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High Exposure to Respirable Dust and Quartz in a Labour-intensive Coal Mine in Tanzania

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Labour-intensive mines are numerous in several developing countries, but dust exposure in such mines has not been adequately characterized. The aim of this study was to identify and quantify the determinants of respirable dust and quartz exposure among underground coal mine workers in Tanzania. Personal respirable dust samples (n = 134) were collected from 90 underground workers in June–August 2003 and July–August 2004. The development team had higher exposure to respirable dust and quartz (geometric means 1.80 and 0.073 mg m^{-3}, respectively) than the mining team (0.47 and 0.013 mg m^{-3}), the underground transport team (0.14 and 0.006 mg m^{-3}) and the underground maintenance team (0.58 and 0.016 mg m^{-3}). The percentages of samples above the threshold limit values (TLVs) of 0.9 mg m^{-3} for respirable bituminous coal dust and 0.05 mg m^{-3} for respirable quartz, respectively, were higher in the development team (55 and 47%) than in the mining team (20 and 9%). No sample for the underground transport team exceeded the TLV. Drilling in the development was the work task associated with the highest exposure to respirable dust and quartz (17.37 and 0.611 mg m^{-3}, respectively). Exposure models were constructed using multiple regression model analysis, with log-transformed data on either respirable dust or quartz as the dependent variable and tasks performed as the independent variables. The models for the development section showed that blasting and pneumatic drilling times were major determinants of respirable dust and quartz, explaining 45.2 and 40.7% of the variance, respectively. In the mining team, only blasting significantly determined respirable dust. Immediate actions for improvements are suggested to include implementing effective dust control together with improved training and education programmes for the workers. Dust and quartz in this underground mine should be controlled by giving priority to workers performing drilling and blasting in the development sections of the mine.

Keywords: coal mine; determinants; quartz; respirable dust; Tanzania

INTRODUCTION

A coal mine in Mbeya is the only place producing bituminous coal in Tanzania. This mine uses intensive manual labour for most of the tasks in coal production. The major underground job teams in this mine are development, underground transport, underground maintenance and mining. Epidemiological studies have demonstrated that coal miners have elevated risks of coal workers pneumoconiosis, developing chronic obstructive pulmonary disease, deficit in ventilatory function, bronchitis symptoms and silicosis (Goldstein and Webster, 1972; Morgan and Lapp, 1976; Attfield and Seixas, 1995; Coggon and Newman Taylor, 1998). The dust exposure status in labour-intensive coal mines has to our knowledge not been published, and proper exposure control programmes are usually lacking. Most published dust exposure data are from affluent industrialized countries, where mining operations are more mechanized (Parobeck and Jankowski, 1979; Tomb *et al.*, 1995; Soutar *et al.*, 2004). Dust levels in underground mines

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vary considerably according to the mine location and within the mines (Tomb *et al*., 1995; IARC-WHO, 1997). A study by Attfield and Morring (1992) in the United States showed that workers at the coal face experienced mean respirable dust levels ranging from 6 to 10 mg m^{-3}, whereas those working far from the coal face had exposure of 1–2 mg m^{-3}. Respirable dust exposure (range 1.2–8.2 mg m^{-3}) was similar in underground coal mines in the United Kingdom (Jacobsen *et al*., 1970), whereas Kizil and Donoghue (2002) reported lower exposure in underground mines in Australia (arithmetic mean 1.51 mg m^{-3}).

To our knowledge, there are no reports about the determinants of respirable dust and quartz exposure from labour-intensive mines or from any developing African countries. Identifying and characterizing important determinants of respirable dust and quartz exposure may create a platform for the rational prevention of dust and quartz exposure in such mines.

The purpose of this study was to describe the personal exposure to respirable dust and quartz and to identify important determinants of exposure in a labour-intensive coal mine.

