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Elemental Carbon Levels at a Potash Mine

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A survey of worker exposures in a potash mine and mill was undertaken to evaluate diesel exposures during the feasibility effort of an epidemiologic study. Nineteen occupations were sampled. Results were averaged into six underground groups and three surface groups. Elemental carbon exposures, a diesel surrogate measure, were similar among all surface occupations; however, miners working in the auto shop were the most heavily exposed. Underground, ramcar drivers had the highest mean exposures over a 3-day sampling period, and those miners working in the underground diesel shop and warehouse had the lowest exposures. A multiple comparison of means test in SAS yielded three statistically different exposure groups when compared at the $\alpha = 0.1$ significance level. The results of the survey demonstrate that exposure to elemental carbon varies considerably among mining occupational groups. This should prove useful for dose-response analyses in a future epidemiologic study. STANEVICH, R.S.; HINTZ, P.; YEREB, D.; DOSEMECI, M.; SILVERMAN, D.T.: ELEMENTAL CARBON LEVELS AT A POTASH MINE. *APPL. OCCUP. ENVIRON. HYG.* 12(12):1009-1012; 1997. © 1997 AIH.

A survey of worker exposures to diesel exhaust contaminants in a potash mine and mill was undertaken to determine whether or not exposures were high enough and variable enough to conduct an epidemiologic study of lung cancer and diesel exhaust exposure in nonmetal miners.

Diesel exhaust has been classified as a possible carcinogen in humans by the National Institute for Occupational Safety and Health (NIOSH)⁽¹⁾ and a probable carcinogen in humans by the International Agency for Research on Cancer⁽²⁾ because of excesses of lung and bladder cancer among workers with long-term exposure. Despite the large number of studies in which the relation between diesel exhaust exposure and lung cancer has been examined, exposure to diesel exhaust has been quantitatively estimated in only a few studies.⁽³⁻⁶⁾ NIOSH and the National Cancer Institute propose to conduct a cohort and a nested case-control study of lung cancer among nonmetal miners who have been exposed to diesel exhaust. The selected cohort appeared to present us with an excellent opportunity to quantify historical exposure estimates. To confirm that a cohort and case-control study using quantitative exposure estimates was possible, a feasibility study was undertaken. The purposes of this study included determining the number of diesel exhaust-exposed miners, evaluating the completeness of the work history, and assessing the quantity and quality of exposure-related data available. A comprehensive exposure assessment was undertaken as one of the final steps in assessing

the feasibility of successfully conducting the proposed cohort and nested case-control study. This article presents the results only of the elemental carbon analysis conducted during the comprehensive survey of one underground mine with surface mill operations.

The underground mine selected for study was a nongassy, room and pillar potash operation that used electric continuous miners to extract the ore. Ore was moved from the face to the belt either by ramcars or by an electric continuous haulage system, depending on the type of the working section. These sections were different in terms of diesel usage. One of the sections was a ramcar section and the other was a continuous haulage section. In a ramcar section, ore is moved from the mining area (or face) to a beltline (which moves it out of the mine) on a diesel-powered vehicle. The ramcar is driven by one miner. In a continuous haulage section, ore is moved from the face to the beltline via a system of transport belts which expands from the beltline to the face as the face is being mined and is moving farther from the stationary beltline. The ore can be moved from the face continuously on the system of expandable belts to the permanent beltline. The continuous haulage system is hydraulically powered and requires no diesel engine.

Mined areas extended 5.5 to 6 miles from two centrally located shafts. The ore was then loaded onto the main beltline system and carried to the storage area at the shaft. After being raised out of the mine, the ore was transported to the refinery. A leach-crystallization processing scheme was used to remove the potassium chloride from the ore.

Two main exhaust fans provided 250,000 to 270,000 ft³/m of air from the main shaft. In addition to the main fans at the exhaust shaft, a number of fans were kept underground to boost air flows and force air directly to the face. During the time of the survey, two of the booster fans were malfunctioning, and therefore exposures underground may have been higher than when all booster fans are operating.

Diesel equipment was used throughout the mine for transportation of miners and materials and some of the ore transportation from the face. There were nine active working sections at the time of the study, but sampling was conducted in only two of the sections. To measure the full range of exposures to diesel exhaust at the mine, sampling was also conducted in the maintenance and shop areas underground and in several surface locations.

Methods

The sampling plan included both personal and area monitoring for elemental carbon and other diesel-related contaminants. Area sampling packages also included submicrometer, total and

TABLE 1. Occupations Sampled

Occupational Group	Occupation	Number Sampled
Surface-maintenance	Electrician	1
	Maintenance	1
	Mechanic	3
	Welder	1
Surface-production	CCD operator	1
	Instrument room	1
	Crystallization	1
	Top loader	1
Surface-shipping	Load out	2
	Trackman	1
	Loader operator	1
Underground	Belt crew	2
Underground	Ramcar operator	2
Underground	Continuous miner operator	2
Underground-warehouse/maintenance	Warehouse	1
	Mechanic	2
	Welder	1
Underground-production	Mechanic	1
	Miner	3
Underground-foremen	Maintenance	1
	Production	2

respirable dust monitoring, an eight-stage impactor, Palmes passive dosimeters for nitrous oxide and nitrogen dioxide, and long-term colorimetric tubes for carbon monoxide, carbon dioxide, and sulfur dioxide. This article will focus on the elemental carbon findings and present submicrometer or diesel particulate matter (DPM) and nitrogen dioxide concentrations for comparison purposes.

