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Diesel exhaust exposures in an underground mine

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ABSTRACT

The mining industry is a major contributor to the Quebec and Canadian economy. In Canada, more than 400,000 workers are involved directly or indirectly in the mining industry. Health and safety challenges in underground mines are unique due to the complexity of the environment. Exposure to diesel engine exhaust is a major concern in underground mines due to the presence of off-road diesel-powered machinery. Diesel engine exhaust has been linked to cardiopulmonary diseases and was classified as a human carcinogen by the International Agency for Research on Cancer in 2012. Here we present the results of a preliminary study conducted in an underground gold mine in the province of Quebec in 2014-15 to assess diesel engine exhaust exposures among mine workers. The goal of this study was 1) to compare three surrogates of diesel engine exhaust exposure (total carbon, elemental carbon and respirable combustible dust) and 2) to assess diesel exhaust concentrations among the similar exposure groups and the variability of the exposures. Results were also compared to the Ontario and Quebec occupational exposure limits for compliance purposes. Environmental and breathing zone measures were taken. Average environmental results of 0.31 mg/m^3 in total carbon, 0.24 mg/m^3 in elemental carbon, and 0.17 mg/m^3 in respirable combustible dust were obtained. Average breathing zone results of 0.32 mg/m^3 in total carbon, 0.19 mg/m^3 in elemental carbon and 0.36 mg/m^3 in respirable combustible dust were obtained. The highest exposures were obtained in the conventional, scooptram and jumbo workers. The average total carbon/elemental carbon ratio was 1.3 for environmental measures, and 1.9 for breathing zone measures. The variability observed in the total carbon/elemental carbon ratio shows that interferences from non-diesel related organic carbon can skew the interpretation of results when relying only on total carbon data. However, more data is needed to support this.

KEYWORDS: diesel; exposure; underground mine; respirable combustible dust; elemental carbon; total carbon; similar exposure groups

1. INTRODUCTION

Exposure to diesel engine exhaust (DE) has been linked to increased cancer risk and cardiopulmonary diseases. DE has recently been classified as a human carcinogen (group 1) by the International Agency for Research on Cancer (IARC, 2012) and has become a contaminant of primary interest at the international level. Vermeulen et al. (2014) reported that 6% of deaths from lung cancers could be linked to occupational exposures to DE. Acute exposures to DE have been associated with respiratory irritation and inflammation, and cardiovascular effects (Hussain et al., 2012; Kipen et al., 2011; Lucking et al., 2008; Mills et al., 2005; Nordenhall et al., 2000; Salvi et al., 1999).

DE refers to the complex mixture of chemical substances found in solid, liquid or gaseous states resulting from the incomplete combustion of fuel. The type of engine, fuel, oil, and operation are all factors that can affect the composition of DE. Carbon (mono- and di-) oxides (CO and CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), water vapour, sulfur compounds, low molecular weight hydrocarbons (e.g. benzene, 1,3-butadiene), and oxygenated compounds (e.g. aldehydes) can all be found in the mixture. Diesel particulate matter is composed of elemental carbon (EC) onto which organic carbon (OC) compounds and other particles (unburnt fuel, lubricant droplets, metallic additives, etc.) are adsorbed. The majority of the particles in diesel particulate matter are within the respirable fraction (4 µm in diameter or less) and most are ultrafine particles (100 nm in diameter or less) (Carex Canada, 2015).

