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PAST, PRESENT AND FUTURE OF DUST RESEARCH AT THE ELLIOT LAKE LABORATORY

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PAST, PRESENT AND FUTURE OF DUST RESEARCH AT THE ELLIOT LAKE LABORATORY

by

M. Grenier* and J. Bigu**

ABSTRACT

A brief history of the dust research work at the Elliot Lake Laboratory is given. Two decades of dust research work are studied and reviewed. This review clearly shows where, when, and with what intensity various components of dust research were performed. From the data presented here, it is suggested that a major portion of the future efforts be aimed at research directed towards the control and suppression of dust in underground mines.

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ACTIVITÉS DE RECHERCHE SUR LA POUSSIÈRE, ANTÉRIEURES, EN COURS ET FUTURES, AU LABORATOIRE D'ELLIOT LAKE

par

M. Grenier* et J. Bigu**

RÉSUMÉ

Le rapport comprend un bref exposé sur les activités de recherche sur la poussière qui sont effectuées au Laboratoire d'Elliot Lake ainsi qu'une revue et une étude des travaux réalisés en ce domaine au cours des vingt dernières années. L'étude indique clairement à quel endroit et à quel moment les diverses composantes de l'activité de recherche ont été réalisées et de quelle manière elles ont été effectuées. À partir des données présentées dans ce rapport, on suggère que, dans l'avenir, la majeure partie des efforts soit consacrée aux activités de recherche qui visent le contrôle et l'élimination de la poussière dans les mines souterraines.

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INTRODUCTION

Exposure of mining industry workers to excessive amounts of airborne dust has long been linked to a variety of lung ailments generally referred to as pneumoconiosis: more specifically, asbestosis, silicosis and black lung. The amount of dust exposure, the site of deposition in the respiratory system (affected by particle size, density, shape, as well as other physical properties) and the biological activity of dust in the lung are known to affect the onset of pneumoconiosis.

Lung diseases in the mining industry have an immense negative impact both financially and sociologically. Indeed, over and above the financial aspect, lung diseases are probably the most serious health problems associated with mining.

In hard rock mines, guidelines for what are presently believed to be acceptable levels of airborne concentrations of dust (for example SiO_2) have been set (1). These guidelines vary in Canada from province to province and they address some aspects of the problem: they recognize the increased danger with exposure and the biological impact that different chemicals or minerals may have (silica, asbestos, etc.) on human health.

On the other hand, monitoring done over the years by Elliot Lake Laboratory personnel shows that the shift averages for respirable dust at times exceed the guidelines. Research also shows that the quartz content in the ore and the type of work performed can affect mine workers exposures. Many questions remain unanswered or their answers are uncertain. For example, should account be taken of individual breathing patterns and lung capacity? Although the size distribution of dust in the respirable range is known to affect the site of deposition in the lung, and hence the retention period in the body, data are sparse on compounding factors, such as cigarette smoking and radioisotope decay both short and long-lived.

If the present guidelines are to be heeded (and perhaps modified), means of dust control will have to be studied carefully. Furthermore, such control methods will have to be experimented with extensively in underground environments. Such methods include filtering, waterspraying, ventilation and electrostatic means of dust control.

In view of some obvious scientific gaps that exist, it seems that dust research in the field should be geared up with more emphasis being put on the control aspect. Some suggestions on the introduction of dust control in the research program are outlined in references 2 and 3.

The present report gives a brief history of dust research at the Elliot Lake Laboratory. It comprehensively summarizes and categorizes the work done in the last two decades. This review on the subject clearly shows where, when, and with what intensity various components of dust research were performed. From the data presented, the future direction of the dust research program at Elliot Lake can be suggested.

HISTORICAL BACKGROUND

The CANMET dust research program was initiated to provide a broad data base to help deal with the airborne dust problem in Canadian mines. In the beginning, dust research originated in Ottawa. The first task undertaken consisted of compiling dust standards and a list of dust sampling instruments used in various industrialized countries. This information was summarized in 1960 (4).

