a ground control approach, was introduced to underground coal mining in the 1940s, although some applications were attempted earlier. Today, roof bolting is the principal method of roof support in underground mines. In 2005, an estimated 68 million roof bolts were installed, including 1 million cable bolts (Tadolini & Mazzoni, 2006).

Several different types of bolt-anchoring systems exist, but regardless of the type of bolt used, all require a hole to be drilled to accept the bolt. The diameter of the hole created to accept the bolt is larger than the bolt diameter. As an example, one roof bolt manufacturer recommends hole diameters ranging from 1.1 to 1.6 times the bolt diameter (Jennmar Corporation, 2009). The volume of drill cuttings – the dust – will be slightly

Table 1 Proportion of evaluated miners with rapidly progressive CWP by state and county.

	Miners Examined (n) 1996-2002	Miners Evaluated (n)#	Miners Evaluated with Rapid Progression (%)
Kentucky			
Floyd	68	6	50.0%
Harlan	400	24	41.7%
Knott	289	9	66.7%
Leslie	123	5	60.0%
Letcher	504	23	43.5%
Martin	141	10	60.0%
Perry	223	9	44.4%
Pike	748	73	53.4%
Virginia			
Buchanan	736	122	49.2%
Dickenson	292	31	51.6%
Lee	142	5	80.0%
Russell	99	13	46.2%
Tazewell	121	26	61.5%
Wise	1,095	63	58.7%
West Virginia			
Grant	42	7	57.1%
Nicholas	140	11	45.5%
Preston	199	16	50.0%
Raleigh	302	51	43.1%
Randolph	17	8	62.5%
Upshur	170	13	46.2%

A minimum of two medical examinations, including pre-1996, was required for a miner to be evaluated for progressive disease.

greater than the hole volume due to the loss of consolidation, but ignoring that small difference, the amount of dust generated on a 'typical' underground coal entry 5.5 m wide x 6.1 m deep (18 ft x 20 ft) using a 1.2 m long, 16 mm diameter bolts on a 1.2 m center pattern (4 ft long x 5/8" diameter bolts on 4-ft center pattern) would be about 0.05 m^3 (1.7 ft^3). This represents a considerable amount of dust that could potentially be released into a small, confined volume subject to variable ventilation rates.

The dust released from drilling bolt holes has long been recognized as a potential health hazard (Mark, 2002). MSHA regulates miner exposure to respirable dust generated from drilling under the requirements of 30 CFR Part 70.100 (respirable dust) and 30 CFR Part 70.101 (respirable dust when silica is present). MSHA also regulates how the control of dust generated from drilling is to be achieved in 30 CFR Part 72.630. The dust controls specified include permissible dust collectors, the application of water or water containing a wetting agent through the drill steel, by ventilation, or by any other equally effective, MSHA-approved method.

In the United States, dry vacuum dust collectors are commonly used as the control method on roof bolting machines in coal mines. The arrangement and specifications of the dust control systems differ depending on the equipment manufacturer. The mines included in this study were all utilizing roof bolters manufactured by J.H. Fletcher & Co. There was no pre-selection decision to limit the study to a single manufacturer; the selected mines comprised a convenience sample.

In general terms, the dust collector currently used on Fletcher bolting machines is composed of an initial cyclone called the pre-cleaner, followed by a collector box where undersized dust from the pre-cleaner either impacts on a plate, or enters a dust collection bag. The airstream exits the collector box after passing through two additional cyclones and a final cartridge filter. The pre-cleaner cyclone is intended to remove larger size dust particles, and dump this fraction onto the mine floor. The removal of the larger size dust reduces the volume of material that must be removed from the airstream in the collector box. The air blower is located downstream from the cartridge filter, so the entire system is designed to handle dust-laden air under negative pressure.

The dust accumulated in the collector box must be removed occasionally to maintain system performance. Various approaches to reduce the dust exposure of miners from this activity utilizing engineering changes and/or work practices have been developed. These include providing a handled tool to scrape the dust from the box, and manufacturer-developed procedures incorporating the use of existing mine ventilation and respiratory protective equipment. On machines equipped with dust collection bags, the bag containing dust is removed from the collector box and placed against a rib or other location away from traffic. Miner exposure to airborne dust from cleaning the collector box has been shown to be reduced when bags are utilized as compared to machines without the dust bag configuration (Listak & Beck, 2008).

