FEEDBACK OF CLEANED EXHAUST AIR INTO WORKPLACE ATMOSPHERES—EXPERIENCES ON TESTING EQUIPMENT

HELMUT BLOME, Dr. • Manfred Heimann • Wolfgang Pfeiffer
Occupational Safety Institute—BIA, Sankt Augustin, FRG

Under defined conditions, the feedback of cleaned exhaust air into workplace atmospheres is approved in the industry of the Federal Republic of Germany. Requirements to be met by capturing and precipitating systems are stipulated in technical regulations. These regulations differentiate according to:

- dust collecting machines and instruments for mobile use and
- central exhaust systems.

Dust collecting machines and instruments have to fulfil the conditions of a technical test. Occupational Safety Institute (BIA) is an authorized test institute for industrial vacuum cleaners, exhaust sweeping machines and dust collectors. Industrial vacuum cleaners and exhaust sweeping machines are used for the removal of deposited dust. Dust collectors are used for the exhaustion and precipitation of suspended dust emitted from individual dust sources. Technical requirements to be met by these systems were stipulated in 1973 for the first time. Since then, a total of 450 systems has been tested, about 50 percent of them being industrial vacuum cleaners and 33 percent dust collectors. Acccording to the size of these devices, suction volume flows range from about 100 to 4000 $m^3 \cdot h^{-1}$ (see Table I).

Table I
Dust Removal Equipment

equipment	application	exhaust flow rate $[m^3 \cdot h^{-1}]$	tested equipments number	tested equipments [%]
industrial vacuum cleaner	sucking up of deposite dust	100 - 1.000 (7.000)	220	49
exhaust sweeping machine		200 - 1.000	82	18
dust collector	sucking off of airborne dust on machines	80 - 4.000 (11.000)	148	33
		Summary (1973 - 8/88) :	450	100

Table II contains a survey of dust technique demands on these instruments. According to their use for the removal of dust of variable nocuousness, instruments are graded in different categories (dust classification). In general, demands increase from the top to the bottom of the list mainly referring to the required throughput.

With the exception of category L, the specific load per unit filter surface must not exceed 200 $m^3 \cdot m^{-2} \cdot h^{-1}$. In addition to requirements concerning the effects, demands with regard to the construction rise as well beginning at category L and ending with category V.

Any dust capturing machine has to be equipped with precipitators primarily supposed to protect the main filter from being damaged by sharp-edged or pointed objects.

Precipitators are frequently combined with dust collecting containers or are integral elements of them.

With the exception of category L, any system has to be provided with a control device.

1. Indicating in industrial vacuum cleaners the decrease of the average air velocity in the exhaust tube below 15 $m \cdot s^{-1}$ (in this case, dust transport would no longer be maintained);
2. Indicating in exhaust sweeping machines that the low pressure in the broom chamber decreases below 50 $N \cdot m^{-2}$ so that dust may be emitted;
3. Ensuring in dust collectors that the volume flow—adjusted to the dust source—does not fall short of the required minimum. This function can be performed for instance by a suction air control flap installed between capturing element and dust collector system. The control flap is supposed to switch off the dust source (e.g. a brake lining processing machine) when the adjusted minimum value is reached.

The cleaning of systems graded in categories H, T and C is intended to separate the dust deposited on the filter and to transport it to the collecting basin. If filter change is possible without dust production, easy-change filters—obligatory for systems of category V—can be used alternatively.

Dust of systems in categories T, C and V has to be disposed of without dust occurrence, for example using densely locking,

Table II
Dust Removal Equipment
Effective Requirements

dust class	dust with limit values for occupational exposure	example	degree of penetration [%]	flow rate per m^2 filter plane [$m^3 \cdot m^{-2} \cdot h^{-1}$]
L - light	> 1 [$mg \cdot m^{-3}$]	chalk	< 5	≤ 500 (≤1000)
H - hazard	> 0,1 [$mg \cdot m^{-3}$] incl. L	quartz	< 1	≤ 200
T - toxic	toxic incl. L and H	lead	< 0,5	≤ 200
C - cancer	carcinogenic incl. L, H and T	asbestos	< 0,1	≤ 200
V - virus	pathogens incl. L, H, T and C	virus	< 0,05	≤ 200

robust plastic boxes incorporated in dust collecting containers.

Density checking of systems and the checking of operating instructions are important since dust disposal without risk cannot solely be ensured by construction measures but frequently is only possible in combination with instruction and their observation.

Systems are provided with a certificate of three years validity which certifies the suitability for the specific category of clean air feedback after each of dust technique requirements has been met.

At the beginning, BIA only tested requirements regarding dust technique. Since 1979, noise emission of machines and instruments has been checked as well.

Increasingly, manufacturers are demanding an overall safety technique test including mechanical and electrical safety. In case of positive test results, BIA certifies the fulfilment of any presently valid safety technique condition. Each year, the institute publishes a list of systems tested with positive results. At present, about 90 percent of devices meet overall safety technique requirements.

Small dust collectors—referred to the space volume of workplaces—are in general operated with low air volume flows. In accordance with valid regulations, air recycled from small dust collectors must only amount to 1/10 of the fresh air volume flow for working areas.

When different exhaust devices are connected with a central dust capturing system and exhaust air has to be fed back to workplace atmosphere after cleaning, the conditions are different. In this case, the proportion of recycled air is mostly distinctly above 1/10 of the fresh air volume flow.

The cleaned air of stationary dust collectors can only be fed back to working areas after having obtained the permission of authorities in charge of occupational protection or of professional associations. Permission is granted under the condition that the quartz fine dust concentration in cleaned air does not exceed 1/3 of the maximum workplace concentration value. Since a permanent control of quartz fine dust concentrations in recycled air is hardly realizable by technical means, an evaluation of systems after initial operation has to ensure that the required threshold value is not exceeded and that this condition can be constantly maintained.

In general, systems are evaluated after a certain period of operation. This time comprises between 4 and 6 weeks, i.e. when filters in the precipitator obtain their optimum efficiency.

An assessment of the system includes the concentration determination in recycled air and in workplace atmospheres. At the same time, the accordance of system performance data (volume flow, pressure etc.) with actual values (nomimal values) is checked.

Parallel to measurements of recycled air, quartz fine dust concentrations in workplace atmospheres are determined to control whether emitted dusts are sufficiently captured by exhausting equipment. If threshold values for quartz fine dust in workplace atmospheres as well as in recycled air are observed, an exceptional permission for operating the systems with clean air feedback is given.

An exceptional permission is not granted if technical data of the collector do not guarantee a permanently safe observation of threshold levels for clean air. Cleaning type of precipitating elements (filters) and the so-called load per unit filter surface (air volume flow, referred to filter surface) are essential.

The pressure drop within the precipitator increases if dust deposits on filter elements grow higher. If dust is not extracted on time the suction volume may decrease due to higher pressure loss, thus deteriorating dust capture.

The risk of a higher dust exposure by reduced capturing degrees is the consequence.

Precipitating elements can either be cleaned continuously during operation (on-line cleaning) or discontinuously while out of operation (off-line cleaning). Continuous cleaning is mainly performed by a pressure drop-dependent control system or by a time control system. Discontinuous cleaning demands the observation of the maximum pressure loss between cleaning intervals stipulated for proper operation. To maintain the safe function of systems a continuous cleaning is preferable. The pressure loss in units that are discontinuously cleaned has to be registered and indicated. If pressure loss increases above maximum level, suitable measures to prevent risks have to be taken. For example, a special control system interrupts dust emitting procedures and restarts them after cleaning.

Another parameter of operational safety is the filter surface load. A too high filter surface load results in:

- premature filter wear and
- worse characteristics to cleaning.

Filter surface load must not exceed levels between 80 and 100 $m^3 \cdot m^{-2} \cdot h^{-1}$.

Test Results of Dust Measurements

BIA has performed numerous measurements in various industrial plants. Clean air as well as harmful material concentrations in workplace atmospheres were measured to evaluate the efficiency of dust capture in addition to dust precipitation.

1. Workplace atmospheres in foundry iron casting cleaning rooms.

   After 7 foundries had been found to exceed the levels of workplace concentrations, new exhaust systems recycling clean air were installed. The evaluation showed average fine dust concentrations of 0.43 mg/m³ and average quartz fine dust concentrations of 0.017 mg/m³ in cleaned air. Levels varied between 1.33 mg/m³ and 0.03 mg/m³ for fine dust concentrations and between 0.05 mg/m³ and 0.004 mg/m³ for quartz fine dust concentrations.

   Measuring results showed the observation of concentration threshold values for recycled air, partly the levels were even distinctly below these limits.

Measuring values for workplace atmospheres varied between 1.5 mg/m^3 and 0.3 mg/m^3 for the fine dust concentration and between 0.16 mg/m^3 and 0.03 mg/m^3 for the quartz fine dust concentration, thus proving the efficiency of exhaust systems.

2. Workplace atmospheres in rooms for the hand-grinding of quartz containing construction elements.

   In some inspected enterprises, grinding was performed in front of an exhaust wall with water screen. Dust included in suction air was supposed to be precipitated in the water screen. The air cleaned in this way was led to workplace atmospheres via a mist collector. Concentration measurements in the whole working room showed the following results: the average fine dust concentration was 1.5 mg/m^3, the quartz fine dust concentration of 0.3 mg/m^3 was on the average twice higher than that of the maximum workplace concentration value of 0.15 mg/m^3. In recycled air a fine dust concentration of 1.6 mg/m^3 and a quartz fine dust concentration of 0.32 mg/m^3 were measured. This outcome was the reason to demand the system to be improved.

   The exhaust wall was replaced by a cabin. Subsequent measurements had the following results: in the working area, the fine dust concentration could be reduced to 0.11 mg/m^3 on the average and the quartz fine dust concentration to 0.01 mg/m^3. At the same time, the fine dust concentration of recycled air decreased to 0.1 mg/m^3 and the quartz fine dust concentration to 0.004 mg/m^3 compared to the approved quartz fine dust clean air concentration of 0.05 mg/m^3 (1/3 of the maximum workplace concentration value). The outcome was decisive for granting an exceptional permission to operate the system since the limits for clean air as well as those for workplace atmospheres were observed.

EXPOSURES OF END-USERS TO AIRBORNE CONCENTRATIONS OF FIBROUS GLASS DURING INSTALLATION OF INSULATION PRODUCTS AND FABRICATION OPERATIONS

C.W. AXTEN* • J.R. Bender* • P.F. Aubourg† • T.R. Jabobs† • M.R. Kalinowski† • E.J. Klotz†

*Owens-Corning Fiberglas Corp., Fiberglas Tower, T/11, Toledo, OH 45659
†Owens-Corning Fiberglas Corp., Technical Center, P.O. Box 415, Granville, OH 43023, USA

INTRODUCTION

Owens-Corning Fiberglas has supported for many years a comprehensive industrial hygiene program for the evaluation of employee exposures to fibrous glass and other airborne contaminants in the Corporation's manufacturing facilities. We have also collected and analyzed data on the exposures of end-users of the Company's products.

In order to expand the data on end-users, an extensive study of end-users' exposures to fibrous glass during the installation, fabrication, and use of the Company's products was instituted. This paper presents the results of this study, and compares exposures observed in end use applications to those normally seen in manufacturing situations.

MATERIALS AND METHODS

Several hundred paired personal and area samples were collected in parallel on 0.8 micron pore size mixed cellulose ester filters mounted in 37 mm diameter polystyrene plastic cassettes with 16 mm non-electrically conductive extension cowls (i.e. NIOSH P&CAM 239 sampling method[1]) and in 25 mm diameter polystyrene plastic cassettes with 50 mm electronically conductive extension cowls (i.e. NIOSH 7400 sampling method[2]). This correlative sampling was performed since the majority of fibrous glass monitoring results obtained in the "in-plant" program were collected using the NIOSH P&CAM 239 Procedure. It was felt that if comparisons were to be made between the "in-plant" and end-user data, both sampling methodologies should be employed.

During the initial phase of the study, additional samples were collected using 0.45 polycarbonate filters mounted in 37 mm diameter cassettes with 16 mm extensions cowls. However, this approach was quickly discontinued due to the poor fiber retention (i.e. fibers were collected but were easily dislodged during transportation).

All samples were collected at a flow rate of two liters per minute (i.e. 2.0 1/m) using constant flow sampling pumps. The pumps were calibrated, with the filter and sampling train in line, before and after sampling using a precision rotameter calibrated against a primary standard (i.e. soap bubble meter for volumetric rate of air flow).