Shortly thereafter efforts were aimed at the design of a laboratory dust chamber. The construction and preliminary testing of this chamber was completed in 1963 (5). The chamber was designed to permit the evaluation of dust sampling instruments under laboratory-controlled and simulated underground conditions. In 1965 the chamber was moved to the Elliot Lake Laboratory, where it has since been used to provide a wealth of information on environmental dust research. Because of the move, most of the efforts from 1965 to 1966 were aimed at setting up the chamber and developing ancillary equipment for appropriate dust cloud production (6).

From 1965 to 1967 a large number and variety of dust samplers were tested and evaluated in the chamber. These instruments were designed to assess dust concentration by number (konimeters, thermal precipitators and impingers), by light scattering, as well as by gravimetric means (horizontal elutriators and cyclones). Approximately 22 reports were prepared from these early experiments. All are summarized in a very comprehensive research report (7).

By 1969, quartz content determination from airborne dust samplers had become a major topic in dust research. Quartz content measurement by X ray diffraction (8), and by infra red absorption (9), were studied separately. Practical work done on X-ray diffraction was conducted for the most part at the Elliot Lake Laboratory. By 1972, the X-ray diffraction (XRD) analysis apparatus now used by many Canadian mining companies was operational (10). Since then, many improvements have been introduced to the system, especially in the automation of data acquisition by interfacing to more sophisticated computer systems.

In 1970, and the ten years that followed, the knowledge acquired through sampling instrumentation testing and the state-of-the-art means of sample analysis encouraged many underground dust surveys. Studies in several different types of mines and mills were conducted in various provinces. By 1980, approximately twenty reports had been produced that compiled the results of these surveys. Starting in 1978, some radiation [illegible] ventilation studies were conducted in local and surrounding underground mines. This cooperation came about from the long standing awareness that the relationship between these fields is a very close one.

Expertise in dust sampling instrumentation and means of airborne quartz dust analysis also led to the development of the CAMPEDS dust samplers. The CAMPEDS are meant to be used as personal gravimetric dust sampling instruments, and are a modified version of an English design used in coal mines (SIMPEDS). Design modifications were made for practical reasons to suit sampling conditions in Canadian hard rock mines, and for ease of interfacing with the X-ray apparatus for analysis of quartz content (11).

More recently, means of dust control in underground mines have been studied for possible immediate and future application. From some work done in 1980 (12), it is immediately obvious that a great deal of work is needed in order to achieve proper dust control in underground mines.

A REVIEW OF TWENTY-FIVE YEARS OF DUST RESEARCH

To illustrate what the main aims of dust research have been at CANMET, reports written by the dust research staff have been categorized. Using basic statistics, the reports and categories in which they fell were analyzed to yield information as to the history of dust research at the Elliot Lake Laboratory. The results of this survey are shown graphically in Figures 1 to 3.

The histograms in these figures all represent frequency distributions as a function of time (i.e., number of reports per year). Before proceeding any further, however, certain points should be indicated pertaining to the statistical approach followed here. Firstly, the reader should bear in mind the difficulty of performing a statistical analysis with a reduced number of samples (115 reports for an average of twenty-three when divided into five groups). Secondly, it should be clear that the amount of research work and

