EVALUATION OF THE CONTRIBUTION OF LIGHT-DUTY VEHICLES TO THE UNDERGROUND ATMOSPHERE DIESEL EMISSIONS BURDEN

Submitted to

The Diesel Emissions Evaluation Program (DEEP) Technical Committee

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Prepared by Michel Grenier, Manager, Underground Mine Environment Research Program Sudbury Laboratory, CANMET, Natural Resources Canada.

OBJECTIVE

The extent of the contribution of light-duty vehicles to underground air pollution is not well known. Whereas these vehicles may appear to have had an insignificant impact in the past, trends in the Canadian mining industry indicate that some attention should be focused on this part of the underground fleet (1). This information suggests that the relative portions of the underground power associated with light-duty vehicles could be increasing. This work will characterize the exhaust emissions from light-duty (LD) and heavy-duty (HD) vehicles in a metal mine and estimate the relative contributions of both types of vehicle to the overall underground contaminant burden. If light-duty vehicles are found to have a significant impact, contributing factors will be identified and recommendations made in order to apply the results of this work to other mine sites.

COLLABORATORS

CANMET will be the main delivery group for this study, which will be conducted in close co-operation with the management, labour and safety and health representatives at Falconbridge's Kidd Creek Mining Division. CANMET will co-ordinate and perform the work associated with characterisation of the underground fleet, exhaust sampling of dpm and evaluation of the relative contribution of both types of vehicles.

IMPACT

Data that show the relative contribution of light-duty vehicles in a test mine will provide information that can be used to determine whether further efforts and work aimed at small engine emission reduction research are needed. Enhanced efforts in emissions control and maintenance aimed at the light-duty fleet may benefit the underground environment.

BACKGROUND INFORMATION

It is usually assumed that most of underground diesel emissions originate from heavy-duty production equipment. While this may have been the case in the past, new data suggests that light-duty vehicles could be responsible for an increasing portion of the airborne diesel emissions burden in the mining environment.

Definition of Light-Duty Vehicle

Whereas, the size of the engine has traditionally been used to differentiate between light, and heavy-duty vehicles, this work will expand to include vehicles regardless of horsepower that are not used in regular production cycles. In other words, all vehicles except higher horsepower units involved in ore, waste or fill handling (trucks and scooptrams) will be considered light-duty vehicles. The reasoning behind this approach will be discussed further on.

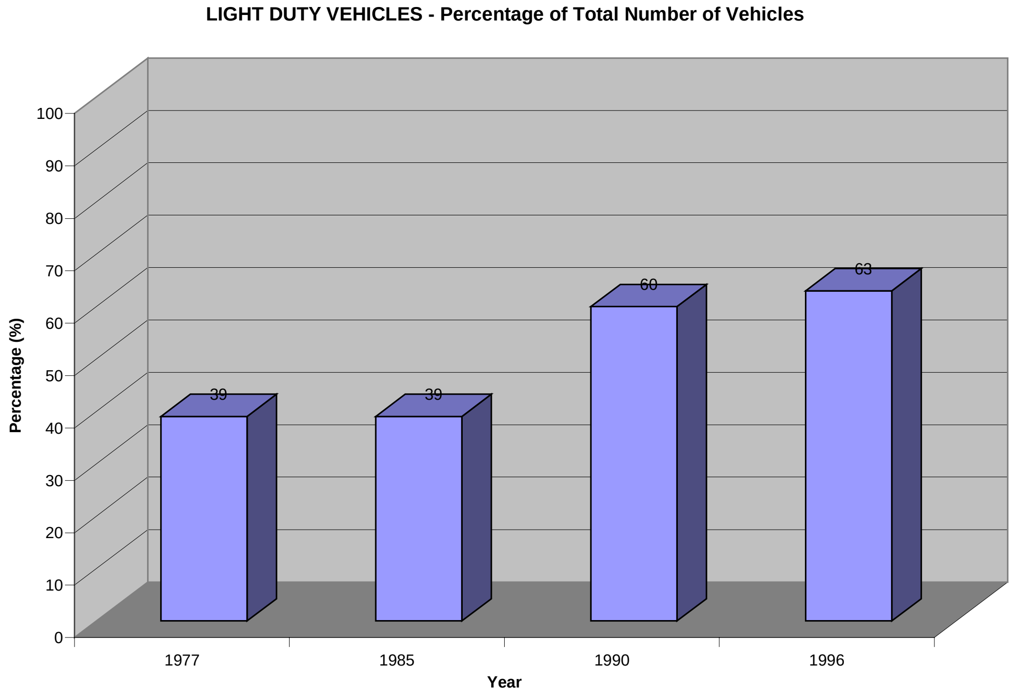

Figure 1. Light-duty vehicles as a percentage of total number of underground vehicles in the province of Ontario.