Roof bolter operator exposure to respirable coal mine dust (RCMD) is generally low. Much of the RCMD exposure of bolter operators results from operating the bolting machine downwind in the return airflow from the continuous mining machine. Mine ventilation plans, which specify mandatory dust control methods, generally limit the time the bolting machine may operate downwind from the continuous miner, but it can be very difficult to eliminate this undesirable situation completely. The concern regarding roof bolter activities focuses on the respirable quartz content of the dust created when drilling into the rock roof. This exposure, as demonstrated by MSHA inspector sampling data, can be problematic (Table 2) (MSHA).

The original equipment manufacturer (OEM) roof bolter dust collector system is very effective in controlling dust from drilling, but proper operation, maintenance and cleaning are very important to preserve this level of performance (Thaxton, 1984). Questions have been raised about the potential for exposure from the pre-cleaner cyclone dust discharge and from the disposal of collector box dust. The concern about the pre-cleaner cyclone discharge centers on the potential for this dust to become airborne as a result of the dust falling approximately 0.3 m (1 ft) from the pre-cleaner to the mine floor, and/or becoming re-suspended after being deposited onto the mine floor. The collector box dust presents a potential exposure hazard when the accumulated dust is removed from the box and dust collection bags have not been utilized. A further potential exists once the collector box dust has been transferred onto the mine floor. Mechanisms to make dust from the mine floor become airborne may include foot and mobile equipment traffic, supplemented by ventilation air currents. The likelihood of re-entrainment of coal dust from a mine floor was examined in wind tunnel tests and in an experimental mine (Shankar & Ramani, 1996a, 1996b). At the lowest air velocity reported in these tests – 2.13 m/s (419 ft/min) – re-entrainment of dust was observed with only airflow as the source of energy. The amount of re-entrainment increased further when persons walked through the dust. The measured increase in re-suspension varied with height above the floor and downwind distance from the dust source.

Table 2 Roof Bolter Occupation Respirable Dust and Quartz Exposures.

MSHA Inspector Roof Bolter Occupations Samples 1999 – 2008			
Respirable Coal Mine Dust		Respirable Quartz	
Sample N	% > Dust Standard*	Sample N	% > 100 μg/m^3
50,072	6.3%	9,624	21.5%
* The dust standard associated with a sample is 2.0 mg/m^3 unless the quartz content of the airborne respirable dust exceeds 5%.			

In these in-mine tests, coal dust was spread onto a flat, dry and smooth floor surface. The testing also utilized high ventilation air velocities. These conditions do not closely represent typical underground coal mine production sections where the floor is normally uneven and wet, and the ventilating air velocities are rarely as high as those in the test conditions. These differences limit the application of the test results to producing mines. The hazard from re-suspension of floor-deposited dust after a production section evolves into a transportation heading and bears frequent traffic from mobile equipment (e.g., shuttle cars) and personnel has not been investigated.

In a test conducted under contract to the United States Bureau of Mines to examine the question of re-entrainment of roof bolter dust from the floor of two active coal mines, an object weighing approximately 2.25 kg (5 lbs) was dropped onto dust piles while a Simslin real-time aerosol monitor was operated 1 m (3 ft) downwind and 30.5 cm (1 ft) above the floor (Colinet *et al.*, 1985). In five tests at one mine, no indication of increased dust was observed on the aerosol monitor. In four tests at a second mine, the average dust concentration on the aerosol monitor was 0.2 mg/m^3. The report concluded that vehicular traffic was not a significant source of quartz. No information about the air velocity or dryness of the mine floor was reported in association with these tests.

The study reported here developed additional information about the size distribution and quartz content of the dust discharged to the mine floor from the pre-cleaner cyclone (the oversize fraction), and from the dust contained in the collector box.

2 Methods

The mines included in this study comprise a convenience sample, and although a sizeable number were sampled, a representative sample of mines in MSHA Coal Districts 4, 5, 6, and 7 is not implied. The majority of the bulk dust samples were collected by district-based MSHA inspectors as they performed their scheduled duties. Bulk dust samples were collected from five mines in District 4, ten mines in District 5, five mines in District 6 and six mines in District 7. The mines sampled by NIOSH personnel were in District 6 and volunteered to participate in the research; they were also a convenience sample and were not selected on a statistical basis.