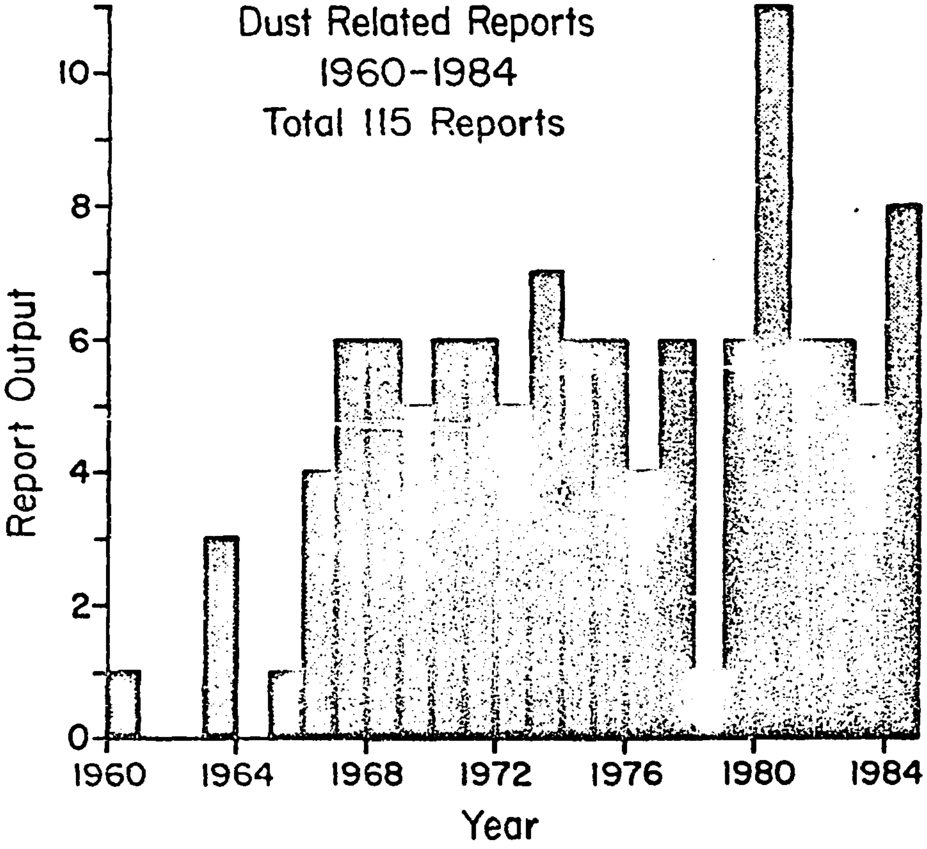

Fig. 1 - Frequency distribution histogram showing the output of dust reports as a function of time. A total of 115 pertinent reports were used.