<u>Number of Light-Duty Vehicles</u>

In October 1996, the Ontario Ministry of Labour published the results of a province wide survey that gave an up-to-date profile of the diesel fleet used in underground mines (1). While these data apply to Ontario, there is no reason to believe that this is not representative of the mining industry at large. Reported data indicate that on a by number basis, the light-duty vehicles (80% of which are equipped with engines of 100hp or less) have gone from 30% of the fleet in 1977 to 63% in 1996 (Figure 1). Opposite trends are observed for both LHDs and haulage vehicles which go from 41% to 26% and 20% to 11%, respectively, in the same time interval. As ore is mined at greater depth, efficient use of staff means that the dependence on utility vehicles will probably increase and there is every reason to believe that the present trends might be maintained in the short to medium term.

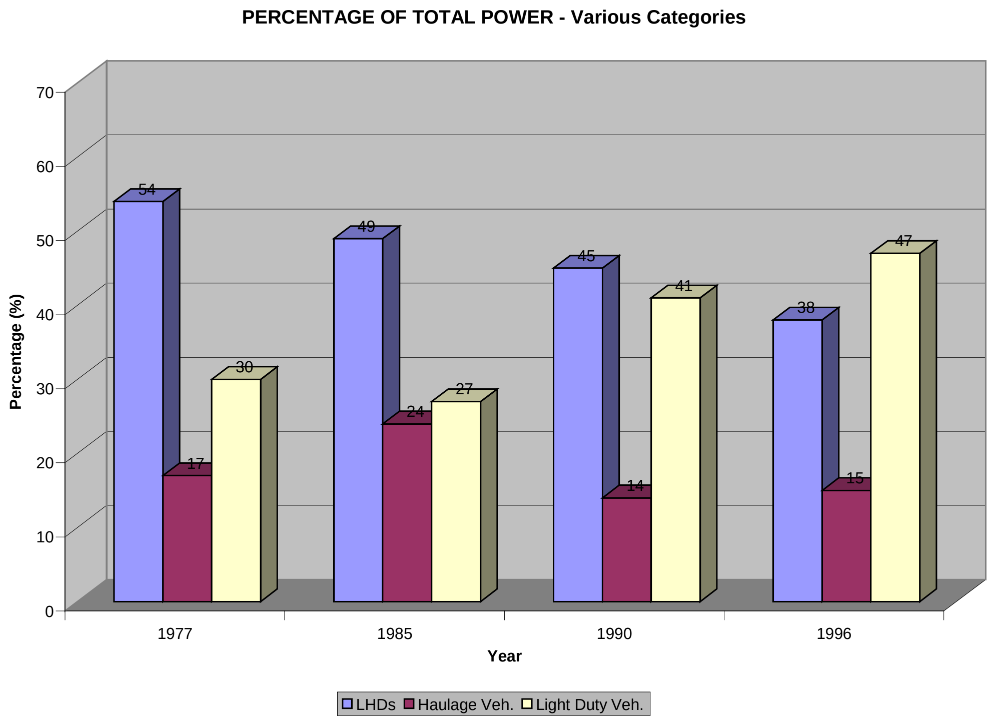

Figure 2. Total underground power for various types of vehicles in Ontario.

Power Associated with Light-Duty Vehicles

While on a number basis, light-duty vehicles may be gaining on the production fleet, the total power underground is still perceived as being made up mostly by heavy duty vehicles. Information shown in Figure 2 indicates that this is no longer the case. When data related to engine power is used in conjunction with the number of vehicles, it is possible get an idea of the relative percentage of total underground power. Figure 2 also shows the relative percentage of power that can be assigned to LHDs, haulage vehicles (trucks) and light-duty vehicles.

The total power associated with haulage vehicles has remained essentially stable in the 20 year spanned by the survey. LHDs have gradually gone from 54% to 38% of the underground power with light-duty vehicles now make up close to half of the underground diesel power.

Other Aspects

Other important points need to be addressed in order to study the impact of small engines. First, the duty-cycles of light-duty and heavy-duty vehicles have to be assessed to determine the relative overall contribution to the underground pollutant burden. This is when the concept of a utilization or load factor is used. The CSA (2) uses maximum machine load factors of 85% relative to full load for LHD vehicles, 70% for haulage vehicles and 50% for light-duty type vehicles. While there is a basis in fact for the figures reported for LHDs and haulage equipment, the light-duty vehicle utilization factor of 50% is more of a rule of thumb assessment (3,4). A true picture of the impact of light-duty vehicles in mines requires a better knowledge of duty-cycles. This could be achieved in this study by discussions and interviews with users, and by testing target vehicles by observing exhaust temperature, rpm, etc. over several shifts.