Area samples were collected in three locations on the surface:

- the auto shop, where diesel equipment is repaired;
- an office, to evaluate employees working indoors in laboratory and office environments; and
- outdoors near the mine exhaust shaft, to estimate maximum ambient concentrations.

Underground area samples were collected in the overhaul shop, on a continuous haulage section, and on a ramcar section.

Personal samples were collected from all miners working on two representative production sections. The two sections selected included one ramcar section and one continuous haulage section. Exposures from other underground miners were measured as well. These included three foremen (the supervisor, a shift foreman, and a section foreman) and four workers in the maintenance and warehouse areas. A sample of workers from all of the surface locations was also included. Table 1 notes the occupations sampled. Thirty-one miners, representing a majority of the occupations and exposures in this potash mine and mill, were sampled for 2 to 3 days each. All jobs were grouped into nine occupational groupings (Table 1) based on the similarities of their exposure-related tasks.

Elemental Carbon

Elemental carbon estimates were collected using a Mine Safety Appliances Co. (MSA) cassette modified to collect particles less than 1.1 μm in aerodynamic diameter at an air flow of 1 L/min according to NIOSH Analytical Method 5040. Multiple samples were collected from three areas on the surface during two consecutive day shifts. Multiple samples were collected during three day shifts in three underground locations.

Samples were analyzed at Sunset Laboratories using a thermal-optical method designed to obtain speciation of elemental and organic fractions in the deposited aerosol.⁽⁷⁾

Submicrometer or Diesel Particulate Matter

Submicrometer particulate was measured in area samples only, using a dichotomous sampler from a design modified by the Mine Safety and Health Administration. The impactor is an expanded version of the MSA respirable dust cassette. A spacer, inserted between the cassette halves, holds the impaction plate. The inlet of the impactor is fitted with a brass insert which has a 1.0-mm diameter nozzle. A 10-mm nylon cyclone precedes the impactor to remove the larger particles. At a flow rate of 1.7 L/min, the respirable particulate which passes through the impactor inlet is separated into two fractions. The submicrometer particulate (0.9 μm) passes through the holes in the impaction plate and is deposited on a filter. The remainder of the respirable particulate is deposited on the impaction plate. The impaction plate is greased to better collect this particulate and prevent bounce.

Results

Elemental Carbon and DPM

There are no current recommended exposure levels for elemental carbon. Comparisons with submicrometer or DPM concentrations collected side by side are presented for reference. In 1995 the American Conference of Governmental Industrial Hygienists added diesel exhaust to their Notice of Intended Changes at a proposed threshold limit value of 150 $\mu\text{g}/\text{m}^3$.

Area-Wide Sampling Results

Elemental carbon levels on the surface ranged from 0 to 27 $\mu\text{g}/\text{m}^3$. Underground, the area-wide exposures ranged from 17 to 606 $\mu\text{g}/\text{m}^3$. On average, over the 3-day sampling period, exposure in the ramcar section was the highest (453 $\mu\text{g}/\text{m}^3$). The lowest average concentration measured underground was in the diesel and overhaul shops (60 $\mu\text{g}/\text{m}^3$), but even this concentration was more than twice as high as concentrations seen on the surface.

By comparison, DPM concentrations ranged from 116 to 279 $\mu\text{g}/\text{m}^3$ at the surface locations and from 104 to 1035 $\mu\text{g}/\text{m}^3$ in the underground locations. Average concentrations at all sampled locations are shown in Table 2.

While the Pearson correlation coefficient between elemental carbon and DPM is very high ($r^2 = 0.98$), the ratio of the two contaminants is variable and increases as the contaminant concentrations increase. This may be due to a variety of reasons; primary among them is the fact that DPM measures all particulate less than the sampler cutpoint (approximately 0.9 μm with this sampler), while the elemental carbon analysis mea-

TABLE 2. Average Elemental Carbon and Submicrometer Particulate (DPM) Concentrations by Area

	EC ($\mu\text{g}/\text{m}^3$)		DPM ($\mu\text{g}/\text{m}^3$)		EC/DPM Ratio (%)
	Average	SD	Average	SD	
$r^2=0.98$					
Surface-office	3	4	179	51	2
Surface-auto shop	9	2	176	75	5
Surface-shaft area	22	4	232	63	9
Underground diesel shop	60	44	340	163	18
Continuous haulage	312	240	760	334	41
Ramcar	453	114	798	172	57

sures only the carbon particles in that size range. This makes the elemental carbon measure much more specific to diesel exhaust, because in addition to the elemental carbon particles, which are produced almost solely by diesel combustion, DPM can include organics (such as cigarette smoke), oil mists, and ore particles in the submicrometer size range.