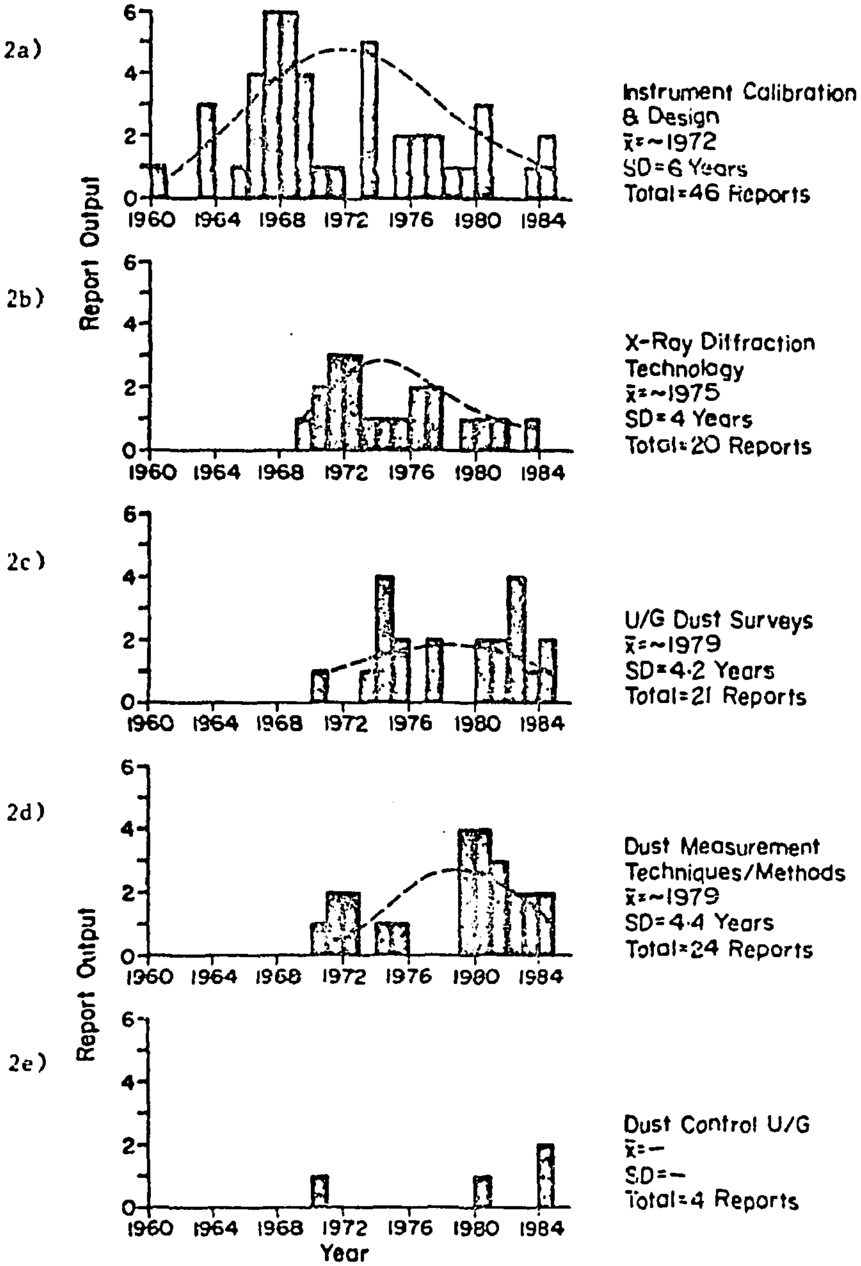

Fig. 2 - Frequency distribution histograms of the 115 reports of Figure 1 as a function of time. In this figure the reports are divided into five categories. In these histograms the average (x̄) is meant to represent the year when interest for a particular category peaked, while the standard deviation of the distribution gives an idea of the comparative time span over which the research work was conducted.

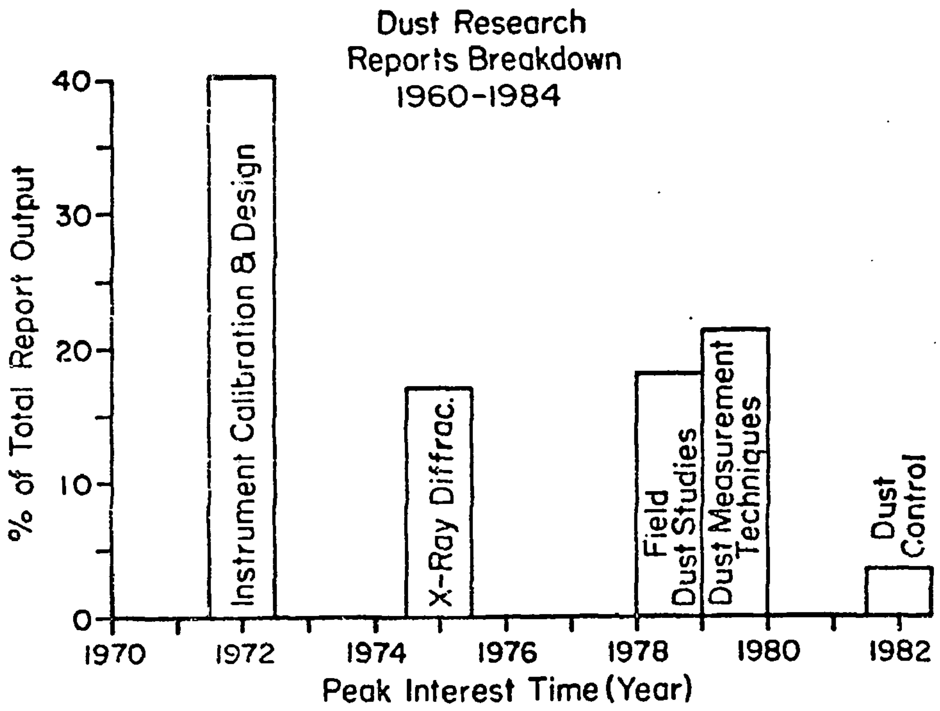

Fig. 3 - Histogram showing the relative importance or volume of work accomplished in each research category. Except for dust control the histogram also shows the point in time where each category is thought to have reached maximum intensity.

time that a report is meant to represent can vary substantially from one report to the next. Nevertheless, and in spite of the obvious shortcomings, the classification of dust reports is probably the best way of establishing what was accomplished in dust research during the various periods.