Applications sampled included installation operations involving traditional insulation products (i.e.batts, blankets, rolls, and loose fill insulation); and fabrication operations involving duct board, duct liner and other industrial products (e.g. range insulation, mobile home insulation, etc.). Both residential and commercial sites were evaluated.

All sample filters were mounted using the acetone/triacetin clearing method and analyzed via phase contrast optical microscopy (PCOM) at a magnification of 400X. Fiber counts for all sample filters were derived utilizing the procedures specified in both the NIOSH P&CAM 239 method as well as the NIOSH 7400 "A" method (i.e. all fibers > 5 microns in length with aspect ratios equal to or greater than 3:1 were counted). Glass fibers were differentiated from other fibers by morphology and shape recognition. For fibers that could not be easily identified by phase contrast microscopy, the samples were cross checked using polarized light microscopy. Additionally, fiber length and diameter measurements were determined for some of the samples.

To address fiber adherence to the sampling cowls, after filter removal, all cowls were rinsed with 25% isopropanol in distilled water. Rinse solutions were then filtered through 0.4 micron polycarbonate filters, and analyzed using the counting procedures described above.

To determine if some of the glass fibers present on the filters were too fine to be detected by optical microscopy, 40 filters were also counted by scanning electron microscopy. Two randomly chosen samples were also counted by transmission electron microscopy. Both analyses incorporated the "A" counting rules.

After all sample results had been obtained, matched pair results were analyzed statistically to determine differences between the 37 and 25 mm diameter filters. Natural log transformed data were used to determine statistical difference at the 0.05 significance level.

RESULTS AND DISCUSSION

The sample results obtained from this study are presented in Tables I and II and Figures 1 and 2. Because a significant concentration of fibers were found adhering to the sidewalls of the cassettes (i.e. NIOSH P&CAM 239 Procedure) and to the sampling cowls (NIOSH 7400 Procedure), these fibers were

Table I

Total Airborne Fiber Concentrations
Obtained by Using the NIOSH P&CAM 239 and 7400 "A" Methods
(Combined), Fibers per Cubic Centimeter

ITEM	ALL FIBERS							
	Filters				Filters and Cowls			
	# Samples	Exp. Value	95% LL	95% UL	# Samples	Exp. Value	95% LL	95% UL
Plants	75	0.024	0.018	0.030	71	0.031	0.020	0.043
Batts - Installers	60	0.17	0.12	0.22	60	0.24	0.18	0.31
Loose Fill Loaders								
Cubed	86	0.23	0.19	0.28	85	0.37	0.31	0.43
Milled	18	0.37	0.20	0.56	18	0.56	0.34	0.81
Loose Fill Installers								
Cubed	88	0.75	0.66	0.83	87	1.0	0.87	1.1
Milled	20	0.91	0.51	1.4	20	1.3	0.77	1.8

Table II

Total Airborne Fiber Concentrations
Obtained by Using the NIOSH P&CAM 239 and 7400 "A" Methods
(Combined), Fibers per Cubic Centimeter

ITEM	ALL FIBERS							
	Filters				Filters and Cowls			
	# Samples	Exp. Value	95% LL	95% UL	# Samples	Exp. Value	95% LL	95% UL
Fabricators	44	0.11	0.083	0.14	44	0.15	0.11	0.19
Metal Building Ins	26	0.034	0.026	0.042	26	0.045	0.030	0.059
Mobile Home	20	0.11	0.052	0.17	20	0.17	0.096	0.24
Pipe	19	0.12	0.067	0.18	19	0.16	0.085	0.23
Range	25	0.054	0.034	0.075	25	0.069	0.041	0.097
Duct Liner	24	0.024	0.013	0.036	24	0.030	0.013	0.048
Water Heater	13	0.037	0.022	0.053	13	0.047	0.022	0.071
Flex Duct	60	0.062	0.049	0.074	60	0.078	0.060	0.096

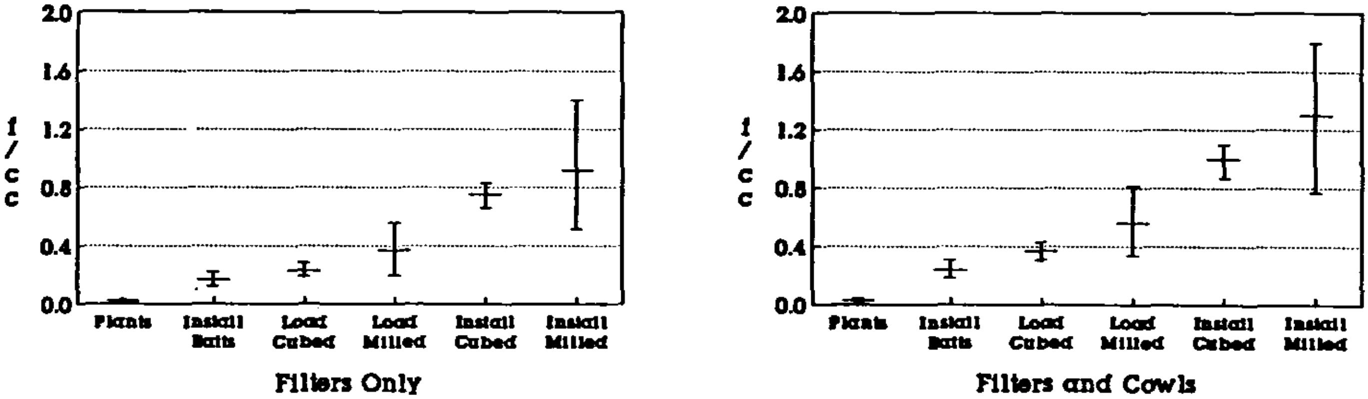


Figure 1.

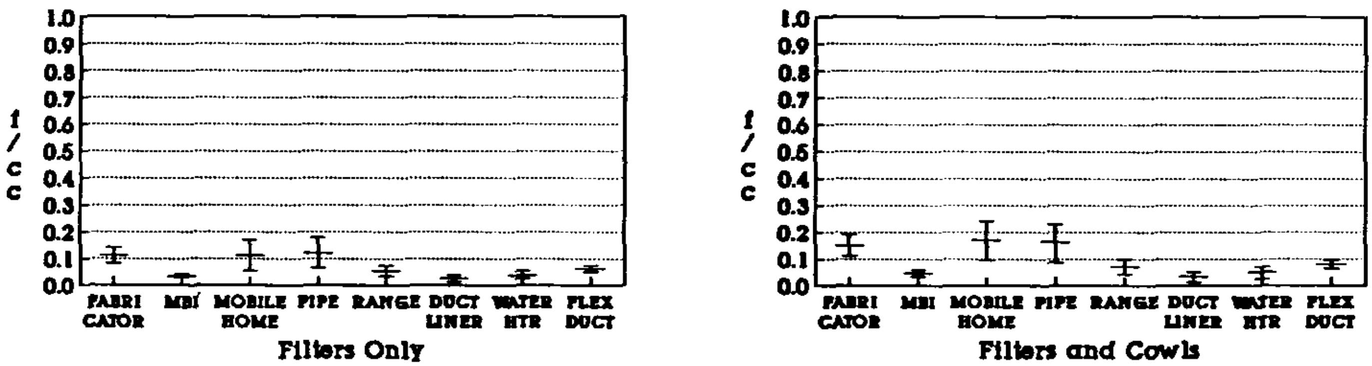


Figure 2.

also counted. Results are reported as filter only and as filter and cowl combined. Statistical analysis indicated that there was no difference between the total fiber results obtained from the NIOSH P&CAM 239 and 7400 methods using the "A" counting rules for either filters only or filter and cowls combined. Therefore, results from the two sampling methodologies were combined for the data summary and statistical analysis.

As indicated in Table I and Figure 1, the mean total fiber (both glass fiber and all other fiber) exposures of employees in OCF production facilities involved in the manufacture of fibrous glass insulation products were 0.024 f/cc for filters only and 0.03 f/cc for filters and cowls combined. Further analyses revealed that 70 to 75% were glass fibers. Of the glass fibers, 60% were of a respirable size. (Respirable fibers are defined as those with diameters $<$ 3.5 microns, lengths of 5 to 250 microns, and length to diameter ratios of 3:1). These exposures are representative of 8-hour time weighted average exposures.

The mean total fiber (both glass fiber and all other fiber) exposures of individuals installing batt, blanket, and roll insulation was 0.17 f/cc for filters only and 0.24 f/cc for filters and cowls combined. Additional analyses revealed that 50% were glass fibers. Of the glass fibers, 75% were of a respirable size. As anticipated, loose fill loaders and installers were exposed to higher mean concentrations of total fiber in the range of 0.23 to 0.91 f/cc for filters only and 0.37 to 1.3 f/cc for filters and cowls combined, primarily due to the nature of the installation process. Additional analyses revealed that 50 to 75% were glass fibers. Of the glass fibers, 50 to 75% were of a respirable size. These exposures represent those measured during the actual installation operations and not during transportation and preparation activities. Therefore, actual 8-hour time weighted average exposures will be less than those reported above.

Exposures of employees involved in installing a variety of OCF products are indicated in Table II and Figure 2. Mean total fiber (both glass fiber and all other fiber) ranged from 0.024 f/cc to 0.12 f/cc for filters only and 0.03 to 0.17 f/cc for filters and cowls combined.

Scanning electron microscopy analysis of 40 samples, collected at OCF plants and during installation of OCF products, revealed that all fibers (i.e. length $>$ 5 micron and length to width ratio $>$ 3:1) are seen by phase contrast microscopy. Two samples analyzed by transmission electron microscopy also revealed that all fibers are seen by phase contrast microscopy.

CONCLUSIONS AND RECOMMENDATIONS

Total fiber exposures of both OCF insulation production employees and end users are appreciably lower than the NIOSH recommended exposure limit for glass fibers (i.e. 3 f/cc). Statistical analysis indicated that there was no difference between the total fiber results obtained from the NIOSH P&CAM 239 and 7400 methods using the "A" counting rules. A significant concentration of fibers were found adhering to the sidewalls of the cassettes (i.e. NIOSH P&CAM 239 Procedure) and to the sampling cowls (NIOSH 7400 Procedure).

There was no statistical difference between the total fiber results obtained from the NIOSH P&CAM 239 method when combining fibers counted from the filters and cassette sidewalls and the total fiber results obtained from the NIOSH 7400 method when combining fibers counted from the filters and cowls. Furthermore, scanning electron microscopy analysis revealed that all fibers (i.e. length > 5 micron and length to width ratio > 3:1) are seen by phase contrast microscopy. Additional research is needed on the optical microscopy methodologies for determining respirable fibers and for identifying glass fibers.

REFERENCES

1. Analytical Method P&CAM 239 for "Asbestos Fibers in Air" in *NIOSH Manual of Analytical Methods—Second Edition,* DHEW (NIOSH) Publication No. 77-157, U.S. Department of Health, Education and Welfare, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.
2. Analytical Method 7400 for "Fibers" in *NIOSH Manual of Analytical Methods—Third Edition,* DHHS (NIOSH) Publication No. 84-100, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health.

EXPOSURE OF WORKERS TO RESPIRATORY HAZARDS AT COLUMBUS COAL AND REFUSE MUNICIPAL ELECTRIC PLANT

IBRAHIM M. SOBEIH, MSPH

Columbus Health Department, Columbus, Ohio, USA

BACKGROUND

The Columbus Refuse and Coal Fired Municipal Electric Plant (RCFMEP) is the largest refuse derived fuel plant in the United States. It became operational in June of 1983. The facility occupies 52 acres, is made up of an eleven story boiler house, a shredder station and a crane area. The boiler house contains six balanced draft boilers where a mixture of 90:10 refuse and coal is burned to generate electricity with a maximum generating capacity of 90 megawatts. These boilers consume between 500,000–750,000 tons of refuse generated by Greater Metropolitan Columbus and Franklin County annually.

The plant is a 24 hour and 365 days per year operation with the majority of the work performed by three workshifts and a workforce of nearly 200 employees.

PROBLEM DESCRIPTION

The RCFMEP has striven to apply existing technologies to new uses, in this case the use of coal fired power equipment for reclaiming energy from refuse. The use of this ill-defined and constantly changing fuel has resulted in a work environment that presents numerous and varied worker exposures to both identified and unidentified contaminants. Since the primary fuel used is refuse, a reasonable assumption is that most anything that is likely to be discarded in the Columbus Metropolitan area and Franklin County, may at some time appear at the plant.