Next, the advent of clean engine technology in the form of more efficient mechanical engines and electronically controlled engines for large production vehicles may mean that light-duty vehicles may be slowly losing ground from the point of view of exhaust quality. This is reflected in the ventilation volumes required on a per brake horsepower fashion according to certification documentation. Over the past ten years ventilation values for light-duty vehicles have remained relatively constant while in some instances large engines require in the order of 30% less ventilation volume (5). This could significantly affect the exposure of light-duty vehicle operators and the general mine population at peak times such as the beginning and the end of the shift. Finally, emissions may be affected by any differences that may exist between the way in which light- and heavy-duty vehicles are used (duty-cycle) and maintained.

Light-duty vehicles have grown in numbers and the portion of installed power made up by these units has and could go on increasing. Because of new pressures related to the exposure to diesel particulate matter (6), light-duty vehicle operators have to be protected if it can be shown that these are responsible for more than their pro-rated share of diesel emissions. Then, if state of the art emission control techniques and technologies can be applied to small engines, the underground mine environment could significantly benefit. This project will attempt to establish the extent of this impact in an operating mine.

SURVEY OVERVIEW

The objectives of this investigation require that the following steps be taken:

- A host mine needs to be selected that will provide the necessary collaboration and which is representative of the hard rock mining industry at large.
- The fleet needs to be characterized and separated into classes (LD and HD) and sub-classes.
- A typical duty cycle needs to be developed for each vehicle sub-class.

- Raw exhaust DPM contribution need to be measured for each of the duty cycles developed.
- The impact of each class and sub-class of vehicle can then be calculated over a shift period and perhaps as a function of time through the shift.

Test Mine

The aim is to choose a mine whose fleet is large enough and whose profile will allow the research to target several types of light- and heavy-duty vehicles. The mine will also need to be representative of an average Canadian metal mine (fleet size, ventilation, etc.). The typical mine profile could be selected by comparing to Ontario mine fleet data as reported by the Ontario Ministry of Labour (1).

Some clarification is required as to the meaning of the term typical mine and the implications on the possibility of extrapolating results to other operations. While a mine fleet can be fairly similar to that in another operation, factors such as the ventilation system, the depth of the mine and indeed the type of mining can differ significantly. These factors can have a significant effect on the airborne concentration of dpm and it would be difficult to extrapolate airborne concentration values to make inferences about other mines. The objective of the present work deals more with raw exhaust measurement of dpm and the relative contribution of LD vs HD vehicles. Making a minimum amount of field measurement and reasonable assumptions could perhaps make extrapolation to other operations possible, in the future.

Some potential mine sites along with a summary fleet breakdown are shown in Table 1. Most of these mines closely reflect the fleet breakdown as reported by the Ontario Ministry of Labour, with Onaping/Craig mine most closely reflecting the average mine profile. Kidd Creek has the largest percentage of electronically controlled engines in production vehicles. Lockerby and Lindsey on the other hand have comparatively smaller fleets, which may make it easier to economically test a statistically significant number of vehicles.

	Kidd Creek		Lockerby		Lindsey		Onaping/Craig	
LHD	10151	34%	2547	44%	1554	53%	5655	34%
Haulage Truck	8125	28%	1220	21%	435	15%	3020	18%
Service/Utility/Drills	11169	38%	1996	35%	958	32%	8110	48%
Total	29445	100%	5763	100%	2938	100%	16785	100%

Table 1. Fleet description (installed power, bhp) in typical metal mines.

There are several benefits associated with working with Kidd Creek, namely, the opportunity to assess the impact of electronically controlled, heavy-duty vehicles. Management at Kidd Creek has been contacted and while final approval will require a more complete description of their involvement, a commitment in principle has been obtained. Kidd Creek would also be required to help with the fleet description and duty cycle survey in Phases I and II.

Fleet Profile Determination

The mine has already supplied a comprehensive listing of underground diesel equipment. Furthermore, ancillary information such as hours of operation, maintenance history, raw exhaust monitoring data, after-treatment, duty, usual operator names, etc., will be collected as part of phase I.

After this phase is completed, each vehicle in the fleet would belong to a class (LD or HD) and a sub-class. For example an M5030DT Kubota Tractor would be categorized as a LD vehicle in the personnel carrier sub-class. A JC1 Jarvis Clark Dump Truck would be categorized as a HD vehicle in the haulage truck sub-class.

Raw Exhaust Testing and Duty-Cycle Determination

<u>Duty-cycle assessment</u>

Heavy-duty vehicles are likely to have a regular duty cycle, which consists of trips between set points. This will be confirmed in Phase II monitoring of raw exhaust temperature and rpm over several days of production.