Bulk samples were collected from the collector box and from the pre-cleaner cyclone dump discharge into clean, unused plastic containers. Particle size distributions (volume basis) were obtained for each of the bulk samples by sieving, followed by analysis using a Saturn 5200 DigiSizer low-angle laser scattering instrument. This analysis measures light scattered from particles in a liquid suspension according to Mie theory. The weight-basis quartz content of the bulk dust was determined by x-ray diffraction analysis (CDC, 2003).

On a subset of mines, NIOSH collected air samples during the roof bolting process. Six air-sampling racks, each consisting of two coal mine dust personal sampling units (CMDPSU) and one Thermo Fisher pDR-1000AN real time aerosol monitor were used on each roof bolting machine. The CMDPSU is the standard sampling system used by MSHA to measure respirable coal mine dust. The pDR monitors were programmed to log concentrations on 2-second intervals. The air samplers were operated continuously while the roof bolting machine was operating. Air samples were not collected if the roof bolter was in the return airflow from the continuous mining machine.

The sampling racks were located at the rear corner, above the pre-cleaner cyclone and at the operator’s controls on the left and right sides of the roof bolting machine. The racks were suspended from the body of the roof bolting machine as permitted by material storage and operational access requirements, and were approximately 0.7 m (28”) above the mine floor.

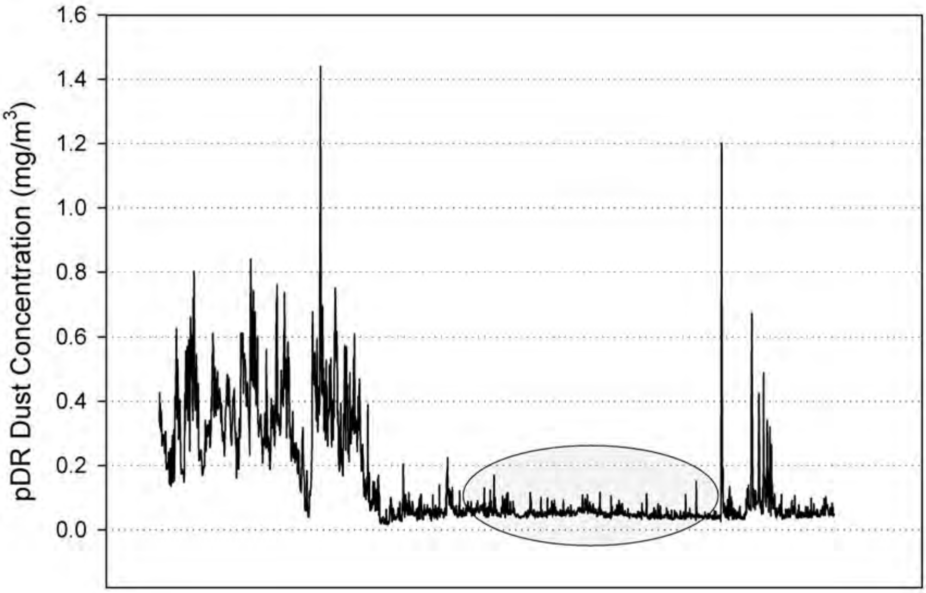

Figure 1 Real-time respirable dust concentration output from a pDR aerosol monitor. The circled area is an example of a low baseline dust interval.