Figure 1 is a frequency distribution histogram showing most of the dust related reports (totalling 115) written by the Elliot Lake Laboratory staff between 1960 and 1984. It should be mentioned that some reports could not be easily categorized, such as annual type reports. These were omitted altogether. The histogram in Figure 1 could best be described as a rectangular distribution showing that the output of the dust staff was fairly constant and independent of time beyond 1965. The output, it is assumed, is also independent of the number of professional and technical staff. This was relatively constant over the period in question. Taking the above observations into consideration, the 115 reports were filed under the following five different categories:

1. Instrument calibration, testing and development;
2. X-ray diffraction technology development;
3. Results of underground dust surveys;
4. Dust measurement techniques and methods;
5. Dust control methods underground.

The reports classified using this scheme were also plotted as frequency distribution histograms. These are shown in Figures 2a to 2e. Before going into an in-depth analysis of these Figures, it is worthwhile studying them as a whole.

Focusing on the mean point of the frequency distributions it can be seen that this value shifts from approximately the year 1972 to 1979 from Figures 2a to 2d, respectively. If we define the mean point of any distribution in Figure 2 as the point when interest in that research category peaked, then, not only does it stand to reason that there should be a shift in research interests and goals, but also that there should be a logical explanation for that shift. The shifts displayed in Figures 2a to 2d illustrate the evolution of research interest at the Elliot Lake Laboratory: from instrument calibration, testing and development, as well as X-ray diffraction technology development, to the implementation of dust measurement techniques and methods, as well as characterization of airborne dust in underground environments.

As shown, dust research started with studies of instrumentation for dust sampling (Figure 2a, peak at 1972), and of means to analyze samples obtained using these instruments (Figure 2b, peak at 1975).

After the dust sampling and analyzing skills had been built-up, attention shifted to dust surveys in underground mines (Figure 2c, peak at 1979). These surveys were aimed at determining the major contributors to airborne concentrations of respirable dust, the composition (mineral and combustible), and the size distribution of the dust clouds. As a direct consequence of, and in order to assist underground dust surveys, dust measurement techniques and protocols peaked almost simultaneously in 1979 (Figure 2d).

This progression shown from Figures 2a to 2d, leads to a better understanding of dust production processes underground. With such information in hand, dust control measures (Figure 2e) could be implemented.

Figure 3 shows the relative importance of the categories described in Figure 2 and the point in time where peak interest seems to have occurred. It should be noted that the dust control bar in Figure 3 is added for the sake of completeness only. It is not implied here that the study of dust control methods has peaked at all. Rather, the topic is identified clearly as that of the highest priority for future research.

Taking a closer look at histograms from Figure 2, it can be seen that instrument calibration, testing and development (Figure 2a) is centered about 1972, with a standard deviation of about 6 years.

After the Elliot Lake Laboratory opened in the early 1960's, a lot of emphasis was put on laboratory testing of gravimetric and other types of non-continuous dust samplers. These calibration projects started in 1965 and were being wound down by the early 1970's. This is shown by the large, well defined peak between 1965 and 1971, in Figure 2a. After 1972, emphasis in this field shifted to personal dust samplers. Between 1975 and 1979, several underground experiments were conducted that eventually led to the development of the CAMPEDS II personal dust sampler.

From 1979 onwards attention has slowly gone to continuous dust samplers or monitors. By this time, however, interest had shifted from instrument calibration to underground dust surveys as well as to dust measurement techniques and methods (Figures 2c and 2d).

Figure 2b is concerned with X ray diffraction technology and, as such, could have been included with Figure 2a: since, as is the case with sampling instrumentation, X-ray diffraction for quartz analysis is a 'tool' in dust research. Unlike most sampling instruments however, the X-ray analysis apparatus developed in Elliot Lake is a fairly unique system. The facility is used extensively by the mining industry from coast to coast. The distribution in Figure 2b is centered at about year 1975, with most of the work having taken place between 1970 and 1978. The histogram is definitely skewed to the right which indicates a feverish pace at the start of year 1969. After the system was well established (1974 onwards) the work done in this category was mostly aimed at maintaining or improving the system.

The distributions in Figures 2c and 2d have fairly similar averages and degrees of spread. Since they are also closely linked, they are described together here. It is first worthwhile noticing that the activity in the categories that these histograms represent has increased markedly, while the sectors in 2a and 2b have decreased within the period between 1976 to 1982. Both Figures (2c and 2d) could also be described as bimodal, with some activity taking place between 1970 and 1977. There was, then, a hollow period about 1978, after which activity picked up again. This reflects the fact that the resident scientist in charge of environmental dust was away on sabbatical leave during 1978. A summary and brief discussion of the results of measurements conducted in underground dust surveys are given in Appendix A.