Light-duty vehicles present a very different problem because their duty cycle is very irregular. The selection of a statistically representative portion of the fleet and the development of a theoretical and <u>representative</u> duty cycle is key. The selected light-duty vehicles will be instrumented to accurately monitor several days of activity (again rpm and temperature tracing). This would be performed during Phase II and would also involve full time technical staff who would observe the cycles. This will ultimately lead to duty-cycles being broken down into distinct types or categories of activity such as the percentage of time the vehicle is off, left idling, traveling up ramp, traveling down ramp and other activities as required. The rationale for breaking down the cycle into this type of fixed percentages will simplify analysis and for all intensive purposes, is just about the only way that raw exhaust contaminant production can be characterized on light-duty vehicles.

Raw exhaust contaminant measurement

Exhaust quality will be determined by sampling raw exhaust for the main combustion gases and particulate matter for heavy-duty vehicles and light-duty vehicles. Gases will be measured using the ECOM raw exhaust gas sampling apparatus.

Dpm sampling in raw exhaust presents more of a challenge proposition. Historically a lot of work has gone into the development of raw exhaust dpm sampling devices. The objective is to construct a portable system, which will allow dpm to be measured in the field and permit the evaluation of dpm control methods and technology. The important aspect of raw exhaust sampling for dpm is the need to maintain constant and as low as possible conditions with respect to exhaust temperature at the point of sampling. Doing so will minimize the problems associated with the condensation of hydrocarbons and allow inter-comparison of vehicles and engines at specific operating conditions.

Particulate matter will be sampled using one of three approaches, which is yet to be determined and this will depend on the results of lab testing taking place this summer in CANMET's Bells Corners laboratory. The three methods to be tested will be a heated sampling probe and filter assembly, a dilution approach which uses nitrogen gas as a dilution medium and a field micro-dilution tunnel sampling system. The selection of one of the three methods will be based on simplicity and ease of application U/G as well as on the results of the lab tests mentioned above. In any event the expectation of accurate raw dpm concentration values will not be compromised.

Evaluation of the contribution of light and heavy-duty vehicles

The measured concentrations of raw exhaust contaminants have to be rationalized on the basis of milligrams per cubic meter of dry exhaust gas for any given sampling period. This will be done by logging the engine RPM and the exhaust CO_2 percentage. The RPM values along with the engine displacement and corrections for volumetric efficiency and/or turbo-charger contribution will be used to calculate the exhaust airflow over the same sampling period. The CO_2 percentage is related to the fuel air ratio and can be used to estimate the dry exhaust gas flow. The details of these calculations are shown in the Appendix and described elsewhere (7,8).

For heavy-duty vehicles, the above approach will be used in a fairly straightforward fashion over typical duty cycle periods. These data will then be extrapolated over the entire shift making assumptions and allowances for non-productive periods.

With light-duty vehicles the approach will have to be slightly different. Using the rpm and temperature traces as well as the observations made by technologists, duty cycle for selected groups of light duty vehicles will be constructed. For tractors and personnel carriers for example, heat tracing and rpm monitoring would be used to break down this type of vehicles duty cycle into simple percentages of various engine regimes. For example, tractors used by supervisors or maintenance people could end up being characterized as operating 5% of the time at idle, 20% on level ground, 25% going up ramp, 25% going down ramp and 25% of the time shut down.

A section of the mine would be chosen to test selected vehicles specifically under conditions of idle, up ramp, down ramp or level operation over predetermined periods of time which will allow sufficient mass samples to be collected. The measured exhaust concentrations would then be used along with the above percentages to reconstruct the light-duty fleet contribution over a shift period. These same values could also be used in conjunction with rpm values and observations made during the second phase to estimate light-duty vehicle contributions at key times during the shift (beginning, lunch and end of shift).

Recommendations

Based on the results of the mine wide extrapolation it should be possible to gauge the amount of effort that should be put to controlling the emissions from small engines and to suggest means of emissions reduction. Cost effective dpm reduction measures for light-duty vehicles may include revisiting maintenance practices and direct control methods which may differ from those applied to heavy-duty engines.

TECHNOLOGY TRANSFER

The DEEP consortium is committed to education and the transfer of technology for the benefit of the mining industry. This commitment implies contact/feedback with and the active involvement of mine personnel including Joint Occupational Safety and Health people, local labour representatives, fleet maintenance and ventilation personnel as well as any other mine employee who may benefit from exposure and participation to this project. At the end of the project time will be set aside for a debriefing session/seminar where a round-table discussion may be used to focus on the participants views of the study and the anticipated impact. This forum can also be used to bring any technical point, which may need to be explained or further clarified about the study.