The processing and incinerating of refuse, mechanical and electrical maintenance of the plant, the disposal of the fly and bottom ash, and the production of steam to generate electricity causes a host of hazards to workers. These hazards include microbiological agents, heat, cold, noise, vibration, dust, heavy metals, pesticides, organics, dioxins, free silica and possibly asbestos in addition to stress and ergonomic problems.

Of these hazards free crystalline silica, respirable dust, cadmium, beryllium, arsenic, nickel, and chromium (total and hexavalent) are the respiratory hazards considered in this investigation which is a part of an ongoing comprehensive industrial hygiene and medical surveillance of the plant workforce. The reason for evaluating the adverse health effects and characterization of the airborne levels of these contaminants is their proven capability of causing injury to the lungs by either irritation, scarring or cancer formation.[7,8,9,10,11,12]

METHODOLOGY

Industrial Hygiene

Respiratory hazards under investigation have been chosen based upon analytical results of bulk ash and dust samples collected by NIOSH investigators from eight locations in the plant during a survey in March 1985.[1] In this investigation, bulk ash and dust samples were analyzed for their content of thirty one chemical elements, free silica (quartz) and cristobalite. Cadmium, chromium, beryllium, arsenic, nickel, respirable dust and free silica (quartz) were chosen based upon their presence in the ash and dust, and their definite toxic nature against the pulmonary system.

To characterize levels of the airborne respiratory hazards under study in areas of the plant, the plant was divided into eleven major areas. They are the first floor—quench basins, second floor—boilers, third floor—electrostatic precipitators, first floor B—preheater room, fourth floor—refuse feed, fifth floor, seventh floor, ninth floor, crane area, shredder station and office. The workforce was divided into mechanical maintenance, electrical maintenance, crane operators and area workers, steam operating engineers, boiler operators, laborers-quench basins area, laborers-ash tunnels and system, laborers-shredder house, and laborers-refuse feed area. Mechanical maintenance group works in two twelve hour shifts, the shredder station is operational only for the day shift, office personnel work only the day shift, whereas the rest of the workforce performs the duties on the basis of three eight hour shifts.

Area air sampling was carried out during January, November and December of 1987 where as personal monitoring of the first shift was carried out during January, November and December of 1987 and once per month for 1988 and is an ongoing process to the end of this year. Second and third shifts have been monitored since January of 1988 and will continue to the end of this year.

Respirable dust, free silica (quartz), cadmium, arsenic, nickel, beryllium, chromium (total) and chromium VI were air sampled. These samples were shipped and analyzed by NATLSCO Industrial Hygiene Laboratory in Chicago, Illinois, for the period prior to June 30, 1988 and Clayton Environmental Consultants Industrial Hygiene Laboratory in Novi, Michigan beginning July 1, 1988. Sampling and analysis were performed according to NIOSH Manual of Analytical Methods, third edition.[2]

Medical Surveillance

New workers are screened during the probationary period of employment with emphasis on the respiratory and cardiovascular systems by means of posterior-anterior X-ray, pulmonary function testing, electrocardiogram and blood chemistry to determine the health status of the worker and his/her ability to use a respirator and work with the forementioned hazards. Emphasis are on new workers at this point where nearly 50 workers have been examined. Eventually all employees, permanent and new, will undergo medical evaluation to establish baseline medical data to be followed by an annual follow-up, the purpose of which is to prospectively follow the health of all workers.

STANDARDS AND CRITERIA OF EXPOSURE

Threshold Limit Values (TLVs) of the American Conference of Governmental Industrial Hygienists (ACGIH),[3] National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limits (RELs)[4] and the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs)[5] are the sources of standards and criteria of exposure. Table I shows the three standards of exposure to cadmium, nickel, arsenic, chromium-total, chromium VI, respirable dust, beryllium and crystalline free silica (quartz).

RESULTS AND DISCUSSION

Evaluation of airborne arsenic, cadmium, total chromium, beryllium, nickel, respirable dust and free silica in several locations in the plant was attempted to try to detect gross variations in the airborne levels of these contaminants in those areas (Tables II and III). These contaminants were either not detected or below their respective OSHA PELs, NIOSH RELs and ACGIH TLVs and without significant variations between areas. Therefore the idea of characterizing workers' exposure on the basis of estimating area airborne levels of contaminants was abandoned.

Evaluation of workers' exposure to the forementioned contaminants on the basis of breathing zone or personal sampling proved to be more useful. Since the plant operation is a 24 hour operation with work performed in three 8-hour workshifts in the most part, evaluation of personnel was performed accordingly. Concerning workers' exposure to hexavalent chromium, airborne levels of chromium VI were within the OSHA PEL-TWA of 400 $\mu g/m^3$ and ACGIH TLV-TWA of 50 $\mu g/m^3$ for the three shifts and all worker groups (Table IV). However, the NIOSH REL-TWA of 1 $\mu g/m^3$ was exceeded in several samples. First shift mechanical maintenance, laborers-quench basin, laborers-shredder house personnel exposure exceeded the NIOSH REL-TWA with levels of 2.2, 1.8 and 1.2 $\mu g/m^3$ respectively. Of the second shift personnel only steam operating engineers group exceeded the NIOSH REL-TWA at 2.7 $\mu g/m^3$, whereas in the third shift only laborers-ash system group exceeded NIOSH REL-TWA at 1.9 $\mu g/m^3$. A 1985 NIOSH study reported chromium VI levels of ND-.8 $\mu g/m^3$ from 25 samples with none of the levels exceeding the three standards.[1]

Breathing zone samples of the three shifts showed that all airborne arsenic levels fall below the OSHA PEL-TWA of 10 $\mu g/m^3$ and ACGIH TLV-TWA of 200 $\mu g/m^3$ (Table V A). However, the NIOSH REL-TWA of 2 $\mu g/m^3$ was exceeded once where a second shift boiler operator breathing zone sample showed arsenic levels of 5.8 $\mu g/m^3$. The Industrial Commission of Ohio Survey of August 1984 showed levels of arsenic of 0.8–54 $\mu g/m^3$ in five samples where ACGIH

Table I

Standards and Exposure Evaluation Criteria

CONTAMINANT	NIOSH REL-TWA (ug/m3)	OSHA PEL-TWA** (ug/m3)	ACGIH TLV-TWA (ug/m3)
Cadmium	40	200	50
Arsenic	2	10	200
Nickel	15	1,000	1,000
Chromium VI	1	100	50
Beryllium	0.5	2	2
Chromium (Total)*	25	1,000	500
Respirable Dust	5,000	5,000	5,000
Crystalline Silica (Quartz)	50	100	100

* Includes chromium metal, chromium II compounds and chromium III compounds as chromium

** Revised exposure limit published by OSHA June 7, 1988

Table II
Area Air Samples of Arsenic, Cadmium, Total Chromium, Beryllium and Nickel

AREA	n	DURATION RANGE (MINUTES)	CONCENTRATION RANGE (ug/m3)				
			ARSENIC	CADMIUM	CHROMIUM	BERYLLIUM	NICKEL
First Floor-690 Level Quench Basins	2	422-476	0.18-0.23	ND-0.29	0.34-0.77	ND	ND-0.58
Second Floor-713 Level Boiler Floor	2	420-470	0.078-0.12	0.087-0.099	ND-2.3	ND	ND-0.18
Third Floor-723 Level Electrostatic Precipitators	2	415-462	0.080-0.62	0.92-.94	ND-1.6	ND	0.37-0.64
Fourth Floor-735 Level Refuse Feed & Boilers	3	404-460	0.038-0.091	ND-0.1	ND-1.5	ND	ND
Fifth Floor-757 Level	1	458	0.16	0.10	0.4	ND	ND
Seventh Floor-775 Level	2	391-452	ND-0.14	0.099-0.10	0.5-1.6	ND	ND
Eighth Floor-785 Level	2	380-440	ND-0.043	ND-0.043	1.0-1.4	ND	ND-.31
Nineth Floor-799 Level	2	388-447	ND-0.16	0.098-0.11	0.49-4.8	ND	0.20-0.32
Shredder House	3	372-453	ND-0.076	ND-0.11	ND-2.3	ND	ND-0.30
First Floor B-Preheater Room	1	420	0.30	0.095	1.1	ND	0.38
Office Area	1	387	ND	0.11	0.42	ND	0.21

ND - Not Detected

Table III
Area Air Samples of Respirable Dust and Free Silica (Quartz)

AREA	n	DURATION RANGE (MINUTES)	RESPIRABLE DUST RANGE (mg/m3)	SILICA (ug/m3)
First Floor - 690 Level	2	359 - 420	0.17 - 0.36	ND
Second Floor - Boiler Floor 713 Level	2	352 - 420	0.27 - 0.33	ND
Third Floor - Electrostatic Precipitators 732 Level	2	355 - 420	0.49 - 2.2	ND
Fourth Floor - 735 Level	3	350 - 420	0.013 - 0.72	ND
Fifth Floor - 757 Level	1	336	0.37	ND
Seventh Floor - 775 Level	2	327 - 400	0.22 - 0.29	ND
Eighth Floor - 785 Level	2	347 - 400	0.16 - 0.32	ND
Ninth Floor - 799 Level	2	323 - 396	0.29 - 0.59	ND
Shredder House	4	348 - 453	0.031 - 0.088	ND
First Floor B Preheater Room	1	420	0.066	ND

ND - Not Detected

Table IV
Personal Air Samples of Hexavalent Chromium for the Three Work Shifts

WORKER GROUP	n			DURATION RANGE (MINUTES)			CONCENTRATION RANGE (ug/m3)		
	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance	3	3	-	414-681	720-820	-	ND-2.2	ND-0.56	-
Laborers - Quench Basins	2	3	2	360-480	480	480	ND-1.8	ND-0.98	.30-.76
Crane Operators and Area	2	2	1	352-388	360	480	0.27-0.85	ND-.75	0.36
Boiler Operators	5	4	5	388-420	230-480	480	0.27-.82	ND-.94	ND-.73
Electrical Maintenance	3	1	2	392-400	480	464-480	ND-.54	ND	ND-.43
Laborers - Refuse Feed	2	2	3	396-420	480	480	.24-.45	ND-.47	ND-.38
Laborers - Shredder House	5	-	-	384-720	-	-	.31-1.2	-	-
Steam Operating Engineers	3	2	3	392-461	455-480	480	ND	ND-2.7	ND
Laborer - Ash System	2	1	2	400-420	480	261-480	0.33-0.54	0.38	.91-1.9

ND - Not Detected

* There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

Table V A
Personal Air Samples of the Three Work Shifts for Arsenic

WORKER GROUP	n			DURATION RANGE (MINUTES)			ARSENIC CONCENTRATION RANGE (ug/m3)		
	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance*	5	3	-	217-455	700-720	-	.14-.47	ND-.26	-
Electrical Maintenance	6	2	2	354-465	456-480	470-480	ND-.48	ND	ND
Steam Operating Engineers	4	2	3	420-476	480	381-480	ND-.11	ND	ND
Boiler Operators	6	3	5	321-477	480	401-480	ND-.41	ND-5.8	ND
Crane Operators & Area	4	2	1	420-473	360-480	480	ND	ND	ND
Laborers-Shredder House**	9	-	-	346-450	-	-	ND-.18	-	-
Laborers Quench Basins	5	3	3	291-491	480	369-480	ND-.21	ND-.60	ND-.81
Laborers Refuse Feed	2	2	3	420-450	480	335-480	ND	ND	ND-.25
Laborers-Ash System	4	2	1	320-480	359-480	480	0.10-0.70	.19-.40	.24

ND - Not Detected

* There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

arsenic standard was not exceeded. However, NIOSH standard was exceeded in three of four samples and OSHA standard was exceeded in two samples.[6] As for cadmium, airborne levels were all below the OSHA PEL-TWA of 200 $\mu g/m^3$ and with the exception of one sample all were below the NIOSH REL-TWA of 40 $\mu g/m^3$ (Table V B). The one sample that exceeded NIOSH REL-TWA described the exposure of a first shift electrical maintenance worker with 64 $\mu g/m^3$. On the other hand, all samples with the exception of two were below the ACGIH TVL-TWA of 5 $\mu g/m^3$, where a first shift electrical maintenance worker and a second shift boiler operator exposure exceeded ACGIH TVL-TWA at 64 and 11 $\mu g/m^3$ respectively. The NIOSH study showed airborne cadmium levels of ND-18 $\mu g/m^3$ in 38 samples with none of the samples exceeding the three standards.[1] The Industrial Commission of Ohio study reported airborne cadmium levels of 0.4–25 $\mu g/m^3$ in 5 samples with none of the levels exceeding the three standards.[6]