Figure 2e is concerned with methods of dust suppression underground. Methods using filtration and water sprays have been discussed in those reports. Clearly, this is a key area of emerging work, and the number of reports in this category does not permit any in-depth statistical analysis.

CONCLUSION

From the above discussion, it may be surmised that there is a need for extensive research in dust control measures. A strong emphasis on work dealing with dust suppression techniques in underground mines would be the logical next step in dust research at the Elliot Lake Laboratory.

ACKNOWLEDGEMENT

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APPENDIX A

In this section, data from underground field surveys are tabulated. This is done for the sake of completeness, and although it is enlightening to some degree, no attempt is made to analyze the data in too much depth. This would be a formidable task, as these data are merely averages calculated from hundreds of samples obtained from several field surveys under different environmental conditions.

Table 1 lists instruments used in the field surveys. It classifies them by size selection mechamism as well as by specification by the British Medical Research Council (BMRC), or American Conference of Governmental Industrial Hygienists (ACGIH).

Table 1 - Instruments used in the field to obtain the data listed in Tables 2 to 17.

Instrument	Size Selection Mechanism	Specification
Casella 113A	Horizontal elutriation	BMRC
Casella 13040	Cyclone separation	BMRC
10 mm Nylon cyclone	Cyclone separation	ACGIH
CAMPEDS	2-stage impaction	BMRC
H & H Aluminium Cyclone	Cyclone separation	BMRC
SIMQUADS	Cyclone separation	BMRC

Tables 2 to 10 list data from underground surveys where the airborne concentrations of total, combustible and quartz respirable dust were measured in mg/m^3. In Tables 11 to 15 the airborne dust load is measured and quoted as mg of dust produced per ton of ore handled, or per foot drilled depending on the operation. Listing the results in this fashion permits the author to calculate the amount of ventilation that would be required to dilute the total airborne respirable dust to a concentration not exceeding 2 mg/m^3. Table 16 lists the average respirable dust concentrations obtained from Tables 2 to 10.

Table 17 lists average respirable dust productions from data in Tables 11 to 15. Both tables list these data as a function of mining operation.

The total respirable dust is measured by weighing the filter on which the dust is deposited prior to, and after sampling. The quartz portion of the respirable dust is measured using X-ray diffraction. The combustible respirable dust is determined by weighing the filter before and after ashing it at a temperature of 500°C. This portion of the respirable dust found in underground mines can be made up of diesel machinery exhaust as well as oil mists from compressed air equipment.

Upon calculating the percentage of airborne quartz dust in air and comparing this to the percentage of quartz mineral in ore (see Tables 2 to 10) one can see that the percentage of airborne quartz is consistently lower. From data presented elsewhere (13) it can be shown that on an average, a rock matrix containing 65% quartz will result in approximately 20% of the airborne respirable dust being silica. Similarly, for 30% and 10% quartz in the matrix, airborne silica will form 7.5% and 1.5% of the total airborne respirable dust, respectively.

Two factors could help explain this 3-7 fold reduction in airborne silica from the host rock (14).

1. Differential breakage: quartz is a very strong mineral. In the crushing process, there is a good possibility for a large portion of the quartz grains to be forced out of the weaker matrix as opposed to being broken. This would cause a lot of the respirable dust produced to be rich in matrix and poor in quartz.
2. Differential wetting: some evidence suggests that silicate minerals are more readily wetted than sulphides, hence dust from silicates may be more easily controlled by efficient wetting.

The data in Tables 2 to 10 also show that the airborne quartz concentration varies between .03 and .16 mg/m^3. The average from Table 16 becomes .13 ±.12 not taking operations into account. The Ontario Ministry of Labour guidelines for airborne respirable silica stipulate that all means at the employers disposal shall be used to achieve the lowest practical level of .1 mg/m^3 for silica and that this figure shall not in any way exceed .2 mg m^3 for an eight hour shift. With this in mind it is apparent that the need exists for more effective dust control methods underground.