REFERENCES

1. **Vergunst, J. and C. Paquette**; "1996 – Ontario Underground Diesel Equipment and Procedure Survey"; Report by the Ontario Ministry of Labour, Occupational Health and Safety Division, Mining Health and Safety Programme; October 1996.

2. **Canadian Standards Association**: " Flameproof Non-railbound Diesel-Powered Machines for Use in Gassy Underground Coal Mines"; CAN/CSA-M424.1-88; 1994.

3. **Dainty, E.D. and J.P. Mogan**; "Comparison of Diesel Engine Types and Treatment Devices for Underground Mining Vehicles"; Presented at the Potash '83 Conference, Saskatoon, Saskatchewan and published in the Proceedings; Oct. 1993.

4. **Stuart, D.B., Ebersole, J.A.D. and J.P. Mogan**; " The Measurement of Exhaust Temperatures on Operating Underground Diesel Equipment"; Canadian Institute of Mining and Metallurgy Bulletin, vol. 72, no. 801, pp. 70-73; Jan. 1979.

5. **Natural Resources Canada:** *List of Diesel Engines Approved by CANMET in Accordance with CSA Standards* M424.1-88 & M424.2-90 *National Standards of Canada 1995-97)* Anon. (Division Report MMSL 97-041(TR)). CANMET, Mining and Mineral Research Laboratories, 1997.

6. **American Conference of Governmental Industrial Hygienists**: "Threshold Limit Values for Chemical Substances and Physical Agents Biological Exposure Indices"; ACGIH, 1996.

7. **Chan, L.M., Carlson, D.H. and J.H. Johnson**; "Evaluation and Application of a Portable Tailpipe Emissions Measurement Apparatus for Field Use"; SAE Technical Paper 921647; Sept. 1992.

8. **Chan, L.M., Carlson, D.H. and J.H. Johnson**; "Deterioration criteria for servicing mine diesel vehicles based on tailpipe pollutant concentration data"; Mining Engineering, Dec. 1992, pp. 1472-1476.

APPENDIX

WORK SCHEDULE

PROJECT TITLE: Evaluation of the Contribution of Light-Duty Vehicles to the Underground Atmosphere Diesel Emissions Burden.

PROJECT LEADER: Michel Grenier, CANMET

CLIENT NAME: DEEP Consortium

CLIENT CONTACT: Bill Howell, DEEP Secretariat

Phase I								
Phase II								
	Oct 98	Nov 98	Dec 98	Jan 99	Feb 99	Mar 99	Apr 99	May 99

SURVEY COSTS

The survey costs can be summarized as follows:

Phase I	**$12,200.00**
Phase II	**$142,400.00**
Contingency (15%)	**$23,000.00**
TOTAL	**$177,600.00**

The participating mine would be expected to provide about $40,000.00 of in-kind support work that would come as a result of staff time and some loss in the utilization of production and light-duty equipment.

SURVEY DETAILS

The study will be sub-divided into two phases. The first phase would consist in the selection of the mine and the acquisition of necessary information related to the fleet. Key mine personnel will be interviewed and the information will help in the classification of vehicles as light-duty or heavy-duty and in the selection of a statistically significant number of test vehicles. The second phase would deal will the determination of duty cycles and the characterization of exhaust contaminants for light-duty and heavy-duty vehicles.

Synopsis

Phase I

- Mine selection and confirmation from mine management for collaboration
- Obtain preliminary fleet information and classify vehicles as light or heavy-duty
- Go to mine site, perform interviews with maintenance, engineering, production and operators to get information on: maintenance procedure and schedules for key vehicle groups, details of duty cycles from operator feedback, general mine ventilation data.
- Select statistically sufficient numbers of vehicles in each designated group and sub-group to go on to phase II
- Write phase I report and submit.

Costs

Prep. 3 days, 1 person - $2300
Travel costs - $1000
Site (inc. travel) - $6600
Post 3 days - $2300

Total $12200

Phase II

- Phase II field trip preparation (instrumentation, logistics)
- Go to mine site, perform temperature and rpm trace and log entire shifts for selected LD and HD vehicles have technologist be present all day to log vehicle activity.
- Build theoretical duty cycle for selected LD and HD vehicles
- Characterize dpm emissions for these duty cycles and rationalize in order to obtain dpm production over a shift period and as a function of time through the shift if possible.
- Report on Phase II

Costs

Prep. 10 days, 2 persons - $15,600
Travel costs (two separate trips) - $11,000
Site (inc. travel) - $87700
Post 10 days, 2 persons - $15,600
Instrumentation - $5000
Final Report $7,500

Total $142,400

DESCRIPTION OF AN ON-SITE SAMPLING SCENARIO TO DETERMINE THE DPM CONCENTRATION IN UNDILUTED DIESEL EXHAUST

OBJECTIVE:

To define a simple sampling technique to measure the integrated DPM concentration of the undiluted exhaust gas generated from cyclic diesel machine operation in the field.