Total chromium airborne levels were at or below the NIOSH REL-TWA of 25 $\mu g/m^3$, the OSHA PEL-TWA of 1000 $\mu g/m^3$ and the ACGIH TVL-TWA of 500 $\mu g/m^3$ (Table V C). The Industrial Commission of Ohio study reported airborne total chromium levels of 0.4–15 $\mu g/m^3$ with none of the samples exceeding the three standards.[6] Similarly, beryllium airborne levels were below NIOSH REL-TWA of 0.5 $\mu g/m^3$, OSHA REL-TWA of 2 $\mu g/m^3$ and ACGIH TLV-TWA of 2 $\mu g/m^3$ for all shifts and worker groups (Table V D). For nickel, airborne levels were below the OSHA PEL-TWA and ACGIH TLV-TWA of 1000 $\mu g/m^3$ for all shifts and worker groups (Table V E). However, NIOSH REL-TWA of 15 $\mu g/m^3$ was exceeded twice where a first shift electrical maintenance worker and second shift boiler operator showed exposures of 16 and 24 $\mu g/m^3$ respectively. The NIOSH study reported airborne nickel levels of ND-11 in 38 samples where none of the samples exceeded the three standards.[4]

Respirable dust levels were below OSHA PEL-TWA of 5 mg/m^3, NIOSH REL-TWA of 5 mg/m^3 and ACGIH TLV-TWA of 10 mg/m^3 with the exception of two situations (Table VI A). In these two situations, a first shift electrical maintenance worker and a second shift worker in the cranes area were exposed to 1700 and 19 mg/m^3 respectively. The NIOSH study reported respirable dust levels of 0.09–14 mg/m^3 in 29 samples with only one sample exceeding the three standards.[1] As for crystalline silica (quartz), airborne levels of this contaminant were below the ACGIH TLV-TWA of 100 $\mu g/m^3$ and NIOSH REL-TWA of 50 $\mu g/m^3$ with the exception of one instance (Table VI B). In this situation a worker in the crane area was exposed to 220 $\mu g/m^3$.

It is obvious from the personal sampling data that exposure patterns are not highly unpredictable. This is true since the majority of employees do not perform the exact same duties and are not present in the exact same location every day. In addition, the major groups, mechanical maintenance, electrical maintenance, boiler operators rovers and steam operating engineers rovers perform duties that are different from one day to the next. Perhaps the most important factor

Table V B

Personal Air Samples of the Three Work Shifts for Cadmium

	n			DURATION RANGE (MINUTES)			CADMIUM CONCENTRATION RANGE (ug/m3)		
WORKER GROUP	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance*	5	3	-	217-455	700-720	-	ND-.92	ND-.79	-
Electrical Maintenance	6	2	2	354-465	456-480	470-480	ND-64	ND	ND
Steam Operating Engineers	4	2	3	420-476	480	381-480	ND	ND	ND
Boiler Operators	6	3	5	321-477	480	401-480	ND-.18	ND	ND
Crane Operators & Area	4	2	1	420-473	360-480	480	ND-.45	ND-11	ND-.54
Laborers-Shredder House**	9	-	-	346-450	-	-	ND	-	-
Laborers Quench Basins	5	3	3	291-491	480	369-480	ND-.38	ND-1.4	ND-1.4
Laborers Refuse Feed	2	2	3	420-450	480	335-480	ND	ND	ND-.11
Laborers-Ash System	4	2	1	320-480	359-480	480	ND-1.6	.21-.31	.45

ND - Not Detected

*- There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

Table V C
Personal Air Samples of the Three Work Shifts for Chromium

	n			DURATION RANGE (MINUTES)			CHROMIUM CONCENTRATION RANGE (ug/m3)		
WORKER GROUP	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance*	5	3	-	217-455	700-720	-	.30-14	.71-14	-
Electrical Maintenance	6	2	2	354-465	456-480	470-480	ND-16	ND-.23	ND-.55
Steam Operating Engineers	4	2	3	420-476	480	381-480	ND-2.9	ND-.22	ND-1.0
Boiler Operators	6	3	5	321-477	480	401-480	ND-25	ND-11	ND-1.6
Crane Operators & Area	4	2	1	420-473	360-480	480	ND-.53	ND	ND
Laborers-Shredder House**	9	-	-	346-450	-	-	ND-.98	-	-
Laborers Quench Basins	5	3	3	291-491	480	369-480	.51-2.6	.54-3.0	ND-2.7
Laborers Refuse Feed	2	2	3	420-450	480	335-480	ND-1.5	.15-.22	ND-1.1
Laborers-Ash System	4	2	1	320-480	359-480	480	.36-3.6	.23-1.7	ND

ND - Not Detected

* There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

Table V D
Personal Air Samples of the Three Work Shifts for Beryllium

	n			DURATION RANGE (MINUTES)			BERYLLIUM CONCENTRATION RANGE (ug/m3)		
WORKER GROUP	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance*	5	3	-	217-455	700-720	-	ND	ND	-
Electrical Maintenance	6	2	2	354-465	456-480	470-480	ND-.40	ND	ND
Steam Operating Engineers	4	2	3	420-476	480	381-480	ND	ND	ND
Boiler Operators	6	3	5	321-477	480	401-480	ND	ND	ND
Crane Operators & Area	4	2	1	420-473	360-480	480	ND	ND	ND
Laborers-Shredder House**	9	-	-	346-450	-	-	ND	-	-
Laborers Quench Basins	5	3	3	291-491	480	369-480	ND	ND	ND-0.1
Laborers Refuse Feed	2	2	3	420-450	480	335-480	ND	ND	ND
Laborers-Ash System	4	2	1	320-480	359-480	480	ND	ND	ND

ND - Not Detected

* There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

Table V E

Personal Air Samples of the Three Work Shifts for Nickel

WORKER GROUP	n			DURATION RANGE (MINUTES)			NICKEL CONCENTRATION RANGE (ug/m3)		
	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance*	5	3	-	217-455	700-720	-	ND-.46	.23-5.3	-
Electrical Maintenance	6	2	2	354-465	456-480	470-480	ND-16	ND-.23	ND
Steam Operating Engineers	4	2	3	420-476	480	381-480	ND-.19	ND	ND
Boiler Operators	6	3	5	321-477	480	401-480	ND-1.2	ND-24	ND-.36
Crane Operators & Area	4	2	1	420-473	360-480	480	ND-.71	ND	ND
Laborers-Shredder House**	9	-	-	346-450	-	-	ND-1.4	-	-
Laborers Quench Basins	5	3	3	291-491	480	369-480	ND-1.1	.23-2.8	ND-.72
Laborers Refuse Feed	2	2	3	420-450	480	335-480	.37-.92	ND-.30	ND
Laborers-Ash System	4	2	1	320-480	359-480	480	.16-.83	ND-.23	0.15

ND - Not Detected

* There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

Table VI A

Personal Air Samples of Respirable Dust and Free Silica for the Three Work Shifts

JOB TITLE/GROUP	n			DURATION RANGE (MINUTES)			RESPIRABLE DUST CONCENTRATION RANGE (mg/m3)		
	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance*	3	4	-	420-707	670-820	-	0.10-1.2	ND-3.1	-
Electrical Maintenance	6	2	2	373-447	480	480	ND-1700	ND-.069	ND-.048
Steam Operating Engineers	2	2	4	448-473	480	480	ND-.24	ND-.16	ND-.27
Boiler Operators	5	4	5	231-480	480	445-480	.24-.50	ND-.26	.073-.70
Crane Operators & Area	2	2	1	237-497	390-480	480	.065-.072	.39-19	.30
Laborers-Shredder House**	8	-	-	333-480	-	-	.11-.51	-	-
Laborers-690 Level	5	3	4	420-496	480	480	.30-.83	.20-.67	.13-.30
Laborers-4th Floor	3	2	2	420-447	480	480	ND-.22	ND-.08	.07-.20
Laborers-Ash System	5	1	2	420-497	480	480	.20-1.7	.20	.07-.30

ND - Not Detected

* There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

Table VI B

Personal Air Samples of Respirable Dust and Free Silica for the Three Work Shifts

JOB TITLE/GROUP	n			DURATION RANGE (MINUTES)			FREE SILICA CONCENTRATION RANGE (mg/m3)		
	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT	1ST SHIFT	2ND SHIFT	3RD SHIFT
Mechanical Maintenance*	3	4	-	420-707	670-820	-	ND	ND	_
Electrical Maintenance	6	2	2	373-447	480	480	ND	ND	ND
Steam Operating Engineers	2	2	4	448-473	480	480	ND	ND	ND
Boiler Operators	5	4	5	231-480	480	445-480	ND	ND	ND
Crane Operators & Area	2	2	1	237-497	390-480	480	ND	ND-220	ND
Laborers-Shredder House**	8	-	-	333-480	-	-	ND-31	-	-
Laborers-690 Level	5	3	4	420-496	480	480	ND	ND	ND
Laborers-4th Floor	3	2	2	420-447	480	480	ND	ND	ND
Laborers-Ash System	5	1	2	420-497	480	480	ND	ND	ND

ND - Not Detected

* There is no third shift, rather there are two 12 hour shifts

** Laborers of the shredder house work only the first shift

in the exposure of personnel is the unpredictably variable nature of the refuse which makes it impossible to establish definite exposure trends.

Medical surveillance of workers is still at an infant stage, where only approximately 50 new workers have been examined for the purpose of establishing baseline medical data. This data includes X-ray, pulmonary function testing, electrocardiogram and blood chemistry where the majority of workers examined have been found with normal health. The goal of this medical screening program is to eventually establish baseline medical data on all employees followed with an annual follow-up medical examination to prospectively follow trends in the health of all employees.

REFERENCES

1. U.S. Department of Health and Human Services (1986). *NIOSH: Health Hazard Evaluation Report of the City of Columbus Refuse Coal Derived Fuel Power Plant*, March 4-8 and 12-14, 1985.
2. U.S. Department of Health and Human Services. *NIOSH: Manual of Analytical Methods*, 3rd Ed., 1st and 2nd Volumes. 1984.
3. American Conference of Governmental Industrial Hygienists (1988). *Threshold Limit Values and Biological Exposure Indices for 1987–88.*
4. U.S. Department of Health and Human Services (1986). *NIOSH Recommendations for Occupational Safety and Health Standards.* Morbidity and Mortality Weekly Report Supplement, Vol. 35:#15.
5. U.S. Department of Labor (1985). *Code of Federal Regulations: Labor.* 29-parts 1900–1910, revised June 1988.
6. Industrial Commission of Ohio (1984). *Industrial Hygiene Survey: Refuse Coal Fired Municipal Electric Plant*, August 6–9, 1984.
7. U.S. Department of Health, Education and Welfare (1973). *The Industrial Environment—Its Evaluation and Control.*
8. Carson, B.L., Ellis III, H.V., McCann, J.L.: *Toxicology and Biological Monitoring of Metals in Humans.* Lewis Publishers, Inc., Chelsa, Michigan. 1986.
9. Williams, P.L, Burson, J.L.: *Industrial Toxicology: Safety and Health Applications in the Workplace.* Lifetime Learning Publications, New York. 1985.
10. Gosselin, R.E., Smith, R.P., Hodge, H.C.: *Clinical Toxicology of Commercial Products.* 5th Ed., Williams and Wilkins, Baltimore. 1984.
11. Klaussen, C.D., Amdur, M.O., Doull, J.: *Casarett and Doull's Toxicology: The Basic Science of Poisons*, 3rd Ed., MacMillan Publishing Company, New York. 1986.
12. Patty's Industrial Hygiene and Toxicology. *Toxicology: Heavy Metals*, 3rd Revised Ed., Volume 2A: 1493-2060. 1981.

COMPARISON OF NUMBER AND RESPIRABLE MASS CONCENTRATION DETERMINATIONS

T. TOMB • R. Haney

Mine Safety and Health Administration, Pittsburgh, Pennsylvania, USA

INTRODUCTION

Regulations pertaining to Safety and Health Standards for Surface Metal and Nonmetal Mines; and for Underground Metal and Nonmetal Mines in the United States are specified in Title 30, CFR, Parts 56 and 57, respectively. In these parts of Title 30, exposure limits for airborne contaminants are based on the Threshold Limit Values (TLV) adopted by the ACGIH (American Conference of Governmenta! Industrial Hygienists) as set forth and explained in the 1973 Edition of the Conference's publication, entitled "TLVs Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973." Exposure limits established in this edition for various mineral silicate dusts containing less than one percent quartz are based on the number of particles per cubic foot of air.

