Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

THE USE OF A PORTABLE AEROSOL COUNTING SYSTEM TO CHARACTERIZE DUST CLOUDS AND EVALUATE CONTROL METHODS IN UNDERGROUND METAL MINES

S.G. HARDCASTLE, M.G. GRENIER, J. BIGU AND G. KNIGHT

ELLIOT LAKE LABORATORY

JANUARY 1988

Presented at the 4th Int. Mine Ventilation Congress, Brisbane, Queensland, Australia, July 1988.

Published in the Proceedings.

MINING RESEARCH LABORATORIES
DIVISIONAL REPORT MRL 88-1 (OPJ)

THE USE OF A PORTABLE AEROSOL COUNTING SYSTEM TO CHARACTERIZE DUST CLOUDS AND EVALUATE CONTROL METHODS IN UNDERGROUND METAL MINES

BY

Stephen G. Hardcastle[1]
Michel G. Grenier[1]
J. Bigu[1]
G. Knight[2]

ABSTRACT

Respirable particulate control is a major concern in underground mining and the subject of continuing research world wide. In Canada the federal government's Mining Research Laboratory at Elliot Lake, Ontario, has been using two aerosol counters to aid its investigations. Specific studies with the units include: a) evaluating total and elemental size efficiencies of dust filtration units; b) characterizing the dust particulate cloud from different mining operations; and c) determining dust transportation characteristics.

The particle counters employed are modified HIAC/ROYCO 4102 near forward light scattering units, which count particles greater than 0.5 μm diameter into six threshold size ranges. The dynamic measuring range of the particle counters is 20:1. The units, originally designed for laboratory use, were customized for the underground operating environment. The counters are now portable and have an optional computer controller and data logging facility which is PC compatible and allows stored data to be readily installed in an electronic spreadsheet.

The instruments have been used to characterize the dust clouds by size and their electrical charge distribution. Investigation sites have included crushing operations, mucking, activities at an orepass, and along a conveyor drivage. From these operations the mean optical mass diameter of the dust clouds varied from 0.7 to 3.9 μm with geometric standard deviations of 2.6 and 2.1 respectively, depending on the operation.

In the evaluation of two wet dust collectors, the particle counter indicated that the collector or filter was only 40 to 50% efficient at removing particulate in the 0.5 to 1.5 μm diameter range. Then the collection efficiency rapidly increased and generally exceeded 90% for particles greater than 2.0 μm diameter. The overall mass efficiency of the two wet collectors, as determined with the particle counters, varied from 84 to 92% and is dependent on the mass distribution by size of the dust cloud entering the collector.

The particle counters have provided real-time information on dust concentrations and production. This includes peak values and time weighted averages. The units have also shown the effectiveness of ventilation and/or control mechanism in rapidly removing and/or diluting high dust concentrations.

During the studies using the particle counters, concurrent measurements were made with gravimeteric time-weighted average samplers and cascade samplers. Where applicable, the results from the aerosol counters have been compared with the more conventional instruments.

INTRODUCTION

Since the recognition of dust as a health hazard in mining, great advances have been made in dust prevention, suppression and removal techniques. Despite the great improvements in reducing dust concentrations, workers exposure and resultant pulmonary damage, the industry still strives to further improve conditions. This is becoming increasingly more difficult and will only be achieved through greater understanding of the controlling parameters (Hardcastle, 1984). With this aim, real-time monitors, providing a time history of the dust mass concentration, are now common to dust investigations. For further information and insight to dust conditions, the Elliot Lake Laboratory (ELL) has started using two real-time aerosol counters underground to give mass size distribution and concentration information.

THE INSTRUMENTS

The aerosol counters, modified and marketed by Mono Research Laboratories, Brampton, Ontario, were based on a HIAC/ROYCO 4102 optical particle counting system. These units use near forward scattering of visible light to detect and size airborne particles. They can detect particles of 0.5 to 20.0 μm optical diameter and each employs a six channel analyzer to size the particles into one of six

---

1. Research Scientist, Elliot Lake Laboratory, CANMET, Energy Mines and Resources Canada. P.O. Box 100, Elliot Lake, Ontario, Canada, P5A 2J6.

2. Research Scientist, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, 555 Booth Street, Ottawa, Canada, K1A 0G1.

threshold size ranges. The thresholds can be set by the manufacturer and, to date, two configurations have been used:

i) 0.5, 1.5, 3.0, 5.0, 10.0 and 15.0 μm; and

ii) 0.5, 1.5, 2.0, 3.5, 5.0 and 10.0 μm.