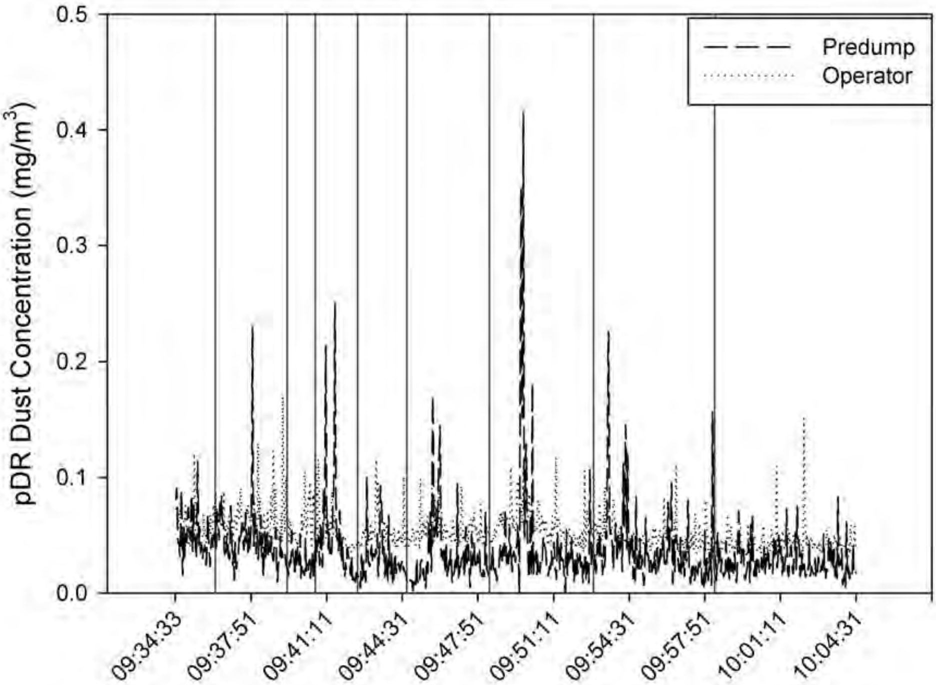

Figure 2 Pre-cleaner cyclone dump events and respirable dust concentration recorded by a pDR real-time aerosol monitor above the pre-cleaner cyclone (pre-dump), and at the downwind operator's position. Vertical lines indicate pre-cleaner cyclone dump events.

PASW Statistics 17.0 was used to generate descriptive statistics and analyze size distributions and quartz content.

3 Results

Particle size distributions were determined for forty-six bulk dust samples from the pre-cleaner cyclone dump material and the collector box. Quartz content was determined for forty of the bulk dust samples. Table 3 presents summary statistics for the analytical results. The size distributions and quartz content of the pre-cleaner cyclone dump dust samples and collector box dust samples and were compared to identify any significant differences.

Table 3 Summary statistics for size distribution and quartz content analytical results.

Pre-cleaner Bulk Dust	% < 100 µm	% < 10 µm	% < 5 µm	Quartz % (w/w)
Mean	43.6	17.9	11.3	27.3
Std Dev	12.3	5.9	3.8	12.4
Median	43.7	18.0	11.2	24.5
Min	16.4	5.3	3.3	9.8
Max	81.9	35.4	22.2	53.0

Collector Box Bulk Dust	% < 100 µm	% < 10 µm	% < 5 µm	Quartz % (w/w)
Mean	75.6	38.1	12.8	26.2
Std Dev	17.1	17.8	5.8	13.3
Median	76.8	34.2	11.8	23.0
Min	34.4	13.0	3.3	1.0
Max	99.3	86.7	28.2	79.0

The size distributions, as represented by the percent of dust less than 10 µm, and the quartz content of the bulk dust samples were tested for normality by evaluation of normal probability plots and by the Kolmogorov-Smirnov test. Both distributions were found to be significantly non-normal; size distribution result: $D = 0.168$, $p < 0.001$, df = 92; quartz content result: $D = 0.118$, $p < 0.001$, df = 80.

Median values of the percent less than 10 µm size of the pre-cleaner dust and the collector box dust were compared using the Wilcoxon Signed Ranks test. The collector box dust is significantly smaller in size than the pre-cleaner dump dust, ($Z = -5.70$, $p < 0.001$). There was no significant difference between the median concentrations of quartz in the collector box dust and the pre-cleaner dump dust according to the same statistical test, ($Z = -0.582$, $p = 0.56$).

The real-time airborne respirable dust concentration recorded by the pDR monitor varied substantially during the operating cycle. It was affected by air velocity over the bolting machine, the position of ventilation curtains, travel of the bolting machine, and the actions of the miners installing the bolts, in particular from the stocking and re-arrangement of supplies and materials on the machine deck. Occasionally the hollow drill steel would become plugged by dust, and this would cause transient very high dust levels at the operator's position due to a loss of vacuum at the drill bit. Any contribution to airborne dust from pre-cleaner cyclone dump events was expected to be brief in duration and possibly small in magnitude. To improve chances of if identifying this increase, bolting periods exhibiting a consistently low baseline level of airborne dust were examined, as depicted in Figure 1.

No definitive association between increases in airborne respirable dust and pre-cleaner cyclone dump events was observed during this study (Figure 2).

Eighteen of the CMDPSU filter samples co-located with the pDR real-time aerosol monitors were analyzed for respirable quartz. All of the samples analyzed were below the limit of quantification for quartz.