METHODS

Mine characteristics

The coal mine in the Mbeya Region of Tanzania has ~600 workers, of whom 240 are involved in underground tasks. It has operated at a capacity of 150 000 tonnes of bituminous coal per year since 1988. The coal seam is accessed through an almost horizontal entrance, where networks of underground roads are constructed for extracting and transporting coal to the surface for processing. Wooden props (timber) with caps (crossbars) are set to support the exposed roof and are allowed to remain in place as the face is advanced. Props with caps are also used to protect the conveyor, the working face and the intake and return airways. A reversible fan placed outside at a higher elevation ventilates the mine. The development site is a dead end, ventilated through an air duct, which has no air return, presumably making ventilation poor compared with other mining sites.

Workers and work description

The total numbers of workers in the four main underground job teams are 41 in development, 75 in the mining team, 37 in underground transport and 34 in underground maintenance. The development team creates mining paths for the miners to extract coal. They are mainly located at the development site, where they create a new mine face and a conveyor roadway with a return roadway connected by a crosscut. They use a pneumatic jack for drilling through hard rock. The mining team mainly extracts coal at the mine face, and their worksite is largely at the coal face. They normally use an electric drill for drilling through the face. The underground transport team operates the locomotives and maintains rail lines. They mostly work in the main tunnel. The underground maintenance team maintains utilities and major equipment at the development sites and at the mine face.

Sampling strategy and job groups

Personal dust exposure was measured in two periods: June–August 2003 (Period 1), and July–August 2004 (Period 2). These periods were chosen due to practical limits for fieldwork at the University of Bergen. Sampling was planned for both surface (ash and cinder, washing plant, boiler and turbine, electricity and administration) and underground workers (development, mining, underground transport and underground maintenance). However, this study only presents data from the samples taken for the underground groups. In the first period of sampling, we had no information on the exposure of the coal miners. Thus, dust samples were allocated into different groups of workers using the method described by Leidel *et al*. (1977) as a guideline. A total of 110 filter cassettes for respirable dust were available for dust sampling. The numbers of samples allocated were 17 to development, 29 to the mining team, 13 to underground transport, 13 to the wash plant, 13 to boiler and turbine and 10 to ash and cinders. Only five samples were taken from each of the three groups presumed to have low exposure: underground maintenance, electricity and administration. The workers selected for personal dust sampling were randomly selected from the list of workers. In the second sampling period, the number of measurements allocated was based on the exposure concentrations obtained from the first period, which were aggregated into low, medium and high exposure (Mamuya *et al*., 2004). Due to a higher expected variability for the most exposed workers the available 100 samples were planned to be distributed to the low, medium and high exposed groups in the proportions of 1:3:5 as indicated by Loomis *et al*. (1994). The low-exposure group comprised administration, electricity, underground transport, and boiler and turbine; the medium-exposure group comprised the mining team, underground maintenance, wash plant, and ash and cinders; and the development team constituted the high-exposure group. For practical reasons, five workers declined to participate, and due to the time limit for conducting the study five samples were not taken. The actual number of samples taken was 41 in development, 17 in the mining team, 10 in underground maintenance, 2 in underground transport, 10 in the washing plant, 10 in ash and cinders, 6 in boiler and turbine, and one in each of administration and electricity.

Dust sampling

Personal dust sampling was performed during the day shift, which normally lasted ~5–10 h. Five full-shift samples were taken on each monitoring day. Personal respirable dust was sampled using a SKC Sidekick pump (model 224-50) with a flow rate of 2.2 l min^{-1}. A rotameter was used to adjust the flow. The rotameter had been calibrated at flow rates between 0.5 and 2.8 l min^{-1} by Technolab Dröbak, Norway in 2002. The respirable dust samples were collected on 37 mm cellulose acetate filters (pore size 0.8 μm) placed in a 37 mm conductive plastic cyclone. The cassette was assembled and labelled at X-Lab in Bergen, Norway. The cyclone was clipped to the worker's collar, allowing it to hang freely and collect dust in the breathing zone. Flow was checked by a rotameter at the end of the sampling period. After sampling, the cassette was removed and the top and bottom of the unit capped to prevent unwanted ingress or loss of dust during transport. The samples were transported to the laboratory by plane and car, carried as hand luggage.