The original instruments were designed for 'clean room' use, manual control, mains power dependence and standard printer output of data. Each of the new aerosol counters (Hardcastle and Cavan, 1987), or optical particle counters (OPCs), include the following modifications; optional rechargeable battery supply, remote control from a hand-held computer with data logger, optional dilution system and extensive repackaging. Both OPCs are now portable and suitable for underground deployment as shown through the following investigations.

The OPCs can monitor on a continuous cycle and typically a 1 or 2 minute time base is used; this results in a virtual real-time history of count data. The data, in a particle count format for each of the six channels, can be readily converted into particle concentrations (ppcc), mass concentrations (mg/m^3) and mass size distributions for each set of results of data analysis using the Lotus 1-2-3 spreadsheet. This spreadsheet can also readily import the data collected by each hand-held computer controller/data logger.

UNDERGROUND STUDIES

Present thrusts into underground environmental research at ELL are concerned with:

i) characterization of particulates generated from mining operations; and

ii) evaluation of control methods.

For both, ELL is primarily concerned with metal mining operations with a further emphasis on uranium mines. In the latter, the effects of radioactive attachments to normally inspirable dust provides an additional health risk.

To date the OPCs have been used specifically or in part in the following investigations:

1. The evaluation of a wet dust collector at an orepass in respect of its efficiency and size selectivity (Knight and Hardcastle, 1987).
2. The impact of replacing a baghouse with a wet dust collector in a crusher room for reducing radioactive aerosol and dust concentrations (Grenier et al., 1987), (Bigu et al., 1987).
3. Investigating dust transportation and its effects on size distribution characteristics in an enclosed conveyorway (Hardcastle et al., 1988).
4. Studying the electrical charge properties of airborne dust (Grenier, 1988).

Each investigation has produced its own interesting results and is starting to provide detailed data of dust characteristics pertaining to specific operations. Initial consideration will be given to demonstrating the variability in mass distribution by size for dust clouds of differing operations and within each operation.

DUST MASS DISTRIBUTIONS FOR MINING OPERATIONS

Mass distribution by size information is invaluable when planning control measures; generally the larger the mass mean particle of dust the easier it is to remove or control because many control methods are size dependent.

The dust producing operations assessed fall into two main categories, primary breakage such as crushing, and transportation such as conveying or tramming. The latter includes mucking and dumping which also produces some breakage.

Figure 1 shows the optically derived mass distribution by size of the dust cloud generated by two types of crusher. Both crushers produce similar distributions and each is defined by a derived mean optical volumetric diameter (MOVD) and associated geometric standard deviation (GSD). These values show that, in this instance, the jaw crusher produces a coarser dust cloud than the cone crusher.

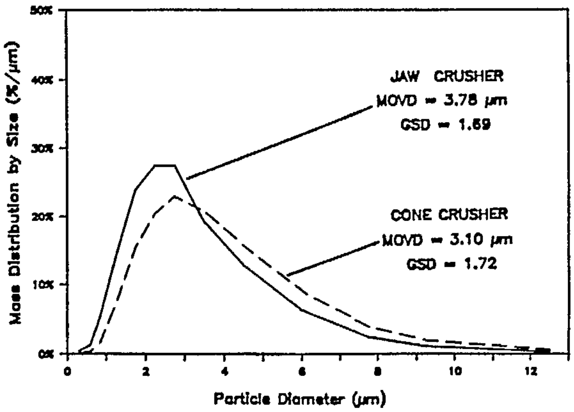

Figure 1. Optically derived mass distribution by size, of the dust clouds generated by cone and jaw crushers.

On comparing the mass distributions of various elements of transporting broken material, (Figure 2), two of the profiles are very similar, and the third distinctly different. Of the three presented, mucking produces the finest cloud closely followed by dumping and then conveying. Note, however, no consideration has been given to wetness of product, nature of ore and/or muck, and the same material is not necessarily being transported throughout.

The five profiles presented are average distributions from each investigation. These demonstrate the great variability of mass distribution by size that can be encountered in mining. Even for each study the distribution had a high variability within itself as well, for example, the MOVD ranged between 1.74 and 3.87 μm along a conveyor while it carried muck.