Occupational exposure limits (OEL) for DE vary greatly between and within countries. In the province of Quebec, Canada, a limit value of 0.6 mg/m^3 of respirable combustible dust (RCD) applies to the

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mining industry (Government of Quebec, 2016). The Canadian province of Ontario has recently adopted a regulatory time-weighted value of 0.4 mg/m^3 of total carbon (TC) transposable to EC via a conversion factor of 1.3 (i.e. about 0.31 mg/m^3 for EC) for the mining industry (Government of Ontario, 2016). The U.S. Mine Safety and Health Administration (MSHA) has prescribed an 8-hour OEL of 0.16 mg/m^3 of TC based on recommendations and methods of the National Institute for Occupational Safety and Health (NIOSH) (MSHA, 2008). There is currently no regulation for TC or EC in the province of Quebec. However, a proposition for the modification of the Quebec regulation of 0.6 mg/m^3 of RCD to 0.4 mg/m^3 of TC has recently been published in the Official Gazette of Quebec (*Éditeur Officiel du Québec*, 2015). There is currently no time-weighted average Threshold Limit Value proposed by the American Conference of Governmental Industrial Hygienists.

Underground mines pose great occupational health and safety challenges due to their very unique work environments. The presence of off-road, diesel-powered mobile machinery is one of these challenges, which is briefly addressed in this paper.

2. METHODS

The DE assessment methods compared were the NIOSH 5040 method (NIOSH, 2003) used for sampling the carbon fraction (EC and OC), and the RCD method (IRSST, 2016). For the NIOSH 5040 method, 37-mm aluminum cyclones (SKC) were used with 37-mm quartz filter cassettes, SKC model 225-1 cassette holders, and SKC pumps (PCXR4 model). Interferences from cigarette smoke, non-metal mining (e.g. coal) and oil mist are to be considered with this method. For the RCD method, 25-mm aluminum cyclones (SKC) were used with 25-mm silver membrane cassettes, SKC model 225-1 cassette holders, and SKC pumps (PCXR4 model). Interferences from oil mist and mineral dust (e.g. sulfides in rock) are to be considered with this method. Personal RCD and NIOSH 5040 samples were taken during two separate periods of two to three weeks; the RCD samples were taken in November and December 2014 while the NIOSH 5040 samples were taken in March 2015. Personal samples were taken 30 centimeters from the workers' breathing zone during their full 10-hour shift. Environmental RCD and NIOSH 5040 samples were taken simultaneously in main circulation routes (i.e. bypasses and ramps) over periods of about 8 hours. The pumps were hooked to the ground support at about 8 feet high to avoid damage to the equipment.

Most samples were taken during the day shift. Field observations were noted throughout the sampling periods. The RCD samples were sent to SGS Laboratories (Lakefield, Ontario, Canada) and the carbon samples were sent to Galson laboratories (New York, USA).

Statistical analyses were done with IHSTAT (American Industrial Hygiene Association - Exposure Assessment Strategies Committee). The geometric mean (GM) and geometric standard deviation (GSD) were used for describing the exposure profiles. The estimated arithmetic mean (AM) and the corresponding 95% confidence limits were used for comparing personal exposure levels to exposure limits and for evaluating the cumulative damage from exposure to diesel exhaust. Non-detected values were replaced by the corresponding limit of quantification (LOQ) for the sample. Similar exposure groups (SEG) were based on job titles and were pre-defined by the company.

3. RESULTS

3.1 Environmental measures

Environmental TC, EC, and RCD concentrations are presented in Table 1. The average TC/EC ratio for environmental measures was 1.3.

Table 1: Summary of environmental TC, EC and RCD measures.

	TC (mg/m^3)	**EC (mg/m^3)**	**RCD (mg/m^3)**
GM	0.31	0.24	0.17
GSD	2.00	2.22	1.90
N	5	5	5

TC: total carbon; EC: elemental carbon; RCD: respirable combustible dust; GM: geometric mean; GSD: geometric standard deviation; N: sample number

3.2 Personal measures

Descriptive and inferential statistics for personal TC, EC, and RCD concentrations are summarized in Table 2. Personal TC measures were close to the Ontarian OEL of 0.4 mg/m^3 (AM = 0.32 mg/m^3 [LCL = 0.28; UCL = 0.38]). Personal EC measures were at about half the Ontarian OEL of 0.31 mg/m^3 (AM = 0.19 mg/m^3 [LCL = 0.15; UCL = 0.24]). The personal RCD concentrations were at about half the Quebec OEL of 0.6 mg/m^3 (AM = 0.36 mg/m^3 [LCL = 0.29; UCL = 0.52]). The average TC/EC ratio for personal measures was 1.9.