Analysis of dust

The respirable dust samples from underground workers (n = 134) were quantified by gravimetric analysis using a Mettler AT 261 delta range with an accuracy of 0.05 mg at the X-Lab in Bergen, Norway. The limit of detection was 0.01 mg m^{-3}. In the first sampling period, all respirable dust samples from the development (n = 17) and mining teams (n = 29) and a random selection of samples from underground transport (n = 6) and maintenance (n = 4) were analysed for quartz. Two measurements from the development team (n = 1) and the mining team (n = 1) were not analysed as they accidentally were not sent for laboratory analysis. In the second period, all dust measurements were analysed for quartz. A total of 125 respirable dust samples from 84 underground workers were analysed for quartz by X-ray diffraction on a silver membrane filter using NIOSH method 7500 at SGAB Analytica Laboratory, Luleå, Sweden. The limit of detection was 0.005 mg m^{-3}. X-Lab in Bergen passed the intercalibration test of the Norwegian Institute of Occupational Health in Oslo, and SGAB Analytica Laboratory passed the intercalibration test of the Swedish Board for Accreditation and Conformity Assessment (SWEDAC). The threshold limit values (TLV) used in our study refer to the guidelines of the American Conference of Governmental Industrial Hygienists, which refer to airborne concentrations under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects (ACGIH, 2002). The TLV are 0.9 and 0.05 mg m^{-3} for respirable bituminous coal dust and for respirable quartz, respectively. These TLV were chosen since Tanzania has no national guidelines or limit values on occupational exposure for respirable dust and quartz.

Main tasks performed

Dust samples were assigned to the workers' main categories of working tasks based on interviewing the workers at the end of their respective work shifts on the day when sampling was carried out. Drilling and blasting were considered the most dust emitting task, and when these activities were reported, the samples were assigned to these main tasks. No sample was taken from any worker who was both drilling and blasting during the same shift. The other samples from the development and mining teams were assigned to lashing, roofing or transport according to the activity on which they had spent most time (Table 1). Transport was assigned for samples taken when the workers reported operating locomotives or repairing rail lines. Maintenance activity was assigned for all samples from the underground maintenance team.

Determinants

At the end of the shift, the workers were also asked about the actual time spent on the main tasks performed. Time spent in hours was converted into time spent on the respective activity as a percentage of the total sampling period. Blasting activity was entered as a categorical variable in the exposure models for the development and the mining teams, whereas the continuous variables entered were in terms of the percentages of pneumatic drilling time, electric drilling time, lashing time and roofing time (Table 1).

Table 1. Definition of potential determinants of respirable dust and quartz exposure in the development and mining team

Main tasks	Definition
Blasting (no/yes)	The process of applying detonator and explosives and of exploding the coal or hard rocks
Lashing (%)[a]	Loading coal or hard rock to the conveyor panel using a spade and hammering coal to reduce the size
Roofing (%)	Supporting the roof using timber planks and steel and also demolishing during retreat
Pneumatic drilling time (%)	Drilling holes in the hard rock using a pneumatic drill
Electric drilling time (%)	Drilling holes in the coal face using an electric drill

[a]Percentage activity time (activity time/total sampling time) times 100.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS Inc., Chicago) version 12.0 was used for analysing data. The exposure data were skewed and were $\log_e$ transformed for analysis (Lyles *et al.*, 1997). Values below the limit of detection, one for respirable dust and 19 for quartz, were estimated by dividing the limit of detection by two (Hornung and Reed, 1990). Analysis of variance was used on $\log_e$-transformed data to compare the mean exposure between groups. $P \leqslant 0.05$ was used as the criterion for statistical significance. Multiple linear regression models were chosen for analysing the determinants of respirable dust and quartz exposure. In the exposure models, respirable dust and quartz were dependent variables and the expected determinants were considered as independent variables. Multivariate regression models were developed for the development and the mining team. The models were built by introducing all potential determinants (Table 1) in the full models (Step 1). In Step 2 the non-significant determinants in Step 1 were removed from the models.