4 Summary

Roof bolter dust, both from the pre-cleaner cyclone dump and accumulated in the collector box is a potential inhalation hazard due to the fraction of dust less than 10 µm in size, and the quartz content of the dust. The pre-cleaner cyclone dust was significantly larger, as determined from the fraction smaller than 10 µm, when compared to the collector box dust. This demonstrates that the pre-cleaner functioned properly in removing the larger dust size fraction from the airstream. However the pre-cleaner dust does still contain a substantial amount of respirable dust.

To maintain the effectiveness of the OEM's roof bolter dust collector requires the periodic removal of dust deposited in the collector box. The task of cleaning the accumulated dust potentially exposes miners due to the proximity of the miner's head and face to the dust, and the possibility of dust adhering to the miner's clothing. Appropriate work procedures and equipment are necessary to minimize exposure during this task.

Utilization of dust collection bags has been shown to reduce operator exposure to respirable dust when performing this task.

In limited field-testing, no noticeable increases in airborne dust concentration could be attributed to pre-cleaner cyclone dump events using a pDR real time aerosol monitor. However, additional laboratory and in-mine study of this issue is warranted due to the difficulty of controlling all potential confounding variables in an operating mine section.

A miner's task training should address the hazards of roof bolter dust, including the importance of proper operation and maintenance of the roof bolter machine dust collector, means to minimize exposure when cleaning out the collector box, and avoiding or minimizing disturbance of roof bolter dust deposited to the mine floor from either the pre-cleaner cyclone or collector box.

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References

Antao, V.C., Petsonk, E.L., Sokolow, L.Z., Wolfe, A.L., Pinheiro, G.A., Hale, J.M. & Attfield, M.D. (2005). Rapidly progressive coal workers' pneumoconiosis in the United States: geographic clustering and other factors. In *Occup Environ Med*, (62):670-674

CDC, (Centers for Disease Control and Prevention) (2003). National Institute for Occupational Safety and Health, Method No. 7500, Silica, Crystalline, by XRD (filter redeposition), In *NIOSH Manual of Analytical Methods, NIOSH Publication No. 2003-154 (3rd Supplement)*, Schlecht, P.C. & O'Connor, P.F., Eds., Cincinnati, OH

CDC (2006). Advanced cases of coal workers' pneumoconiosis - two counties, Virginia, MMWR, (55):909-913

CDC (2007). Advanced pneumoconiosis among working underground coal miners - eastern Kentucky and southwest Virginia, 2006. MMWR, (56):652-655

Colinet, J.F., Shirey, G.A. & Kost, J.A. (1985). Control of respirable quartz on continuous mining sections, U.S. Bureau of Mines Mining Research Contract Report, Contract J0338033, June 1985.

Jennmar Corporation, 2009. http://www.jennmar.com/products/headed_rebar_bolts.html U.S. Products, Headed Rebar Bolts, Specifications, As accessed 12/11/09.

Listak, J.M. &, Beck, T.W. (2008). Laboratory and field evaluation of dust collector bags for reducing dust exposure of roof bolter operators. In *Min Eng*; 60(7):57-63.

Mark, C. (2002). The introduction of roof bolting to U.S. underground coal mines (1948-1960): a cautionary tale. In *Proc. 21st International Conference on Ground Control in Mining*, August 6-8, 2002, pp 150-160 (West Virginia University)

MSHA, US Department of Labor, Mine Safety and Health Administration, Program Evaluation and Information Resources, MSHA Standardized Information System, Arlington, Virginia.

Shankar, S. & Ramani, R.V. (1996a). Effect of air velocity and walking on the re-entrainment of dust in mine airways, in *Trans of the Society for Mining, Metallurgy and Exploration, Inc. (SME)*, 1995, pp 1834-1838 SME, Littleton, CO.

Shankar, S. & Ramani, R.V. (1996b). Re-entrainment of coal-dust particles: wind tunnel and in-mine studies, *Ibid*, pp 1839-1844 SME, Littleton, CO.

Tadolini, S.C. & Mazzoni, R.A. (2006). Twenty-four conferences; more than one-hundred and seventy papers; understanding roof bolt selection and design still remains priceless, In *Proc. 25th International Conference on Ground Control in Mining*, August 1-3, 2006, pp 382-389 (West Virginia University).

Thaxton, R.A. (1984). Maintenance of a roof bolter dust collector as a means to control quartz. In *Proc of the Coal Mine Dust Conference*, pp 137-143 (West Virginia University).