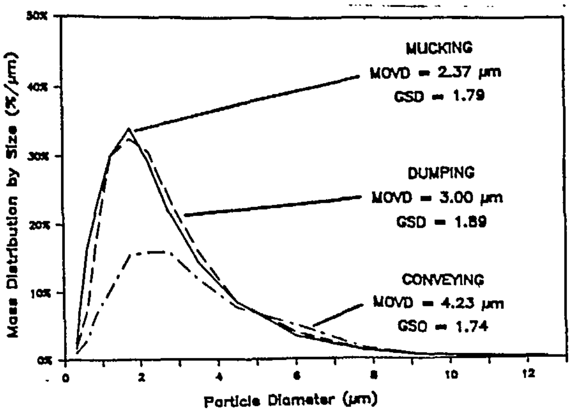

Figure 2. Optically derived mass distributions by size of dust clouds from three operations associated with ore transport.

One of the consequences of differing mass distribution by size is shown in the subsequent evaluation of two similar dust collection units.

EVALUATION OF TWO WET DUST COLLECTORS

Both dust collectors evaluated were Precipitaire (Mark III) units which use a self-induced wet dust collection method. They are commonly referred to as a type of wet scrubber. At both installations, an orepass and in a crusher room, the primary objective was to determine the efficiency of each unit at dust removal and its effectiveness as a control measure.

At the orepass, the OPCs monitored both the inlet and outlet air of the collector. Figures 3 and 4 show examples of the pure count data at the inlet and outlet, and the outlet data converted into a number concentration. In Figure 3, apart from highlighting operations at the orepass the good separation of the inlet and outlet traces is an indication of the collector performance for the presented size range. Throughout, the outlet count shadows that of the inlet, peaks occur on dumping and are relatively short-lived. On, and following, an ore dump the collector emitted dust in peaks of up to 300 ppcc (Figure 4), or on conversion 1.5 mg/m^3. Although the peaks exceed legislative limits if taken in isolation, their contribution to TWA concentrations and their resultant values, 92 ppcc and 0.27 mg/m^3, are not as significant.

The efficiency of this water type dust collector installation (Figure 5) was confirmed to be size dependent with removal values of approximately 45, 84 and 97% by volume (unit mass) for the 0.5 to 1.5, 1.5 to 3.0 and 3.0 to 5.0 µm size ranges, respectively. These combined for an overall volumetric removal efficiency of 82% for the dust cloud produced at this dumping operation. This value compares well with a gravimetric determination at 84% using respirable samplers.

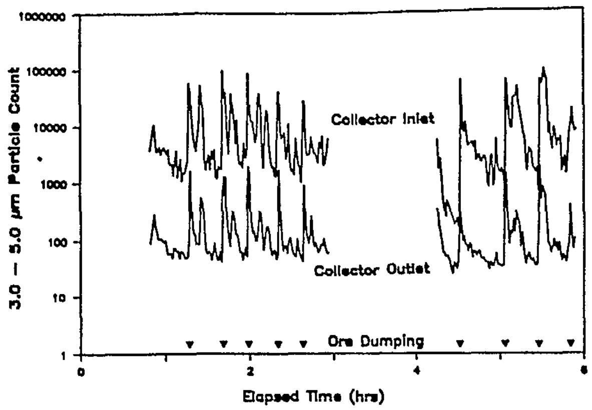

Figure 3. Time history of the number of 3.0 to 5.0 µm particles produced at an orepass measured at a dust collector.

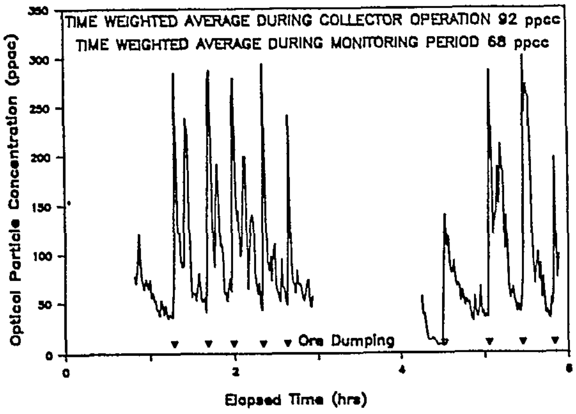

Figure 4. Concentration time history of total number of particles escaping a dust collector at an orepass.