Table 3 presents the TC, EC and RCD concentrations according to the different SEG. Conventional, scooptram and jumbo operators were the most exposed. At the opposite, mechanics, foremen and rock bolter operators were the least exposed groups. As presented in Table 3, most of the geometric standard deviations were around 2 or below. The TC/EC ratio for the conventional and chisel operators were higher than for other SEG (4.1 and 5.8, respectively).

Table 2: Summary of personal TC, EC and RCD measures.

	TC (mg/m^3)	EC (mg/m^3)	RCD (mg/m^3)
AM	0.32	0.19	0.36
95% CL	LCL=0.28 UCL=0.38	LCL=0.15 UCL=0.24	LCL=0.29 UCL=0.52
GM	0.30	0.15	0.25
GSD	1.53	1.87	2.41
N	30	30	36

TC: total carbon; EC: elemental carbon; RCD: respirable combustible dust; AM: estimated arithmetic mean; 95% CL: 95% confidence limits; LCL: lower confidence limit; UCL: upper confidence limit; GM: geometric mean; GSD: geometric standard deviation; N: sample number

Table 3: TC, EC and RCD results by SEG.

	TC (mg/m^3)			EC (mg/m^3)			RCD (mg/m^3)			TC/EC ratio
SEG*	**GM**	**GSD**	**N**	**GM**	**GSD**	**N**	**GM**	**GSD**	**N**	
Shotcrete operators	na	na	na	na	na	na	0.51	1.59	2	na
Truck operators	0.28	1.37	6	0.19	1.47	6	0.19	1.80	3	1.5
Scooptram operators	0.36	1.52	8	0.21	1.54	8	0.30	2.20	8	1.7
Foremen	0.20	1.28	2	0.13	1.17	2	0.14[a]	5.80	2	1.5
Conventional	0.74	1.28	2	0.18	1.42	2	0.72	1.96	4	4.1
Electricians	na	na	na	na	na	na	0.21	1.63	2	na
Diamond driller operators	na	na	na	na	na	na	0.13	1.91	2	na
Jumbo operators	0.33	1.26	2	0.17	1.09	2	0.35	1.39	3	1.9
Mechanics	0.19	1.29	2	0.14	1.36	2	0.11[a]	2.35	3	1.4
Chisel operators	0.29	1.37	2	0.05	10.01	2	na	na	na	5.8
Rock bolter operators	0.21	1.00	2	0.12	1.19	2	na	na	na	1.8

TC: total carbon; EC: elemental carbon; RCD: respirable combustible dust; GM: geometric mean; GSD: geometric standard deviation; SEG: similar exposure group; N: sample number; na: not available
*Only SEG for which there were two samples or more are reported
[a]One value was <LOQ

4. CONCLUSION

In conclusion, as long-term risk indices, arithmetic mean estimates and the corresponding upper confidence limits did not exceed the Ontario and Quebec OELs for personal TC, EC and RCD measures. More data is needed for each SEG to better understand the exposure profiles and to make a comprehensive long-term risk assessment.

The variability observed in the TC/EC ratio shows that interferences from non-diesel related organic carbon can skew the interpretation of results when relying only on TC data. This was most obvious when comparing the ratios between the different SEG. The conventional and chisel operators had a higher ratio, indicating greater interferences from non-diesel related organic carbon, most likely from oil mist. Our results question the use of TC as a measure of occupational exposure to DE. However, more data is needed to validate this.

In future studies, direct reading instruments will be used in addition to the integrated sampling methods described in this paper, in order to better understand the determinants of exposures.

Overall, this preliminary study gives an overview of diesel exhaust exposures in an underground mine.

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