BACKGROUND:

Simple measurement of the undiluted exhaust DPM concentration makes possible comparison of undiluted DPM generation by the engine over time, thus allowing maintenance personnel to evaluate the degree of deterioration of engine condition.

Further, simultaneous measurement of both the undiluted and mine ambient DPM concentrations affords a check on the validity of both measurements, and also provides an assessment of the suitability of the ventilation rate from the standpoint of minimising the health impact on the miners in the mine area in question.

PROBLEM STATEMENT:

The DPM concentration needs to be measured in the undiluted exhaust of the LHD operating during an arbitrary number of repeated cycles. The required number of sampled cycles is dictated by the need to obtain a large enough DPM sample mass. From this mass, and the measurements necessary to determine the integrated undiluted exhaust flow rate on a dry standard volume basis, the integrated DPM concentration pertaining to the circumstances, can be determined.

MAJOR VARIABLES TO BE MEASURED:

(1) ENGINE RPM - This variable along with a simple estimate of engine volumetric efficiency, and knowledge of the engine displacement, allows the calculation of an integrated value of airflow, which is applicable to the LHD operation over the necessary operating period for gathering of an adequate DPM sample. (See calculation (1) of the section below entitled "Method of Calculation of DPM Concentrations").

(2) %CO_2 - The integrated value in undiluted exhaust gas by volume on a dry basis. This value is directly related to the fuel/air (f/a) ratio. Thus the integrated fuel rate can be determined, and then the dry gas flow calculated so that all the gas and DPM concentrations ultimately determined can be reported on the dry basis at standard atmospheric conditions. (See calculation (2) and (3) below).

(3) TOXIC GAS - Concentrations, if desired, can be determined for the machine operating period by a portable multiple gas analyser, thus allowing calculation of the integrated EQI for this LHD cyclic operation.

(4) UNDILUTED DPM CONCENTRATION - This variable is determined by sampling directly in the undiluted exhaust pipe and carefully determining the integrated exhaust flow sampling rate for the machine operating period. (See calculation (4) and (5) below).

METHOD OF CALCULATION OF DPM CONCENTRATIONS:

(1) Calculation of integrated air flow for DPM sampling period:

Engine power rating	100 bhp @ 2200 rpm	
Integrated cycle rpm - η	2,074 rpm	(continuously measured)
Volumetric efficiency - VE	90 %	(assumed)
Engine displacement $V_{disp.}$	387.6 in^3	(from engine manual)

$$W_{air} = V_{disp.} \times \eta \times 0.5 \times \rho_{air} \times 60 \text{ min/hr}$$

$$\rho_{air} = \frac{2116 \text{ psfa}}{1545/28.9 \times 528\ ^\circ\text{R}} = 0.075 \text{ lb/ft}^3$$

$$W_{air} = \frac{387.6}{1728} \times 0.90 \times 2074 \times 0.5 \times 0.075 \times 60 = 942 \text{ lb / hr}$$

(2) Calculation of the integrated fuel rate for sampling period:

Integrated % CO_2	9.05% (measured)
Integrated fuel/air ratio	0.042 (from Figure 1)

$$\text{Integrated}\, W_{fuel} = W_{air} \times 0.042$$
$$= 942 \times 0.042$$
$$= 39.5 \text{ lb/hr}$$

$$\text{Integerated wet gas flow} = W_{gas}$$
$$= 942 + 39.5$$
$$= 981.5 \text{ lb/hr}$$

(3) Calculation of undiluted dry exhaust gas w_{dxg}:

assumed % hydrogen in fuel by weight - 13.5% (from fuel analysis)

$$H_2O \text{ produced} = \frac{W_{fuel} \times 9 \times \% H_2O}{100} = 39.5 \times 9 \times 0.135 = 48 \text{ lb / hr}$$

$$\text{integrated}\, W_{dxg} = \text{weight of dry gas flow} = W_{air} + W_{fuel} - W_{H_2O}$$
$$= 942 + 39.5 - 48 = 933.5 \text{lb/hr for the cycle}$$

(4) Estimation of the DPM sampling rate:

In order to approximate isokinetic DPM sampling conditions, the following simple procedure can be used:

Assumed exhaust pipe diameter	D = 3.0 in
Assumed sample probe diameter	D = 0.125 in