RESULTS

Dust exposure

The overall geometric mean (GM) exposures to respirable dust and quartz were 0.75 and 0.027 mg m^{-3}, respectively. There were no statistically significant differences in respirable dust exposure (P = 0.459) between the two time periods measured. However, the quartz exposure in Period 1 (0.050 mg m^{-3}) was significantly higher than in Period 2 (0.019 mg m^{-3}) ($P = 0.012$). The quartz content of the respirable dust samples in Period 1 (8.2%) was significantly higher than in Period 2 (4.1%) (P = 0.008).

Exposure based on job teams showed that workers in the development team had the highest exposure to respirable dust and quartz (GM 1.80 and 0.073 mg m^{-3}). In this team 55% of the respirable dust samples exceeded the TLV (Table 2). The underground transport team was the least exposed with no samples exceeding the TLV (Table 2). The quartz content of the respirable dust was highest for the underground maintenance team (8.7%), followed by the development team (6.3%) and the mining team (3.9%). In development the exposure to respirable dust and quartz was higher for drilling (GM 17.37 and 0.611 mg m^{-3}, respectively) than for blasting (3.64 and 0.197 mg m^{-3}) (Table 3). Drilling and blasting at the coal face was associated with significant lower exposures than analogous activities in the development. The exposure was also lower for maintenance, lashing, roofing and transporting (Table 3). In development the highest percentages of respirable dust and quartz samples above the TLV were during drilling

Table 2. Exposure of underground coal mine workers to respirable dust and quartz according to job team

Job team	Respirable dust								Quartz						
	n^a	n^b	AM^c	SD^d	GM^e	GSD^f	No. exceeding TLV (0.9 mg m^{-3})	Quartz content (%)	n^a	n^b	AM	SD	GM	GSD	No. exceeding TLV (0.05 mg m^{-3})
Development	34	58	10.3	16.3	1.80	8.85	32 (55%)	6.3	34	56	1.269	3.401	0.073	11.100	26 (47%)
Mining	34	46	0.66	0.61	0.47	2.27	9 (20%)	3.9	33	45	0.033	0.106	0.013	2.970	4 (9%)
Underground transport	13	15	0.18	0.13	0.14	2.13	0	–	9	11	0.007	0.004	0.006	1.836	0
Underground maintenance	9	15	2.35	3.48	0.58	6.37	5 (33%)	8.7	8	13	0.411	0.995	0.016	11.048	2 (15%)
Total	90	134	4.97	11.74	0.75	6.34	46 (34%)	6.0	84	125	0.624	2.363	0.027	8.179	32 (26%)

[a] Number of workers measured.
[b] Number of measurements.
[c] Arithmetic Mean (mg m^{-3}).
[d] Standard Deviation (mg m^{-3}).
[e] Geometric Mean (mg m^{-3}).
[f] Geometric Standard Deviation.

Table 3. Exposure of underground coal mine workers to respirable dust and quartz according to the main tasks performed