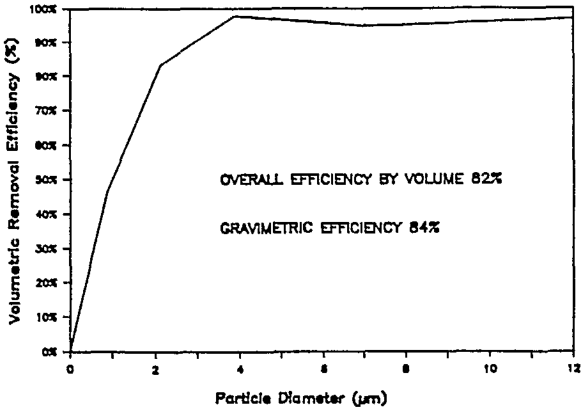

Figure 5. The average size dependent volumetric removal efficiency curve for a water type dust collector at an orepass as derived with OPCs.

Although the overall efficiency of this unit was slightly lower than expected, the collector adequately captures dust generated at the orepass and thus limits its contribution to workers exposure at that location and further downstream in the ventilation system.

In the crusher room, the second collector evaluation was in two parts, firstly the working environment was monitored with the now removed baghouse system in place, and secondly to monitor the environment on replacement with a wet collector and again assess the efficiency of the unit.

At this second installation the efficiency curve of the unit is slightly different (Figure 6), which is in part a function of different OPC thresholds. The size dependent efficiencies were approximately 40, 86 and 96% for the 0.5 to 1.5, 1.5 to 2.0 and 2.0 to 3.5 μm size ranges, respectively. These translated into an overall efficiency of 92% removal by mass of the dust cloud generated at the crusher. Also included in Figure 6 is a cascade sampler derived efficiency curve for the same installation, both show similar size dependent performances. Differences between the two curves at the smaller particle sizes are probably a function of the instruments and method used to derive the curve. The gravimetric determination of the collector gave an 85% removal efficiency. In association with this mass removal the activity concentration of long-lived radioactive dust ([LLRD]) was reduced by 88%.

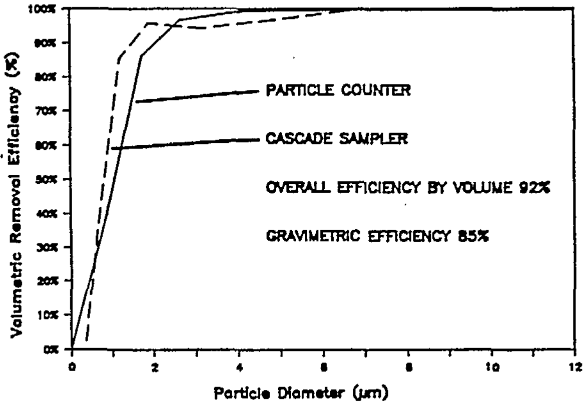

Figure 6. The size dependent volumetric efficiency curve of a water type dust collector at a crushing operation derived by cascade samplers and OPCs.

The differences in the overall efficiencies of the two collectors is attributable to the different mass distributions by size of the dust clouds entering the two collectors. Figures 7 and 8 present the inlet and outlet mass distributions at the two locations. The crusher inlet dust can be seen to be much larger (MOVD, 3.95 μm) than that at the orepass (MOVD, 2.5μm). As the wet collector is more efficient in removing larger particles, the unit that has the higher predominance of large particles has the highest overall efficiency. These two diagrams also show the effect of the filters on the mass distribution between the inlet and outlet. In both collectors the preferential removal of larger particles creates a much finer exhaust distribution. Comparing the two installations the change is again most significant for the unit that had the larger size initial inlet mass distribution. The optically derived outlet mass distribution for the crusher installation lacks detail because of the concentration of the majority of particles counted within the first size range.

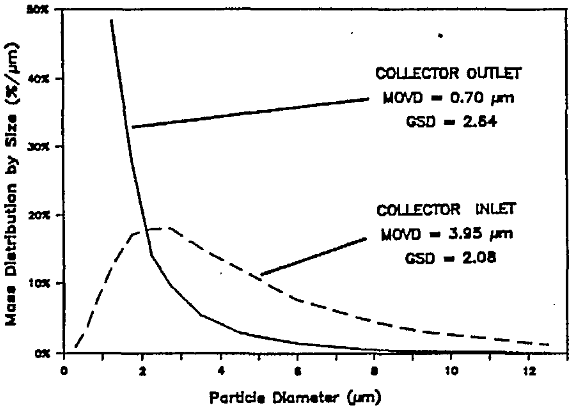

Figure 7. The inlet and outlet mass distributions of dust at a crusher dust collector installation.