Table 2 - Average respirable dust (R.D.) measurements

Date: 1973

Place: Three different hard rock mines.

% Quartz in Ore: >30%

Instruments Used: Casella 113A horizontal elutriators
Casella 13040 cyclones
ACGIH specification nylon cyclones

Reference: 1

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Jack leg drill*	.44	-	-
Long hole drill*	1.25	-	-
Slushing*	.55	-	-

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* Area sampling.
\+ Personal sampling.
= Machine mounted sampler.

Table 3 - Average respirable dust (R.D.) measurements

Date: 1975

Place: Underground mine, highly mechanized open stoping operation.

% Quartz in Ore: >30%

Instruments Used: Casella 113A horizontal elutriators
Casella 13040 cyclones
CAMPEDS personal dust samplers

Reference: 2

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Tramming+	1.74	.98	-
Drifting+	1.96	2.50	-
Rock Bolting+	1.16	.60	-
Stope Drilling+	.82	.58	-
Diamond Drill+	.88	.50	-
Blasting+	.91	.40	-
Crushing+	3.10	.67	-
Conveyor belts+	1.10	-	-
Scoop=	2.41	1.51	-
Jumbo Drill=	1.93	1.73	-
Mini Borer=	1.66	.58	-

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* Area sampling.
\+ Personal sampling.
= Machine mounted sampler.

Table 4 - Average respirable dust (R.D.) measurements

Date: 1976

Place: Underground mine, load, haul, dump operations

% Quartz in Ore: >30%

Instruments Used: Casella 113A horizontal elutriators
CAMPEDS personal dust samplers

Reference: 3

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Scoop tram Op.=	3.33	1.74	.38
Draw point*	2.83	3.03	.46

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* Area sampling.
\+ Personal sampling.
= Machine mounted sampler.

Table 5 - Average respirable dust (R.D.) measurements

Date: 1976

Place: Underground mine

% Quartz in Ore: >30%

Instruments Used: H & H Aluminium cyclones
Casella 113A horizontal elutriators
CAMPEDS personal dust samplers

Reference: 4

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Mill Grinding*	.29	-	-
Crushing*	.20	-	.10
Stope Operations*	.42	-	.07
Raise Operations*	.62	-	.22
Mucking*	1.27	-	.06
Ore Pass Dump*	.58	-	.03

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* Area sampling.
+ Personal sampling.
= Machine mounted sampler.

Table 6 - Average respirable dust (R.D.) measurements

Date: 1976-77

Place: Underground mine

% Quartz in Ore: >30%

Instruments Used: Casella 113A horizontal elutriators
H & H Aluminium cyclones
CAMPEDS personal dust samplers

Reference: 5

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Drilling*	.72	.70	.03
Load, Haul, Dump (ST8)*	1.72	1.30	.16
Slushing*	.73	.37	.11
Crushing*	.69	.37	.18

---

* Area sampling.
+ Personal sampling.
= Machine mounted sampler.

Table 7 - Average respirable dust (R.D.) measurements

Date: 1978
Place: Underground mine
% Quartz in Ore: 65%
Instruments Used: CAMPEDS personal dust samplers

Reference: 6

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Drilling*	.57	-	.027
Mucking*	.80	-	.065
Other Mining Op.*	.67	-	.082

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* Area sampling.
\+ Personal sampling.
= Machine mounted sampler.

Table 8 - Average respirable dust (R.D.) measurements

Date: 1978

Place: Underground mine

% Quartz in Ore: 65%

Instruments Used: CAMPEDS personal dust samplers

Reference: 6

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Drilling*	.54	-	.111
Mucking*	.56	-	.114
Other Mining Op.*	.59	-	.106

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* Area sampling.
+ Personal sampling.
= Machine mounted sampler.

Table 9 - Average respirable dust (R.D.) measurements

Date: 1980

Place: Underground mine

% Quartz in Ore: 65%

Instruments Used: SIMQUADS personal dust samplers

Reference: 7

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Stope and Raise Op.*	.58	-	.17

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* Area sampling.
\+ Personal sampling.
= Machine mounted sampler.