In the 1976 Edition of the "Threshold Limit Values for Chemical Substances in Workroom Air," limits based on the respirable mass of the dust per cubic meter of air that were supposedly equivalent to previously recommended limits based on the number of particles per cubic foot of air were published in Appendix G. The bases for establishing the equivalent mass concentration values were:

1. An empirical relationship, derived by Jacobson and Tomb,[1] that indicated 5.65 mppcf was approximately equal to 1 mg/m^3 of respirable dust sampled with an Isleworth Gravimetric Dust Sampler, Type 113A.[2]
2. A relationship of 6 mppcf = 1 mg/m^3 developed from a calculation that assumed that the average density for silica containing dust is approximately 2.5 grams per cubic centimeter and that the mass median diameter of particles collected in midget impinger samplers, (counted by the standard light field microscopic technique) and in respirable dust samplers is approximately 1.5 micrometers (μm).

In the 1986-87 Edition of the "Threshold Limit Values for Chemical Substances in Workroom Air" references to count standards were eliminated. Respirable mass standards listed were based on the above conversion or when a respirable hazard had not been documented a total dust standard of 10 mg/m^3 was adopted. Additionally the recommended standard for respirable talc dust was reduced from 3 to 2 mg/m^3. Documentation for the rationale of these changes has not been published.

Recognizing that an assessment based on a respirable mass limit would: be more relevant to the health hazard; provide a method of assessing the quality of an environment which is simpler; be less expensive and be more reproducible than the count method; MSHA investigated the validity of the equivalent respirable mass limits recommended. This investigation was principally performed to provide documentation to support any legal actions that would result from the use of the recommended limits as "equivalent" standards.

The purpose of this paper was to investigate the validity of the equivalent respirable mass concentrations recommended. To accomplish this a review of the rationale published in the 1976 and subsequent TLV Handbooks was made, "Documentation of the Threshold Limit Values" was reviewed and empirical relationships were derived from comparative measurements obtained with a long running midget impinger and a respirable dust sampler.

PROCEDURES

To develop the empirical relationships, comparative measurements with the midget impinger and respirable dust samplers were obtained at operations mining or processing natural graphite, perlite, mica, diatomaceous earth and talc (nonasbestiform). Although soapstone was another mineral of interest, at the time of the study, no soapstone mines were operational.

Samples collected with the midget impinger were analyzed for number concentration using light-field microscopy following the Bureau of Mines[3] standard microprojector technique. The results were reported as millions of particles per cubic foot. Respirable dust samples were weighed and the mass concentration of dust was determined and reported as milligrams of respirable dust per cubic meter of air sampled.

The respirable dust sampler was that typically utilized by MSHA's Metal and Nonmetal Mine enforcement personnel to assess the respirable mass concentration of dust in an environment. Airflow through the respirable dust sampling system was maintained constant at 1.7 liters per minute using either an MSA Model G, Bendix 3900 or Bendix BDX30 pump.

The various instruments used to obtain comparative measurements were assembled into a package. Each package contained two modified midget impinger samplers, two respirable dust samplers and a total dust sampler. The modification to the impinger consisted of replacing the standard

1 by 4.5 inch particle collection flask with a larger container that would permit extending the sampling time of the impinger from 20 minutes to four hours. Normally two packages, located at different sampling sites at a respective mineral processing operation, were used. The sampling time for comparative samples ranged from two to four hours. The number of comparative samples obtained for the respective minerals varied.

The total dust samples were collected with a sampling system similar to that used to collect the respirable dust samples, but without the 10 mm nylon cyclone attached. Total dust samples were also collected at a flow rate of 1.7 liters per minute. In addition to determining the total mass concentration of the aerosol in the environment, a representative number of the total dust samples collected were particle sized with a Model TA II Coulter Counter.

TREATMENT OF DATA

Empirical relationships between number concentration, in mppcf, and respirable mass concentration, in mg/m^3, were derived from the comparative measurements for the respective minerals using the method of least squares. For each mineral, the best fit regression line relating the measurements, standard error of estimate, $S_{y/x}$, and correlation coefficient, r, were calculated. The standard error of estimate provides a quantitative measure of the variability of the data about the regression line and the correlation coefficient provides a measure of the degree of linearity between the respective variables (number and mass concentration).

Equivalent respirable mass concentration values derived from the empirical relationships for each of the minerals were compared to the equivalent mass concentration limits specified in the 1976 TLV Handbook. In addition, respirable mass concentration equivalent values were calculated using the method given in the Handbook and the parameters required for that calculation; i.e., aerosol, density and mass median diameter (M'_g).

Data obtained from the Coulter Counter analysis of the total dust samples were used to characterize the size distributions of the aerosols sampled. Count-versus-size data were converted to mass-versus-size data mathematically for each aerosol. Cumulative mass-versus-size data were plotted on logarithmic-probability graph paper, and the mass median diameter (M'_g) and geometric standard deviation (σ_g) were determined using the graphic technique developed by Hatch and Choate.[4] The count median diameter (M_g) was then determined using the relationship:

$$\text{Log } M_g = \text{Log } M'_g - 6.9078 \text{ Log}^2 \sigma_g.$$

RESULTS AND DISCUSSION

Figures 1 through 5 graphically show the data for the comparative measurements obtained for the respective minerals, the regression lines relating the count and mass concentrations obtained and the standard error of estimate and correlation coefficient for each of the relationships derived. The data compiled on Table I are: the density of the respective aerosols; the recommended limits specified in the 1976 and 1986 TLV Handbooks; four count-to-mass ratios (R) derived from: (1) the recommended count and mass concentration limits specified in the Handbook; (2) the empirically derived regression equations; and, (3) and (4) the procedure given in the TLV Handbook using the M_g and M'_g valves that were determined to be representive of the respective aerosols sampled.

A comparison (Table I) was made of the ratio (R) between the count and mass concentrations (mppcf:mg/m^3) recommended

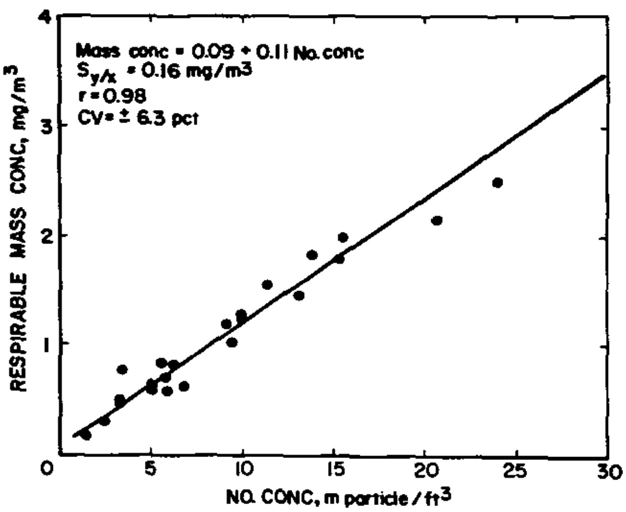


Figure 1. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two graphite processing operations.

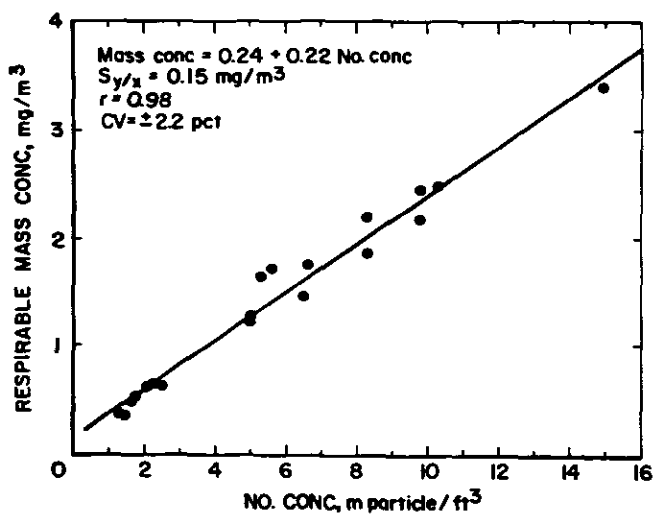


Figure 2. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two perlite processing operations.

in the TLV Handbook for the respective minerals and the ratios established from the empirical relationships and the calculation method using both the M_g' and M_g derived from the total dust samples. The comparison shows that only the empirically derived count to mass concentration ratio established for the mica and talc aerosols approximated the values recommended in the TLV Handbook. None of the ratios established from the calculation method agreed with the values recommended in the TLV Handbook or with the empirically derived values. It is apparent from the data that the M_g' or M_g established from a total dust sample measurement cannot be used to derive a factor for converting number concentration determinations to equivalent mass concentrations.

The method given in the TLV Handbook for calculating a factor based on the M_g' and density of the aerosol makes the implicit assumption that the size distribution of the aerosols is similar; however, as the data show, the M_g' and geometric standard deviation differ significantly for aerosols found in the same type of mineral operations as well as those established for different mineral processing operations. It should also be recognized that when using the calculation method recommended in the TLV Handbook, a 15 percent difference in the diameter used to calculate an equivalency factor can result in a difference in the calculated equivalency factor of greater than 60 percent. This is due to the fact that conversion from a count to a mass concentration is a function of the cube of the particle diameter.

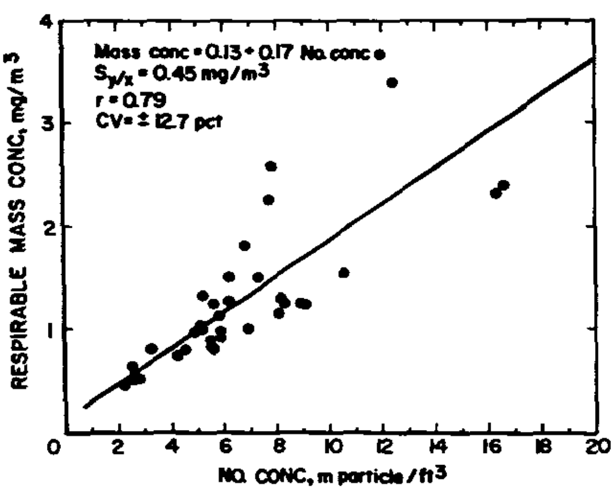


Figure 3. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two talc processing operations.

Review of the documentation, published in the 1976 TLV Handbook to arrive at, or substantiate, the value of "6" as the approximate factor used to obtain respirable mass concentration values equivalent to previously recommended number concentration values, showed that some of the supporting documentation is questionable. First, it is not clear which respirable dust criterion (that defined by the British Medical Research Council [BMRC] or by the ACGIH) was assumed to be followed by the respirable sampler when sampling the respirable fraction of the dust. The empirical relationship of 5.6 mppcf to 1 milligram per cubic meter of air was derived by Jacobson and Tomb,[1] from comparative measurements obtained with the midget impinger and the Isleworth Gravimetric Dust Sampler, Type 113A, an instrument that samples respirable dust according to the BMRC criteria. Mass concentration measurements obtained with a respirable mass sampler sampling respirable dust in accordance with the ACGIH criteria would be significantly lower. For coal mine dust, it has been shown[5] that the ratio between mass concentrations determined with an instrument sampling respirable dust with respect to the BMRC criteria and an instrument sampling with respect to the ACGIH criteria is 1.38.

Another questionable item deals with the statement that "the mass median diameter of particles collected in impinger samplers and counted by the standard light-field technique and

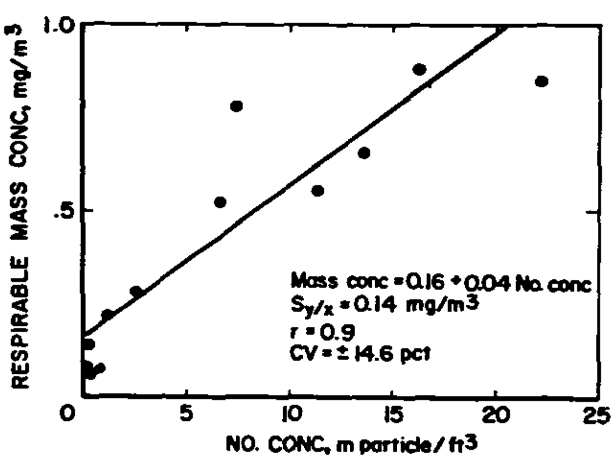


Figure 4. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two diatomaceous earth processing operations.