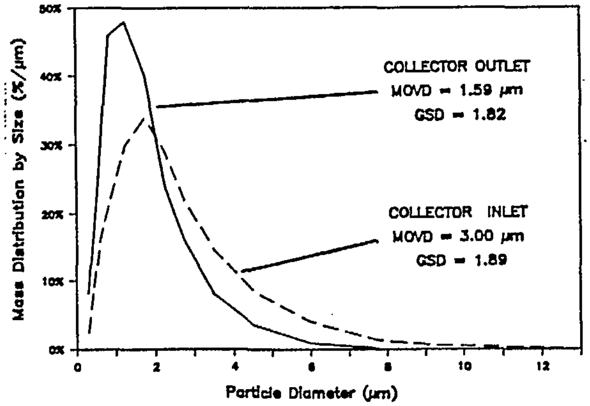

Figure 8. Inlet and outlet mass distribution of dust at an orepass dust collector.

The crusher room installation of a wet dust collector demonstrated a great improvement over the earlier baghouse. Previously the crusher platform was polluted by the crusher operation. This was shown by the dust at that location having very similar mass distribution characteristics to those at the inlet of the replacement wet collector. The OPCs demonstrated a 75% reduction of the MOVD, through the collector, and a slightly lower value at the crushing platform after mixing with 'fresh' air. Gravimetric dust and radiation analyses demonstrated that the working environment at the platform improved as follows:

a) The mass median aerodynamic diameter (MMAD), determined with cascade samplers over full-shift operations reduced 64%;

b) The total α-activity concentration [LLRD] reduced 68%; and

c) The activity median aerodynamic diameter (AMAD) for the radioactivity distribution associated with dust reduced 48%.

In the evaluation of these two collectors, the OPCs have shown that the mass removal efficiency of the system can vary from 84 to 92% purely as a result of the mass distribution. This demonstrates the importance of knowing the mass distribution when selecting a dust collection system. Failure to do so could lead to a dangerous and possibly expensive over-estimation of performance values.

DUST CHARACTERISTICS OF A CONVEYORWAY

The OPCs were used in a follow up study of dust conditions in an enclosed belt conveyor drift. A gravimetric analysis over the first 250 m length of the belt from its loading point indicated that two sources of dust production existed (Grenier et al., 1987). The drift which was ascentionally and homotropally ventilated became polluted from the loading pocket and apparently from the conveyor itself.

In the OPC investigation the counters were successively located at 10 locations along 470 m of the drift from the loading point. After correcting the results for dilution and time shifts, 13 representative mass distributions were obtained for the drift from the optical count data. The distributions, which have each been defined by a MOVD and GSD, have been plotted against the distance from the loading pocket in Figure 9. The distance has been converted into a number of hydraulic diameters to reduce the effect of changes in cross-section.

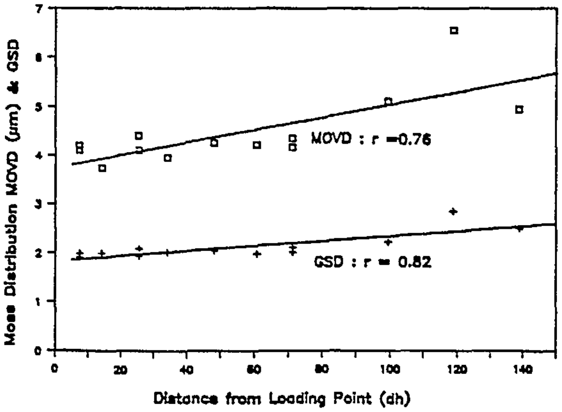

Figure 9. Variation of mean optical volumetric diameter (MOVD) and geometric standard deviation (GSD) of dust cloud mass distributions along a conveyor way.

A linear regression analysis of the MOVD and GSD against length demonstrates that there is correlation between the distance in hydraulic diameters and the distribution defining variables. The analysis and the figure both show that the MOVD and GSD consistently increase with distance. This is not indicative of a discrete source such as a loading point. The MOVD, and possibly the GSD, would decrease with distance from a discrete source through the effects of sedimentation. In this instance, where both are seen to increase linearly, it would appear that a linear source is gradually introducing particles of a larger mass distribution than that generated at the loading pocket. The only source for this is the belt conveyor and this supports the previous gravimetric study.

ELECTRICAL CHARGE PROPERTIES OF AIRBORNE DUST

The most recent underground application of the OPCs has been to investigate the charge distribution of particles within mine dust clouds. The charges on dust particles and their ability to remain charged could easily affect their deposition under a variety of conditions. This effect on deposition can be both an advantage and a disadvantage depending on the circumstances, for example, increased deposition of charged dust is undesirable in personnel samplers such as cyclones, whereas it would benefit certain types of electrostatic dust control techniques.