Table 10- Average respirable dust (R.D.) measurements

Date: 1980
Place: Underground mine
% Quartz in Ore: 65%
Instruments Used: SIMQUADS personal dust samplers

Reference: 8

Operation	Total R.D. (mg/m^3)	Combustible R.D. (mg/m^3)	Quartz R.D. (mg/m^3)
Stope Operation*	.44	-	.05

---

* Area sampling.
\- Personal sampling.
= Machine mounted sampler.

Table 11 - Average respirable dust (R.D.) production

Date: 1973

Place: Underground mine

% Quartz in Ore: 65%

Instruments Used: Casella 113A horizontal elutriator
Casella 13040 cyclone

Reference: 9

Operation	Total R.D.	Combustible R.D. (mg/ton)* or (mg/ft drilled)+	Quartz R.D.
Drilling+	30	27	2
Blasting*	1300	160	320
Mucking*	100	90	12
Slushing*	45	5	32
Chute Loading*	38	15	9
Crushing*	670	20	445

All samples obtained through area sampling.

Table 12 - Average respirable dust (R.D.) production

Date: 1974

Place: Underground mine

% Quartz in Ore: 35%

Instruments Used: SIMQUADS personal dust samplers

Reference: 10

Operation	Total R.D.	Combustible R.D.	Quartz R.D.
	(mg/ton)* or (mg/ft drilled)+		
Crushing*	133	-	17
Mucking*	290	206	30
Drilling+	42	21	2.2

All samples obtained through area sampling.

Table 13- Average respirable dust (R.D.) production

Date: 1974

Place: Underground mine

% Quartz in Ore: -

Instruments Used: SIMQUADS personal dust samplers

Reference: 11

Operation	Total R.D.	Combustible R.D.	Quartz R.D.
		(mg/ton)* or (mg/ft drilled)+	
Jack Leg Drill+	86	10	22
Slushing*	128	39.5	25.3
Jumbo Drill+	1230	1090	23
Mucking*	136	43	23
Ore Pass Dump*	116	7	18

All samples obtained through area sampling.

Table 14- Average respirable dust (R.D.) production

Date: 1974
Place: Mill
% Quartz in Ore: 30%
Instruments Used: SIMQUADS personal dust samplers

Reference: 12

Operation	Total R.D. (mg/ton)* or (mg/ft drilled)+	Combustible R.D.	Quartz R.D.
Autogenous Milling*	47→56	-	8.5→11.5
Pebble Milling*	4→6	-	4→4.5
Magn. Separator*	0.7→1.8	-	0.25→0.4
Flotation*	1.7→5.0	-	0.4→1.0
Balling Drum*	14	-	-

All samples obtained through area sampling.

Table 15 - Average respirable dust (R.D.) production

Date: 1975

Place: Underground load, haul, dump operations

% Quartz in Ore: –

Instruments Used: SIMQUADS personal dust samplers

Reference: 3

Operation	Total R.D.	Combustible R.D. (mg/ton)* or (mg/ft drilled)+	Quartz R.D.
ST-8 Loading (wet)*	61	76	21
ST-8 Loading (dry)*	280	330	59

All samples obtained through area sampling.

Table 16 - Average respirable dust concentration for various operations. Averages obtained from data gathered in a seven year period between 1973 and 1980.

Operation	Total R.D.	Combustible R.D. (mg/m^3)	Quartz R.D.
Stope, Raise and Drift Operation	.75 ± .40	.51 ± .18	.10 ± .06
Jumbo Drilling	1.93	1.73	-
Longhole Drilling	1.25	-	-
Diamond Drilling	0.88	.50	-
Load, Haul, Dump, Mucking, Slushing	1.47 ± .95	1.49 ± .89	.17 ± .16
Crushing	1.33	.52	.14
Overall Average	1.14 ± .82	1.13 ± .79	.13 ± .12

Table 17 - Average respirable dust production for various underground operations. Averages obtained from data gathered in a three year period between 1973 and 1976.

Operation	Total R.D.	Combustible R.D.	Quartz R.D.
	(mg/ton)* or (mg/ft drilled)+		
Stope, Raise, Drift (drill)+	53	19	9
Load, Haul, Dump, Mucking, Slushing*	133 ± 93	90 ± 109	25 ± 15
Crushing*	133	-	-
Jumbo Drilling+	1230	1090	23

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