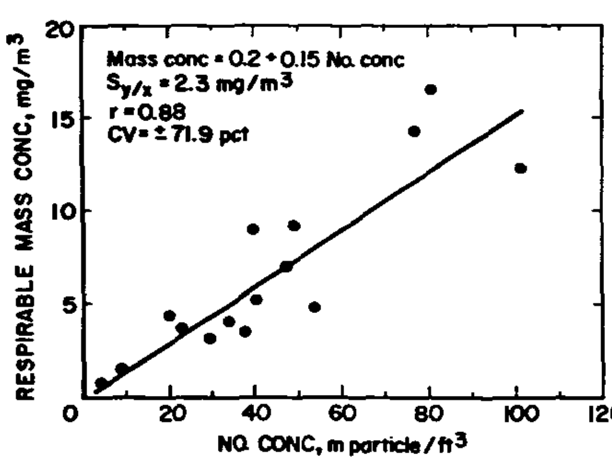


Figure 5. Comparison of dust concentrations obtained from midget impinger and respirable mass dust samples at two mica processing operations.

Table I
Comparison of Values (R) Obtained for Converting Count Concentration Data to Equivalent Mass Concentration Data

Aerosol	Density gm/cm^3	Recommended TLV Count, mppcf	Mass mg/m^3	R ($mppcf/mg/m^3$) TLV	Emp	Calc. (M_g)	Calc. (M_g')	Aerosol Parameters M_g	M_g'	σ_g
Graphite I	1.76	15	2.5(1)	6	9.8	-	1.46	0.07	2.76	3.16
Graphite II					8.8	-	0.54	0.02	3.84	4.65
Perlite I	2.30	30	5 (1)	6	4.4	260	0.05	0.45	7.57	2.64
Perlite II			10 (2)		3.2	0.15	0.004	5.36	18.56	1.92
Talc I	2.75	20	3 (1)	6.6	5.5	28	0.32	0.89	3.95	2.01
Talc II			2 (3)	10	5.3	660	0.05	0.31	7.49	2.80
Diatomaceous Earth	2.20	20	1.5(1) 10 (2)	13	21.7	45	0.05	0.82	7.98	2.38
Mica	2.80	20	3	6.6	6.6	116	0.05	0.55	7.50	2.55

M_g = Count Median Diameter.
M_g' = Mass Median Diameter.
σ_g = Geometric Standard Deviation.
EMP = R Derived from Empirical Relationship.
Calc. (M_g) = R Calculated Using Count Median Diameter.
Calc. (M_g') = R Calculated Using Mass Median Diameter.

(1) Respirable Dust Concentration Based on 1976 TLV Handbook.
(2) Total Dust Concentration Based on 1986-87 TLV Handbook.
(3) Respirable Dust Concentration Based on 1986-87 TLV Handbook.

Table II
Particle Size Distribution Parameters Derived from the 1 to 10 Micrometers Fraction of the Aerosols

Aerosol	Aerosol Parameters M_g	M_g'	σ_g	R ($mppcf/mg/m^3$) Calc. (M_g)	Calc. (M_g')
Graphite I	0.52	2.79	2.11	506	1.41
Graphite II	0.36	3.52	2.39	658	0.70
Perlite I	1.15	4.67	1.98	15.4	0.24
Perlite II	1.86	6.81	1.93	3.65	0.08
Talc I	1.31	3.42	1.76	8.74	0.49
Talc II	1.17	1.22	1.13	12.3	0.25
Diatomaceous Earth	1.97	5.14	1.76	3.21	0.18
Mica	1.42	4.61	1.87	6.60	0.20

M_g = Count Median Diameter.
M_g' = Mass Median Diameter.
σ_g = Geometric Standard Deviation.
Calc. (M_g) = R Calculated Using Count Median Diameter.
Calc. (M_g') = R Calculated Using Mass Median Diameter.

collected in a respirable sampler is approximately 1.5 μm." From the size distribution data obtained from the analysis of total dust samples in the size interval from 1 to 10 micrometers (Table II), and from comparing size distribution data from the Coulter Counter analysis of comparative total dust samples and impinger samples collected during these studies, it would appear that 1.5 μm would be more representative of the M_g than the M'_g. This is also supported by data obtained by Cooper[6] in the Public Health Service's study of the diatomaceous earth industry. It is also highly unlikely that the M'_g of the particles collected in the impinger sample would be the same as the M'_g of the particles collected in the respirable dust sampler because of the nonuniform selection process of the particle classifier on the respirable dust sampler.

The last questionable item has to do with the diameter used in the calculation method to calculate an equivalent mass concentration. The example specifies using the M'_g. It appears from the presentation and definition of various diameters presented by Reist,[7] that the diameter which should be used is the diameter of average mass; which is defined as representing the diameter of a particle whose mass times the number of particles per unit volume is equal to the total mass per unit volume of the aerosol. Although by definition this would appear to theoretically be the diameter to use, the recommended limits also could not be obtained when this diameter was used in the calculation method.

Based on the review of the documentation in the TLV Handbook and the relationships derived from comparative measurements obtained with the midget impinger and the personal respirable dust sampler, it is concluded that: (1) "6" is not a factor that should be universally used to convert number concentration data obtained from the analysis of midget impinger samples using light-field microscopic techniques to equivalent mass concentration data, (2) because of the variability that occurs in the size distributions of the aerosols sampled (even in the 1 to 10 micrometer size fraction), it is unlikely that a single parameter characterizing an aerosol can be used to calculate an equivalent mass concentration; and (3) comparative measurements should be used to derive the necessary factors for converting count concentration to equivalent mass concentration data.

SUMMARY

The validity of respirable mass concentration limits for mineral dusts recommended in the 1976 and 1986-87 ACGIH Threshold Limit Value Handbook as equivalent to previously recommended number concentration limits was investigated. The investigation consisted of reviewing the documentation in the 1976 TLV Handbook that was used to support the respirable mass concentration limits recommended; deriving empirical relationships from comparative measurement obtained with a midget impinger and respirable personal dust sampler at industrial operations processing graphite (natural), perlite, talc, diatomaceous earth and mica; and comparing equivalent respirable mass concentration measurements obtained from the derived empirical relationships to those recommended in the TLV Handbook.

It was concluded from the investigation conducted that the general relationship, 6 mppcf = 1 mg/m^3, used to convert particle count concentration data to respirable mass concentration data was not valid. This conclusion was based on:

1. Equivalent mass concentrations established from the empirical relationships derived from comparative impinger and respirable samples did not always agree with those recommended in the TLV Handbook.
2. The rationale supporting the 6 mppcf = 1 mg/m^3 relationship was questionable and could not be confirmed using data collected during this investigation.

Because there was a significant difference in the empirical relationships derived between count and respirable mass concentration determinations and attempts to mathematically calculate equivalent mass concentrations were unsuccessful, equivalent respirable mass concentration limits should be empirically derived using comparative measurements obtained in the aerosol of interest.

REFERENCES

1. Jacobson, M., Tomb, T.F.: Relationships Between Gravimetric Respirable Dust Concentration and Midget Impinger Number Concentration. *Am. Ind. Hyg. Assoc. J.* 28:554 (1967).
2. Dunmore, J.H., Hamilton, R.J., Smith, D.S.G.: An Instrument for the Sampling of Respirable Dust for Subsequent Gravimetric Assessment. *J. Sci Instr.* 41:669 (1964).
3. Anderson, F.G.: A Technique for Counting and Sizing Dust Samples with a Microprojector. *Am. Ind. Hyg. Assoc. J.* 23:330 (1962).
4. Hatch, T.H., Choate, S.P.: Statistical Description of the Size and Properties of Nonuniforms Particulate Substances. *J. Franklin Inst.* (1929).
5. Tomb, T.F., et al.: Comparison of Respirable Dust Concentration Measured with MRE and Modified Personal Gravimetric Sampling Equipment. *Bureau of Mines RI 7772* (1973).
6. Cooper, W.C., Crally, L.J., et al.: Pneumoconiosis in Diatomite Mining and Processing. *PHS Pub. No. 601*, G/SGPO, Wash. D. C. (1958).
7. Reist, P.C.: Introduction to Aerosol Science. *Micromillan Pub. Co.*, Chapter 2, (1984).

SIZE DISTRIBUTION OF RESPIRABLE COAL MINE DUST

P.C. THAKUR • L.D. Taylor • J.B. Riester
Consolidation Coal Company, Morgantown, WV, USA

ABSTRACT

The 1969 Coal Mine Health and Safety Act set a threshold limit value for respirable dust in U.S coal mines at 2.0 mg/m^3. The upper limit of the respirable dust size is 10 micrometers on a unit density basis. Although the lower limit is not defined, it can be measured to 0.1 micrometer with modern instruments. The amount of dust associated with each size interval from 0.1 to 10 micrometer represents the size distribution of respirable coal mine dust. The size distribution is generally a function of the generation process, which in the case of mechanical grinding, includes the breaking mechanism and more importantly the properties of the material being mined. Coal mine dust is actually an aggregate of fine coal particles, roof and floor dust, rock dust, diesel particulates (where diesel engines are in use), and fluid particles such as water and oil particles. Therefore, it is not surprising that the size distribution varies from coal seam to coal seam and sometimes even from mine to mine in the same coal seam.

The paper reviews major past works and develops a size distribution function most suited for fine respirable coal mine dust. Also investigated are changes in the distribution parameters of the composite dust when two or more dust clouds are mixed. Results of both laboratory and field studies are presented to confirm that coal rank and depth of the coal seam significantly influence the distribution parameters.

No Paper provided.

PERFORMANCE OF RESPIRABLE DUST SAMPLING SYSTEMS IN UNDERGROUND COAL MINES

C.Y. HWANG, Ph.D. • G.W. Bonnell, B.Sc. • G.R. Corbett • D.A. Young • C.H. MacNeil

Canada Centre for Mineral and Energy Technology, Coal Research Laboratories, Sydney, Nova Scotia, Canada

ABSTRACT

Our long-term research on respirable coal mine dust emphasizes the suppression of dust sources for the prevention of coal workers' pneumoconiosis. As part of this research, concentration measurements were made by using various samplers in 2 Canadian underground coal mines. The dust sampling in longwalls and development headings included fixed position and personal sampling. The airflow rates of sampling pumps deviated on average 1.4% from initially calibrated values. The weight of a 37 mm diameter membrane filter changed as much as 0.05 mg due to humidity.

The relationships specific to mine site and mining method, between concentrations measured by fixed position sampling using different samplers and those determined by Casella gravimetric samplers (CGS-113A) are described. Respirable dust concentrations determined by samplers consisting of DuPont (2500A) or Gilian (HFS) pumps with Casella cyclones approached that by the CGS. The samplers made of MSA (F-F) pumps with Dorr-Oliver cyclones measured respirable values on an average at 45.5% for Mine A and 58.5% for Mine B of the values determined by the CGS. The respirable dust concentration ratio of Anderson eight-stage cascade impactors to the CGS markedly varies as a non-linear function of dust level. The shift-length average concentrations determined by a light-scattering system SIMSLIN II were lower than those by the CGS. A Hund's dust monitor TM-DATA measured the concentrations nearly equal to that by the SIMSLIN II. The differences in instantaneous dust level between the 2 systems are presented for coal cutting time.

Precision and practical aspects of coal mine dust measurements and implications of assessing the miner's health risk due to prolonged dust exposure are discussed.

INTRODUCTION

The etiology of coal workers' pneumoconiosis has not yet been fully understood. The prevention of this occupational disease thus depends upon elimination of airborne coal mine dust to which miners are exposed. The objectives of the Canada Centre for Mineral and Energy Technology (CANMET) respirable dust research program are directed to the suppression of the respirable dust in coal mine environments.

Numerous dust sampling systems or dust monitors are available and have been used for dust measurement by the mining industry. For long-term evaluation of dust exposure and for assessment of effectiveness of a dust suppression measure, it is essential that the measurements made by different samplers be reproducible and comparable. This paper describes part of CANMET's dust research program which evaluated the performance of various types of dust sampling systems tested in two Canadian underground coal mines covering three periods of time, i.e. December 1984–March 1985; December 1985–June 1986; and January–February 1987.