For a fixed sample flow, irrespective of load cycle variations, choose for convenience the approximate maximum flow conditions of engine operation. Now, for isokinetic flow at this maximum flow condition, note that:

$$\frac{W_{probe}}{W_{\max gas}} = \frac{A_{probe}}{A_{exhust}} = (d / D)^2 \qquad \text{then assume}$$

$$\text{ass'd } \rho_{sample} = \frac{\text{P}}{(1545/MW)\times T} = \frac{2116\ \text{psfa}}{1545/28.9\times(460+68)\ \text{R}^{\circ}}$$
$$= 0.075\ \text{lb/ft}^3 \text{ at the rotameter}$$

$$W_{\max\ gas} = 1000 \text{ lb / hr per 100 bhp of rated output based on experience with four} - \text{stroke engines}$$

$$W_{probe} = (d\ /\ D)^2 \times W_{\max\ gas}/100 \times \text{rated bhp}$$
$$= (0.125/3.0)^2 \times W_{\max\ gas}/100 \times 100$$
$$= 1.736 \text{ lb / hr for the 100 bhp engine}$$

Although an approximation suitable for use here, this value will in fact be lower due to higher temperature and pressure.

$$q_{\text{sample}} = (W_{probe}/60 \times 0.075)$$
$$= 1.736/(60 \times 0.075) = 0.386 \text{ cfm}$$
$$= 0.386 \text{ cfm } \times 38.3 \text{ L / cfm}$$
$$= 10.9 \text{ L / min}$$

Therefore, from the start of the field test, the DPM sample flowrate can be set at 10.9 litres/min, a number determined from known engine data and known exhaust system geometry. This value would approximate the isokinetic sampling rate for the maximum gas flow through this engine.

(5) Calculation of the DPM concentration (dry basis at std. conditions):

mass of DPM sampled on filter	2.55 mg (measured)
sampling time	7.0 min (measured)
vehicle cycles completed in sampling time	2.0 cycles

Sampling pump flow rate to standard conditions for calculating and reporting the DPM concentration = 0.00980 m^3/min (dry gas conditions). Therefore, the concentration of DPM in dry sample gas at standard conditions is:

$$C_{DPMundiluted} = \frac{2.55 \text{ mg DPM}}{7.0 \text{ min}} \times \frac{1 \text{ min}}{0.00980 \text{ m}^3}$$
$$= 37.2 \text{ mg / m}^3 \text{ (drystd)}$$

Michel G. Grenier

Education

1980. Honours B.Sc., Physics (cum laude), Laurentian University, Sudbury, Ontario.
1982. M.Sc. Physics (cum laude), Laurentian University, Sudbury, Ontario. Research thesis on the affinity of radon decay products to airborne aerosols in uranium mines.

Professional Affiliations

- American Industrial Hygiene Association (AIHA)
- American Conference of Governmental Industrial Hygienists (ACGIH)
- Occupational Hygiene Association of Ontario (OHAO)
- Canadian Institute of Mining and Metallurgy - Sudbury Chapter

Professional Committees

- Technical advisor to the ONRSA's Workplace Environment Committee.
- Member of the Canadian ad hoc Diesel Committee.

Experience

1996 to pres. : Manager of the Underground Mine Environment program which includes diesel research conducted at Bells Corners in the Ottawa region and ventilation, sampling and analytical research conducted at the Sudbury Laboratory.

1991 to 1996: Project leader with the U/G Environment and Ventilation research group with CANMET/Natural Resources Canada. In charge of mining research dealing with dust and gas contaminant monitoring and control including silica and diesel exhaust contaminants. Is also working on workplace sampling programs and strategies and on workplace safety issues.

1985 to 1991: Underground environmental scientist with CANMET/Energy, mines and Resources Canada, involved in dust control and sampling research.

1981 to 1985: Physical scientist with CANMET/Energy, Mines and resources Canada, involved in radioactive contaminants sampling, analysis and control in uranium mines.

Publications

35 refereed papers and published conference proceedings. Over 100 divisional reports of investigation dealing with safety and health related to the underground workplace environment.

Mahendra Gangal

Education

1963. B.Sc., Agra University.
1965. M.Sc., Applied Science, Roorkee University.
1968. M.Sc., Applied Mathematics, McGill University.
1974 Ph.D., Calgary University, computer applications in channel flow problems.

Specialty

- Dynamometer testing for diesel engine emissions, evaluation of after-treatment devices and fuels.
- Assessment of dieselized mine air quality and development of monitoring instrumentation
- Standards development/regulations

Experience

Experience: 20 years Research and Development in the field of underground mine environment.