Personal Sampling Results

Ramcar drivers had the highest average personal exposures to elemental carbon ($345 \mu\text{g}/\text{m}^3$; Table 3). The average exposures of the continuous miner operators and the belt crew were almost identical (225 and $222 \mu\text{g}/\text{m}^3$, respectively). Underground mechanics, along with others working in the shop areas, had the lowest average underground exposures ($53 \mu\text{g}/\text{m}^3$). On the surface, the mechanics had the highest exposures ($31 \mu\text{g}/\text{m}^3$). Again, these exposure levels were approximately half of those seen underground.

Comparison of Average Exposure

To determine whether or not there were any significant differences between the mean occupational exposures to elemental carbon, multiple comparison *t*-tests (Least Significant Difference) and Duncan's multiple range tests were performed using SAS. Table 4 reports the results of the LSD test comparing elemental carbon exposure among the occupational groups at both the $\alpha = 0.05$ and $\alpha = 0.10$ significance levels. Results of the test at the $\alpha = 0.10$ results yield three distinct and logical occupational categories, while the results of the test at the 0.05 significance level yield mixed groupings. The categories are differentiated by the alpha characters in the "Group" columns. Groups with the same alpha character (e.g., A, B, C, or D) have group mean results which are not significantly different from one another. However, if the group

TABLE 4. Comparison of Average Personal Exposures to Elemental Carbon by Occupation

Occupation	Average n	Average ($\mu\text{g}/\text{m}^3$)	Group Alpha = 0.1	Group Alpha = 0.05
Ramcar driver	6	345	A	A
Continuous miner	6	225	B	B
Belt crew	6	222	B	B
Miner	8	193	B	B
Foremen	9	162	B	BC
Underground maintenance/ warehouse	8	53	C	DC
Maintenance (surface)	13	31	C	D
Shipping (surface)	7	19	C	D
Production (surface)	5	12	C	D

alpha characters are different from one another, there is a statistically significant difference between the group means.

The results (Table 4) indicate that the ramcar drivers were in the most highly exposed category. Four occupational groups fell into the moderate exposure category: continuous miner operator, belt crew, miner (unspecified), and foremen. The underground maintenance and warehouse workers and all of the surface workers were in the lowest exposure group.

A comparison of the mean exposures between the area samples was also carried out (Table 5). Here again, three exposure categories were found. The ramcar section had the highest exposure. The continuous haulage section was in the middle exposure group. The underground and surface diesel shops had exposures that were in the lowest exposure group, along with the office area and the outdoor samples near the shaft.

Conclusions

Elemental carbon and submicrometer particulate (DPM; surrogates for diesel exhaust) were measured in underground and mill areas of a potash mine. Nineteen occupations were sampled, as well as six areas. Occupations were grouped into six underground groups and three surface groups. Exposures among all surface occupations were similar; however, miners working in the auto shop were the most heavily exposed. Underground, ramcar drivers had the highest mean exposures over a 3-day sampling period, and those miners working in the underground diesel shop and warehouse had the lowest exposures. A multiple comparison of means test in SAS yielded

TABLE 3. Average Personal Exposures to Elemental Carbon

Elemental Carbon ($\mu\text{g}/\text{m}^3$)	Surface Maintenance	Surface Mill	Surface Shipping	Underground			Underground		Underground Ramcar Operator
				Maintenance	Belt Crew	Miner Operator	Underground Foremen	Underground Miner	
Number of samples	11	5	7	8	6	6	9	11	6
Average arithmetic	31	12	19	53	222	225	162	193	345
SD	54	15	37	46	159	141	65	193	173

TABLE 5. Comparison of Average Exposures to Elemental Carbon by Area

Area	n	Average ($\mu\text{g}/\text{m}^3$)	Group Alpha = 0.05
Ramcar section	6	266	A
Continuous haulage section	8	155	B
Diesel shop (underground)	8	35	C
Auto shop (surface)	6	17	C
Topside	6	13	C
Office	4	2	C

three statistically different exposure groups when compared at the alpha = 0.1 significance level.

Area exposures also yielded three exposure groups. There were two distinctly different underground groups and one group which included all of the surface areas and the underground diesel shop and warehouse areas.

The results of this feasibility study demonstrate that dose-response analyses should be possible in a proposed study of lung cancer. This conclusion has been reached due to the following findings:

- There was almost a thirtyfold difference between the lowest average exposure group (surface production: $12 \mu\text{g}/\text{m}^3$) and the highest exposure group (ramcar drivers: $340 \mu\text{g}/\text{m}^3$).
- Exposures in the mining industry are high. By comparison, in a different study of lung cancer associated with

diesel exhaust exposure, truck drivers' maximum exposure to elemental carbon was $45 \mu\text{g}/\text{m}^3$.⁽⁸⁾

- There were significant differences in the elemental carbon concentrations found between certain occupational groups.

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