INSTRUMENTS AND METHODOLOGY

Gravimetric Samplers

A Casella Gravimetric Sampler (CGS) Type 113A employs a horizontal elutriator to remove non-respirable sized particles by gravitational settlement. A personal sampling system (which can also be used as a fixed position sampler) consists of an electronically flow-controlled pump and a cyclone that selects dust particles by centrifugal action. A cascade impactor is another particle size selector used in a sampler based on inertial impaction. The Anderson (Marple) Cascade Impactor Model 298 has eight stages of dust collection.

Light-Scattering Real-Time Dust Monitors

Two real-time dust monitors were used: a SIMSLIN II and a Hund's TM-DATA. The SIMSLIN II employs a horizontal elutriator as a dust particle size selector. Its laser light source has a wavelength of 0.904 μm and the scattered light by dust particles is detected between 12–20 degrees to the forward direction. The TM-DATA has, as its light source, an infrared light beam with a wavelength of 0.950 μm. This instrument measures the light scattered by dust particles at an angle of 70 degrees to the direction of the beam. Although it does not employ a horizontal elutriator the use of this scattering angle and the specific wavelength permits the measurement of respirable dust concentration. Both the SIMSLIN II and the TM-DATA are portable and thus useful in evaluating real-time dust levels for various coal winning activities. Their output signals may be fed to a computer for analysis, comparison, and graphical presentation.

Field Dust Sampling and Performance Tests

Both fixed position and personal sampling were used in CANMET's dust sampling program. Personal dust sampling, either face-time or portal-to-portal, directly provides information on individual dust exposure. For the fixed position sampling, specific locations were chosen for shift-length sampling in longwall sections and development headings of two underground coal mines (Figure 1). Station D, which is in the tailgate 70 m from the faceline, is a statutory dust control point of an advancing or a retreating longwall. It was this location where various samplers or dust monitors were tested side-by-side at breathing zone height. Similar tests were also carried out at Station Q which is 100 m from a development heading (Figure 1). The results of performance test work which will be described in this paper were obtained by fixed position sampling in five longwall sections of Mine A, in two longwall sections of Mine B, and in one deep development heading of Mine B during the three periods of time as indicated previously.

RESULTS

Sampling Airflow Rates

The pump of each sampler used with a specific type of filter was calibrated at CANMET's Cape Breton Coal Research Laboratory prior to sampling. Following a shift-length survey, the flow rate of this pump was again determined. The absolute differences or deviations between the initial and final flow rates were calculated and expressed as percentages of the initial flow rates. The mean deviations determined in various mine sites appeared different for each pump type used with the samplers. With DuPont pumps in the walls of both mines, the mean deviation varied from 0.7 to 1.0%, while with Gilian pumps in Mine B the mean deviation varied from 1.2 to 1.4%. The mean deviation of CGS was higher (2.1%) in Mine A as compared with those evaluated in Mine B for wall sections (0.9%) and for a development heading (1.0%). The individual deviation in the flow rate ranged from 0 to 6.2% in the two mines for CGS; for all the personal gravimetric samplers, the deviation ranged from 0 to 7.1% in the mines.

Filters as Dust Collection Media

Membrane filters react by weight change in various environmental conditions. Millipore membrane filters (made of mixed cellulose acetate and nitrate) gain weight when the surrounding humidity increases. The enclosed weighing chamber of an electro-microbalance (CAHN C-29) can be a different environment for a membrane filter as compared to the laboratory environment. Therefore the time during which a filter is kept in the chamber before a reading is made, becomes an important factor when weighing filters. We make use of an air conditioner and blanks to overcome this problem. Other filters such as Nuclepore polycarbonate and glass fibre filters showed negligible weight loss. An ionizing unit (Staticmaster) was also used to eliminate static charges on all the filters before weighing.

Variability of Concentration Measurement made by Casella Gravimetric Samplers Type 113A

Two to three sets of the Casella Gravimetric Samplers (CGS) were used for each dust survey. The standard deviation and percent variation expressed as a percentage of the average of concentrations measured by the CGS, were evaluated for each sampling shift and are shown in Figure 2, in which the abscissa represents the concentration values normalized to the maximum average concentration determined during a specific shift. This variation in standard deviation (Figure 2a) from 0.01 mg/m^3 to 0.34 mg/m^3 appears to be fixed regardless of the normalized concentration and thus indicates a systematic error of measurement as high as 0.34 mg/m^3. The percent variation (Figure 2b) varies from 0.1% at the normalized concentration of 0.61 to 10.3% at 0.23. For Mine A, this variation appears to decrease with increasing concentration but for Mine B, it increases slightly as the concentration increases.

Relative Respirable Dust Concentrations Determined by Personal Gravimetric Samplers

At the dust control points of the wall sections of Mine A and Mine B, three to five sets of personal gravimetric samplers (one set with the Dorr-Oliver cyclone and the others with Casella or Rotheroe/Mitchell cyclones) were installed side-by-side with CGS. The standard deviation and percent variation obtained for the samplers using the Casella cyclones are shown in Figure 3. For comparison purposes those evaluated in a dust chamber by using 12 sets of the personal samplers are also included. The variation in standard deviation (Figure 3a) from 0.03 mg/m^3 to 0.45 mg/m^3 in the two mines appears to be fixed regardless of the normalized CGS concentration. The result of testing in the dust chamber (Figure 3a) has shown a systematic error of measurement as high as 0.44 mg/m^3 in the normalized concentration range of 0.24 to 0.65. A high standard deviation value (0.56 mg/m^3) has been observed in the dust chamber beyond the concentration range of interest. Regardless of the mine type, the percent variation decreases from 9.2% to 1.1% in the concentration range of 0.2 to 1.0 (Figure 3b). Similar to the variations of CGS, the percent variations of the personal samplers in Mine B are less than those determined in Mine A. The overall decreasing trend of the percent variation observed in the two mines has been verified by the results obtained in the dust chamber. Regardless of mine dust concentration, the average of percent variations (1.9%) evaluated in Mine B was less than the average (5.3%) in Mine A.

For each individual sampling system, the ratio of respirable dust concentration measured by this sampler during a sampling shift to the average of concentrations determined by CGS in the same shift was calculated. The ratios were grouped by sampler type for the two mines in Table I. On the longwalls

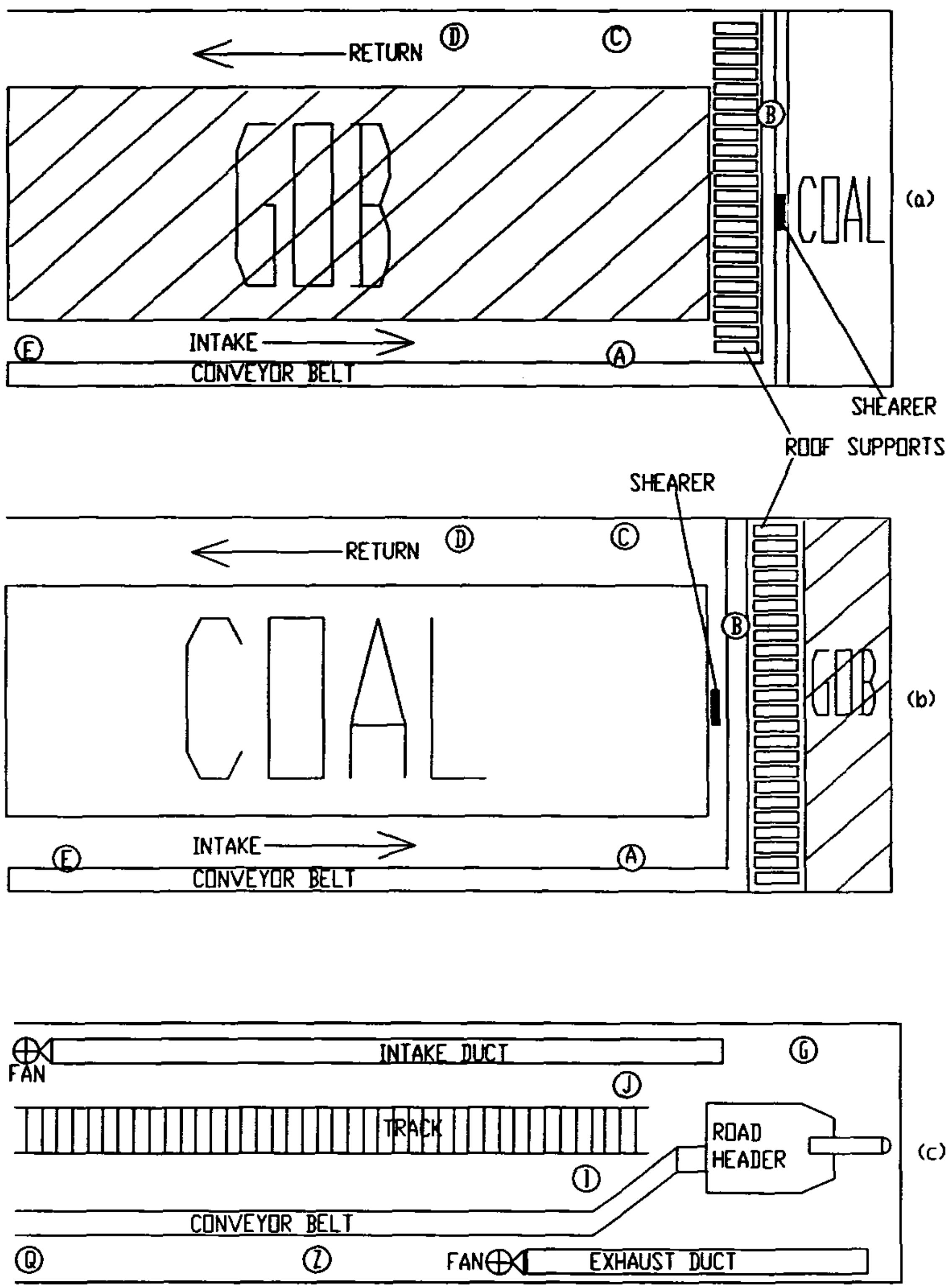


Figure 1. Fixed position sampling locations in (a) an advancing longwall section, in (b) a retreating longwall section and (c) a development heading.