The dust charge determinations have been performed in conjunction with a split flow elutriator (SFE) based on the design of Johnson (1983). The SFE with an OPC attached to each channel and a power supply providing selectable differential voltage across the internal plates of the SFE, readily allows particle mobility and charge to be determined simultaneously in each of the OPC's size ranges.

Studies to date have shown distinct differences in the number of elementary charges on particles from uranium and non-uranium mines. Figure 10 compares the elementary charges per particle diameter of the dust cloud generated at two cone crushers. The population of charge on uranium mine dust particles is much closer to the natural equilibrium state that every dust cloud will reach with time.

DISCUSSION

The underground investigations outlined in this paper have shown some of the differing uses of the OPCs and their potential as analytical instruments. Each study has provided valuable information on the characteristics of dust production and the dust cloud itself.

Depending on a survey's requirements the OPC results can be presented in a variety of formats. These range from the real-time history of raw particle counts through to the individual and time-weighted average mass distributions and mass concentrations. The instrument effectively combines the real-time capability of light based monitors, the size differentiation of cascade samplers and the pure particle counts of the

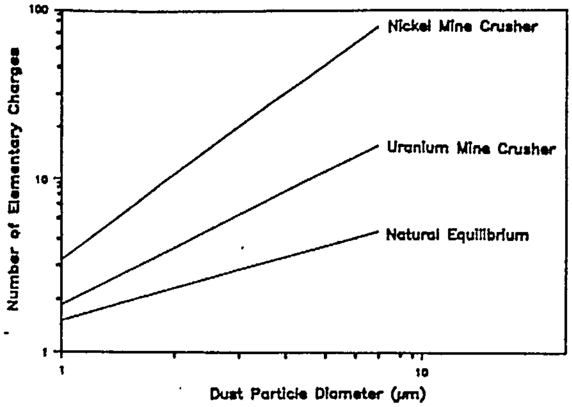

Figure 10. The elementary charge population distribution for dust clouds generated by cone crushers in a uranium and nickel mine.

konimeter.

Throughout, the OPCs have high-lighted the variability of mass distribution and elemental charge population and its distribution in respect to particle size. The mass distribution varies from operation to operation and the charge distribution can vary from mine to mine.

The evaluation of two dust collectors has shown that when planning a dust control technique the variability of mass distribution can create differing results from near identical systems.

The studies with the SFE into charge distributions demonstrated basic differences depending on ore type that could have far reaching implications.

ACKNOWLEDGEMENTS

The authors would like to thank the management and personnel of Rio Algom Ltd., Elliot Lake, and Falconbridge Mines Ltd., Sudbury, for the provision of test sites and their whole hearted support and assistance.

REFERENCES

Bigu, J., Hardcastle, S.G. and Grenier, M.G., 1987. Effect of a wet scrubber to reduce radioactive aerosol and dust concentrations in underground uranium mines, American Industrial Hygiene Association Journal (in press).

Grenier, M.G., 1988. The evaluation of a split flow elutriator to determine the electrical characteristics of dust in uranium and non-uranium mines. In preparation. Division Report MRL 88-, CANMET, Energy, Mines and Resources Canada.

Grenier, M.G., Hardcastle, S.G. and Bigu, J., 1987. Evaluation of a water type dust collector at an underground crushing operation. American Industrial Hygiene Association Journal (in press).

Hardcastle, S.G., 1984. Dust concentrations as a function of air velocity in mines - application of continuous dust sensors and an aerosol counter. Division Report MRP/MRL 84-72(TR), CANMET, Energy, Mines and Resources Canada.

Hardcastle, S.G. and Cavan, J., 1987. A portable computer controlled multi-size range, aerosol counting system for use in underground mining environments. Division Report MRL 87-167, CANMET, Energy, Mines and Resources Canada.

Hardcastle, S.G., Grenier, M.G. and Butler, K., 1988. Characterization by size of the mass distribution of airborne dust along a conveyorway. Division Report MRL 88-, CANMET, Energy, Mines and Resources Canada.

Johnson, A.M., 1983. A semi-automatic method for the assessment of electrical charge carried by airborne dust. Journal of Aerosol Science, pp 643-655, 14:5, Pergamon, London.

Knight, G. and Hardcastle, S.G., 1986. Efficiency tests on a wet dust collector in a hard rock mine. Division Report MRL 87-95(TR), CANMET, Energy, Mines and Resources Canada.