Main task	Median (range) % of sampling time	Respirable dust						Quartz content (%)	Respirable quartz					
		n[a]	AM[b]	SD[c]	GM[d]	GSD[e]	No exceeding TLV (0.9 mg m^{-3})		*n*[a]	AM	SD	GM	GSD	No exceeding TLV (0.05 mg m^{-3})
Drilling in development	27.9 (9.7,68.8)	19	25.16	18.32	17.37	2.70	19 (100%)	9.3	18	3.220	5.217	0.611	9.324	17 (94%)
Drilling in mine	46.2 (24.2,70.7)	9	0.62	0.41	0.53	1.77	2 (22%)	4.0	8	0.024	0.018	0.019	2.075	1 (13%)
Blasting in development	nr[f]	6	6.76	9.34	3.64	3.22	5 (83%)	8.5	6	1.447	3.260	0.197	6.953	4 (67%)
Blasting in mine	nr[f]	7	1.43	0.80	1.14	2.28	5 (71%)	1.8	7	0.027	0.026	0.014	4.238	2 (29%)
Lashing	49.6 (12.9,86.5)	48	1.77	7.19	0.39	3.80	8 (17%)	4.7	47	0.111	0.500	0.016	3.925	5 (11%)
Roofing	63.5 (47.9,65.9)	11	0.52	0.37	0.42	1.92	0	2.7	11	0.015	0.015	0.010	2.790	0
Transport	58.1 (42.9,68.0)	19	0.30	0.49	0.16	2.68	2 (11%)	–	15	0.015	0.024	0.009	2.461	1 (7%)
Maintenance	nr[f]	15	2.35	3.48	0.58	6.37	5 (33%)	8.7	13	0.411	0.995	0.016	11.048	2 (15%)

[a] Number of samples.
[b] Arithmetic Mean (mg m^{-3}).
[c] Standard Deviation (mg m^{-3}).
[d] Geometric Mean (mg m^{-3}).
[e] Geometric Standard Deviation.
[f] not recorded.

(100 and 94%, respectively) and blasting in development (83 and 67%) (Table 3).

Totally 14.1% of eligible workers reported using disposable respiratory masks while working. In addition some workers were observed to cover their nose and mouth with clothing materials.

Statistical modelling of determinants of exposure to respirable dust and quartz in the development team indicated that pneumatic drilling and blasting increased the respirable dust and quartz levels (Table 4), whereas lashing, transporting and roofing did not significantly affect exposure. The variables in the models (Step 1) for the development team workers explained 43.8 and 40.2% of the variance of the respirable dust and quartz exposure. The final models (Step 2) for the development team, including only the significant determinants of blasting and pneumatic drilling time, explained 45.2 and 40.7% of the variance. The regression model for quartz exposure in the development team predicts that drilling for >8.0% of the full shift of 8 h exceeds the TLV of 0.05. For the median time of pneumatic drilling in the present study (27.9%), the workers will be exposed to 0.34 mg m^{-3}, which is ~6.8 times higher than the TLV for quartz. Figure 1 shows the trends of increasing concentration levels for quartz among drillers as the percentage of drilling time increases.

In the mining team, blasting was associated with increased respirable dust exposure, whereas electric drilling, roofing and lashing did not significantly affect exposure. This model (Step 1) explained 21.4% of the variance in respirable dust, and the final model including only the blasting activity explained 19.5% of the variance in respirable dust (Table 4). No significance model was found for quartz for the mining team.

DISCUSSION

Exposure to dust and quartz was highest for the development team in this labour-intensive coal mine. The tasks of drilling and blasting were the major determinants of dust exposure for the development team. The high exposure to dust and quartz for this team is presumably caused by the hard rock encountered. The quartz content in the samples taken in the development team was almost 1.6 times higher than for the mining and underground transport teams. The overall quartz content in the present study was slightly higher than in studies from Germany in which the quartz content ranged from 2.4 to 5% (Leiteritz *et al.*, 1971) and from South Africa (1.4–2.7%) (Naidoo *et al.*, 2004). Differences in geological formations and the fact that most previous studies did not determine exposure in the development section of the mine might explain the difference between our results and those of previous studies.

Table 4. Multiple linear regression analysis of tasks performed related to respirable dust and quartz exposure for development team and mine team workers