- Emissions testing of diesel engines and determination of ventilation prescription according to CAN/CSA M424.2 standard for engine certification
- Technical consultation with Provincial regulators with respect to regulations on the use of diesel machines in underground mines
- Development of an advanced multi-gas monitoring system and other instrumentation specialized for dieselized underground mines
- Assessment of exhaust treatment devices and bio-diesel fuel
- Extensive experience in the design of advanced monitoring systems and air quality assessments at many u/g mines
- Development of RCD/soot sampling and analysis methodology

Publications

Extensive publications in the field of diesel contaminant characterization and control as well as health topics related to the underground workplace environment. Amongst these :

"Ambient Measurement of Diesel Particulate Matter and Respirable Combustible Dust in Canadian Mines", **M. Gangal** and D. Dainty, Proc. 6th US Mine Ventilation Symposium, Published by Society for Mining, Metallurgy, and Exploration, Inc. (SME), 1993.

"Development of a Diesel Vehicle operator CO2 Exposure Meter", **M. Gangal** and D. Dainty, Proc. 6th US Mine Ventilation Symposium, Published by Society for Mining, Metallurgy, and Exploration, Inc. (SME), 1993.

Ernest Don Dainty, M.A.Sc., P.Eng.

Education

1965.	Instrumentation Design Course, MIT.
1956.	M.A.Sc., Mechanical Engineering, Toronto.
1954.	Electronics Course, Ryerson Institute.
1953.	B.A.Sc., Mechanical Engineering, Toronto.

Affiliations

- Association of Professional Engineers of Ontario.
- Canadian Institute of Mining and Metallurgy.

Experience

1991 - date: Part-time (semi-retirement), CANMET, Natural Resources Canada.

1962 - 1991: Full-time, CANMET, Natural Resources Canada. **Health and Safety Research and Development Studies** as summarized by the following:

1968 - date: Established and supervised the CEAL Diesel Emissions Facility (relevant to all underground workings) for:
- certification of diesel machinery;
- researching diesel engine emissions and developing equipment to reduce emissions toxicity.

1987 - 1990 Coordinated an industry\govt. sulfide Dust Explosion Control Group.

1962 - 1970 Improved gaseous explosion control (coal mines) by:
- researching gas explosion fundamentals related to mining electrical equipment and diesel machines; and
- developing a standard for explosive gas instrumentation testing.

Productivity:

Chaired three CSA Technical Committees resulting in **Canadian National Standards**:

1990 "**Diesel Machines in Non-Coal Mines**", CAN\CSA M 424.2
1990 "**Diesel Machines Brake Performance**", CAN\CSA M 424.3
1988 "**Diesel Machines in Coal Mines**", CAN\CSA M 424.1

Recognition:

- **APEO Engineering Medal** for outstanding research in diesel engine emissions and development of equipment to reduce emissions toxicity, 1990.
- **Canadian Award for Business Excellence**, gold medal in the Environment Category, for the diesel exhaust filtration technology, 1990.

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Mine Ventilation Specialist with eighteen years of world-wide experience in a wide range of underground mine environment R&D projects for the European Coal & Steel Community and the Canadian federal government Mining & Mineral Sciences Laboratories at Elliot Lake and Sudbury.

Four years with the Mining Department, Nottingham University, U.K. on ventilation research funded by the European Coal & Steel Community. This included: a definitive investigation of controlled recirculation for coal mines; development of analog and computer ventilation models; evolution of gaseous and particulate concentration prediction software; ventilation optimization: and design of monitoring systems.

Fourteen years with CANMET's Mining & Mineral Sciences Laboratories, Ten years at Elliot Lake and four years at Sudbury as a Project Leader/Research Scientist working on underground environment research programs. Specific areas of responsibility include:

Particulate Research: the development and application of optical particle counters; evolution of asbestos and diesel soot discriminating sensors; creation of dust transportation models; establishment of dust sampler calibration tunnel; and the assessment of underground and surface facility dust sources, personnel exposure and control mechanisms.

Ventilation Research: the introduction and development of tracer gas analysis and applications; the promotion of controlled recirculation for Canadian mines; the evaluation of mine ventilation measuring devices and the establishment of a calibration facility; surveying, modeling and re-design/optimization of mine ventilation systems; the development of 3D-CANVENT ventilation simulation package; monitoring, simulation and prediction of airborne contaminant transport patterns; automation of mine ventilation; promotion of "ventilation on demand"; assessment of underground and surface plant, primary and secondary ventilation systems.

Affiliations: Member of the Institute of Mining Engineers (U.K.); Canadian Representative International Mine Ventilation Congress; Committee Member of U.S. Mine Ventilation Symposium; Member of the Canadian Ad Hoc Diesel Committee.