Agent	Determinants	Step 1						Step 2					
		Regression coefficients				95% CI		Regression coefficients				95% CI	
		R^2_{adj}	B	SE	P	Lower	Upper	R^2_{adj}	B	SE	P	Lower	Upper
Development team													
Respirable dust n = 58													
	Intercept	0.438	−0.290	0.426	0.500	−1.145	0.565	0.452	−0.475	0.265	0.079	−1.006	0.056
	Blasting (0/1)[a]		1.845	0.727	0.014	0.388	3.303		1.767	0.710	0.016	0.344	3.190
	Pneumatic drilling (%)[b]		0.084	0.014	0.000	0.056	0.112		0.088	0.013	0.000	0.062	0.113
	Roofing (%)		−0.015	0.019	0.458	−0.054	0.025						
	Lashing (%)		−0.004	0.009	0.668	−0.021	0.014						
Quartz n = 58													
	Intercept	0.402	−3.892	0.491	0.000	−4.877	−2.906	0.407	−3.757	0.309	0.000	−4.377	−3.136
	Blasting (0/1)		2.215	0.829	0.010	0.551	3.880		2.131	0.817	0.012	0.492	3.770
	Pneumatic drilling (%)		0.098	0.017	0.000	0.063	0.133		0.096	0.016	0.000	0.065	0.128
	Roofing (%)		−0.018	0.022	0.424	−0.063	0.027						
	Lashing (%)		0.006	0.010	0.549	−0.014	0.026						
Mining team													
Respirable dust n = 47													
	Intercept	0.214	−1.163	0.199	0.000	−1.566	−0.760	0.195	−0.912	0.118	0.000	−1.150	−0.675
	Blasting (0/1)		1.168	0.300	0.000	0.561	1.774		1.042	0.302	0.001	0.434	1.650
	Electric drilling (%)		0.007	0.007	0.316	−0.007	0.020						
	Roofing (%)		0.004	0.005	0.491	−0.007	0.014						
	Lashing (%)		0.004	0.004	0.320	−0.004	0.013						
Quartz n = 47													
	Intercept	0.049	−4.727	0.268	0.000	−5.270	−4.184						
	Blasting (0/1)		0.250	0.404	0.540	−0.568	1.067						
	Electric drilling (%)		0.010	0.009	0.272	−0.008	0.028						
	Roofing (%)		0.006	0.007	0.371	−0.008	0.020						
	Lashing (%)		0.005	0.006	0.420	−0.007	0.017						

[a] (0/1): '0' = no, '1' = yes.

[b] %, The percentage activity time (activity time/total sampling time) times 100.

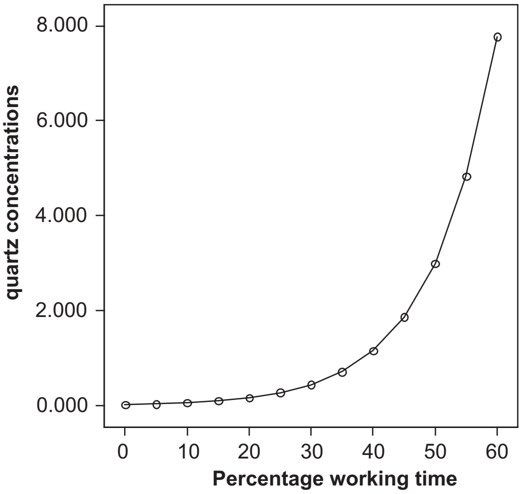

Fig. 1. Predicted quartz concentrations (mg m^{-3}) by percentage pneumatic drilling time at the development site.

A high fraction of samples during drilling and blasting were above the TLV. The TLV values from ACGIH were chosen for comparison as there is strong evidence that, for instance, the South African OEL of 0.1 mg m^{-3} for quartz is not protective against silicosis (Churchyard *et al*., 2004). Our findings are similar to those of Piacitelli *et al*. (1990), who reported that drilling jobs had high percentages of quartz samples >0.05 mg m^{-3} during coal drilling (44%) and hard rock drilling (86%). The current study showed lower personal exposure to both respirable dust and quartz for the mining and the underground transport team. For the mining team, this might be attributed to the nature of coal fragmentation during drilling and blasting, in which the coal pieces have less associated dust, and to the more effective ventilation. The low exposure for the underground transport team might be caused by their proximity to the fresh air entrance and no substantial dust producing operations.

Even though many workers in this labour-intensive mine are close to the dust production process, the dust exposure of the mining team was lower than in previous studies in the United States (1.1 ± 0.5 mg m^{-3}) (Kuempel *et al.*, 2003), Australia (1.51 ± 1.08 mg m^{-3}) (Kizil and Donoghue, 2002) and South Africa (0.9–1.9 mg m^{-3}) (Naidoo *et al.*, 2004). This might be explained by the lower coal production rate of the current mine. A study in the United States (Parobeck and Jankowski, 1979) showed that less mechanized mining operations had mean respirable dust concentrations of 0.7 mg m^{-3} in 1971 and 0.3 mg m^{-3} in 1974, and suggested that enforcing the occupational limit values through dust control programmes had reduced dust exposure.

The influence of determinants

For the development team, the activities of blasting and drilling were the major determinants of respirable dust and quartz, explaining 45.2 and 40.7% of the variance, respectively. The model for respirable dust predicts that blasting workers have exposure six times higher than the reference value indicated for the other less dust producing activities. Thus, a blaster in the development section will have a predicted exposure to quartz equivalent to 0.175 mg m^{-3}, which is ~3.5 times higher than the TLV. Further, the model predicts that drilling at the development site for >7.9% of the total shift (sampling time) would give exposure levels above the TLV of 0.05 mg m^{-3}.

Soutar *et al.* (2004) showed that a worker is estimated to have a risk of 2.5% of acquiring silicosis at a mean exposure of 0.1 mg m^{-3}, rising to 20% at 0.3 mg m^{-3} for 15 working years, which cumulatively will be equivalent to 4.5 mg m^{-3}·years. In the present study the exposure model predicts that a worker in the development team can obtain this cumulative exposure by using a pneumatic jack for 25% of the work shift for 16 years. None of the determinants evaluated significantly influenced the quartz exposure of the mining teams. The low quartz content in the bituminous coal might explain the relatively low quartz exposure during coal handling.

This study had several limitations. Sampling was done only during the morning shift from June to August. Thus, the findings may not be generalized throughout the year and for all shifts. However, the sampling was done for all job categories covering all activities performed during normal mining operations expected to be representative for all shifts. We also assume that the underground activities are not substantially affected by the annual climatic conditions. Furthermore, respirable dust exposure was not different in Periods 1 and 2. The observed difference in quartz exposure between the two periods might be associated with a difference in the geological formations encountered as indicated by the difference in quartz content in the two sampling periods. Information bias was possible in recalling the exact time spent on the particular task performed. Further, by not recording the number of detonations during blasting, the blasting activity was taken as a categorical variable, which may reduce the validity of the associated findings. Considering the variation in size, the extent of mechanization and the technical advancement in the coal mine industry in various countries, this study cannot be considered representative of all types of coal mining elsewhere. However, the present finding might be relevant for labour-intensive coal mining in developing countries. The high respirable dust and quartz exposure for workers in the development section, especially for those involved in drilling and blasting, indicates an increased risk of respiratory health problems such as coal workers' pneumoconiosis and silicosis. Further research is needed on the characteristics of exposure groups to be used in an epidemiological study on respiratory health effects.

Options for control measures

The engineering and administrative measures for controlling dust exposure need to be strengthened, especially for pneumatic drilling and blasting in development sites. Proper training, work practice and dust suppression techniques should be emphasized. Various techniques may be used to reduce or contain dust emission while drilling or blasting or when doing other work in development. A rubber 'skirt' placed around the drill site to provide a containment barrier between the dust and worker might be one option. The use of a dust suppressant, such as water, may also be effective in reducing dust emissions during drilling. A local exhaust ventilation system will capture dust at the drill hole. Unless immediate measures are initiated to reduce the dust levels, respiratory protective masks should be used.

CONCLUSIONS

Workers in the coal mine had high exposure to respirable dust and quartz, especially the development team. Drilling and blasting operations were the major determinants of dust concentrations. Immediate actions for improvement are suggested to prevent workers from developing respiratory disorders.

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