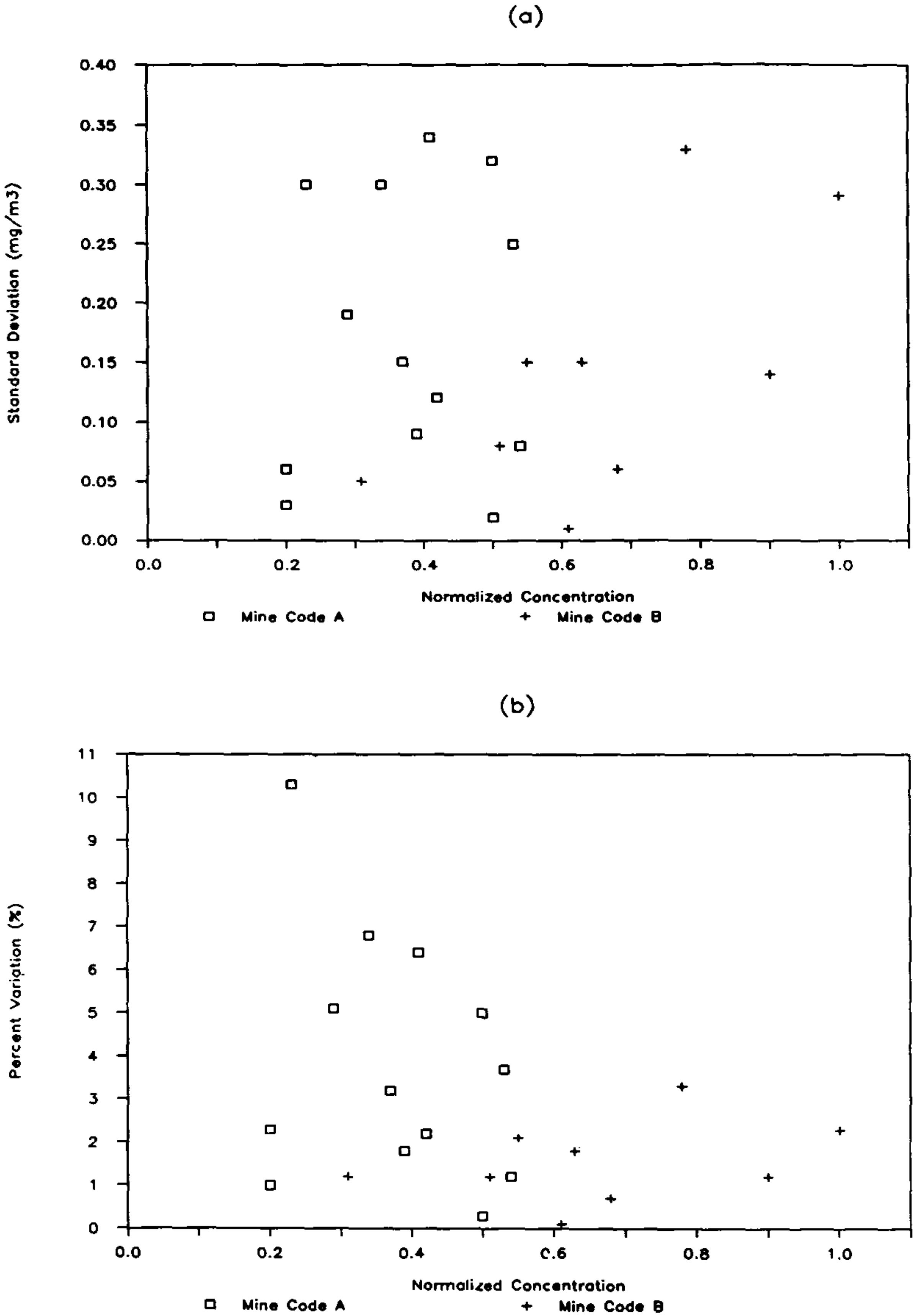
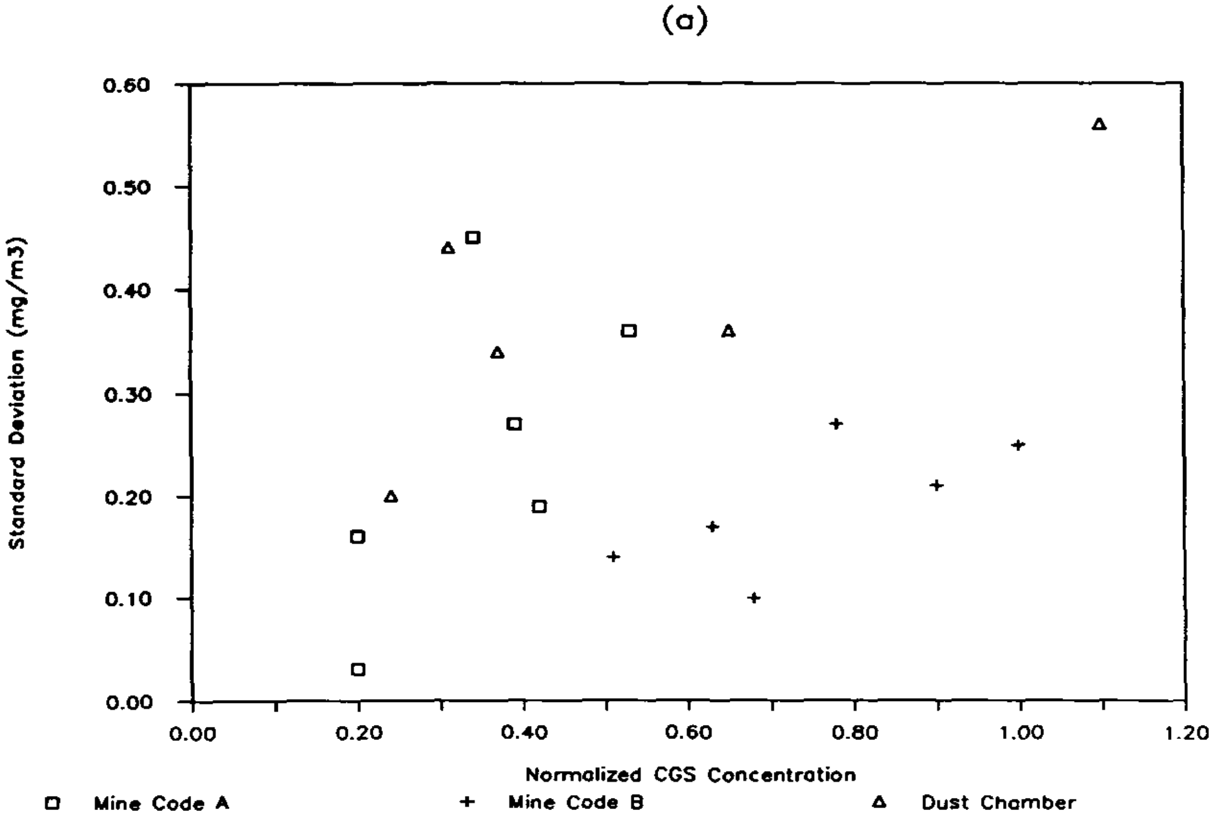


Figure 2. (a) standard deviation and (b) percent variation of concentrations measured at longwalls by Casella Gravimetric Samplers 113A for each field test in Mine A and Mine B.



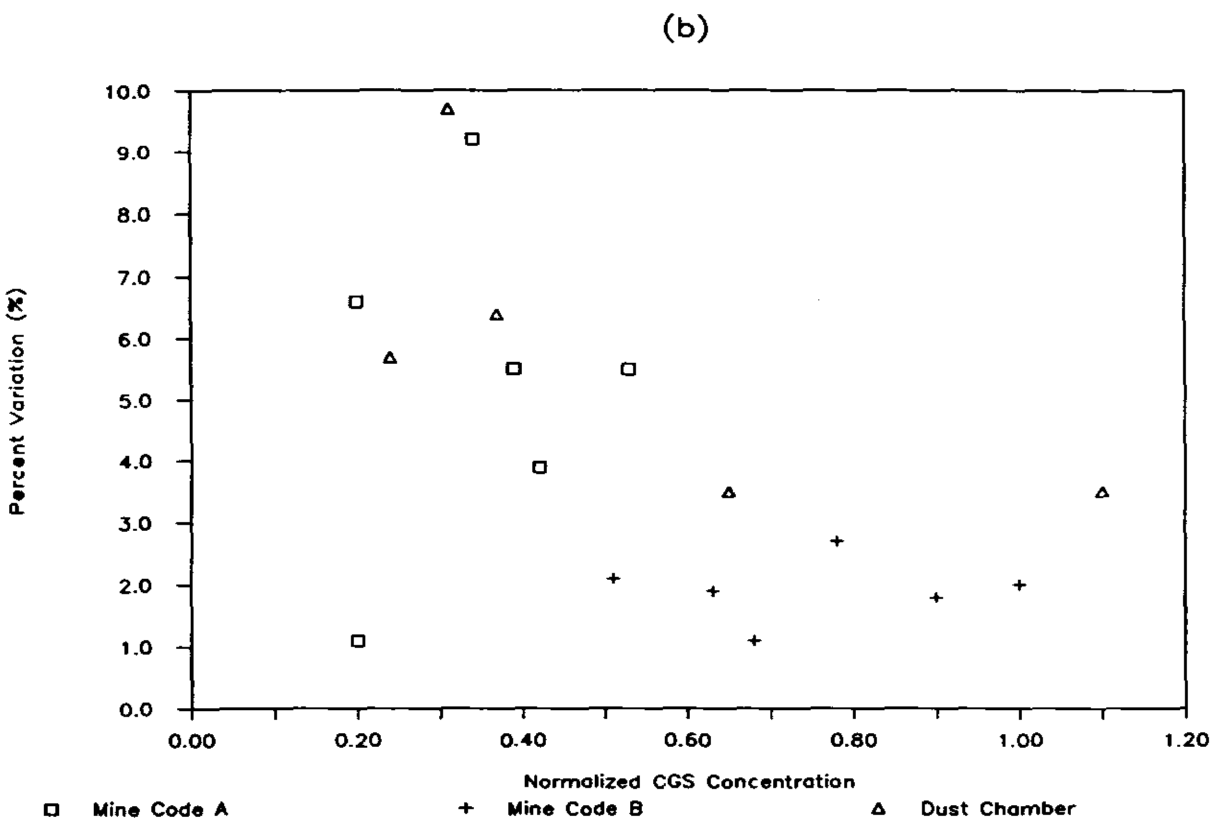


Figure 3. (a) standard deviation and (b) percent variation of Personal Gravimetric Samplers with Casella cyclones tested in Mine A, in Mine B and in a dust chamber.

Table I
Average of Ratios of Concentration Measured by a Personal Sampling System to the Averaged Concentration Determined by the Casella Gravimetric Samples (CGS) 113A

Sampling System	Mine A (5 Walls) Average Ratio	Mine A (5 Walls) Standard Deviation	Mine B (2 Walls) Average Ratio	Mine B (2 Walls) Standard Deviation	Mine B (1 Development Heading) Average Ratio	Mine B (1 Development Heading) Standard Deviation
DCM[1]	0.89 (12)[+]	0.11	1.01 (5)	0.03	1.09 (2)	0.15
DCG[2]	0.89 (8)	0.08	1.01 (7)	0.04	1.11 (2)	0.06
GCM[3]	0.99 (4)	0.06	1.05 (4)	0.04	-	-
GCG[4]	0.96 (4)	0.04	1.04 (6)	0.04	1.11 (2)	0.01
DCN[5]	0.92 (4)	0.06	1.05 (4)	0.04	-	-
MCM[6]	0.94 (5)	0.12	-	-	-	-
MCG[7]	0.89 (2)	0.13	-	-	-	-
MNP[8]	0.45 (9)	0.03	0.58 (6)	0.04	0.60 (2)	0.09

[1]DCM = DuPont Pump + Casella Cyclone (or Rotheroe/Mitchell Cyclone) + Millipore (MP) Mixed Cellulose Acetate and Nitrate Membrane Filter (37 mm dia., 0.8 μm pore).
[2]DCG = DuPont Pump + Casella Cyclone + Glass Fibre (GF) Filter (37 mm dia., 1.5 μm pore).
[3]GCM = Gilian Pump + Casella Cyclone + MP Membrane Filter.
[4]GCG = Gilian Pump + Casella Cyclone + GF Filter.
[5]DCN = DuPont Pump + Casella Cyclone + Nuclepore Polycarbonate Membrane Filter (37 mm dia., 0.8 μm pore).
[6]MCM = MSA Pump + Casella Cyclone + MP Membrane Filter.
[7]MCG = MSA Pump + Casella Cyclone + GF Filter.
[8]MNP = MSA Pump + Nylon Cyclone + PVC Filter (37 mm dia., 0.8 μm pore).

[+]Number of ratios averaged for each sampler type is shown in parentheses.

of the two mines, the averaged ratio appeared to be different from one sampler type to the other. The ratios evaluated for Mine A were less than those determined for Mine B. The average ratio obtained in the development heading of Mine B had greater values than the two walls of this mine had for four types of sampler. The average ratios determined by the samplers with the nylon cyclones had approximately one-half the values of those evaluated by the samplers with the Casella cyclones both in Mine A and in Mine B.

Measurement of Respirable Dust Concentration and Particle Size Distribution by Marple Personal Cascade Impactors Model 298

Two Marple (Anderson) cascade impactors, M1 and M2, were employed in two wall sections of Mine A and in one wall section and a development heading of Mine B. To evaluate respirable dust concentration, the mass determined for Stages No. 5 through No. 8 and for the backup filter were summed as the respirable portion which represented particles less than 6 μm in aerodynamic equivalent diameter. The relative respirable dust concentrations determined in the wall sections of the two mines by the impactors are plotted in Figure 4, versus the average CGS concentration normalized to the maximum CGS concentration value. The relative concentration ranged from 0.81 to 1.24 as determined by the impactor M1, and ranged from 0.69 to 1.18 as determined by the impactor M2 in the normalized CGS concentration range of 0.26 to 1.0. The relative concentrations appear to decrease non-linearly with increasing mine dust levels determined by CGS. For M1 and M2, the size distributions (expressed as percent by mass) obtained from four tests in the wall sections of Mine A, six tests in the wall section of Mine B, and two tests in the development heading of Mine B were averaged and shown in Figure 5. There are larger proportions of particles with sizes greater than 6 μm (expressed in geometric mean diameter, G.M.D.) in Mine A as compared with the distributions obtained in Mine B. The size distributions obtained in the development heading had a greater proportion of particles with size less than 6 μm as compared to those obtained in the wall section of Mine B or the wall sections of Mine A. It must be noted that in calculating a size distribution, the dust collected on the substrate of the first stage (with a G.M.D. of 32 μm) and the backup filter was not used.

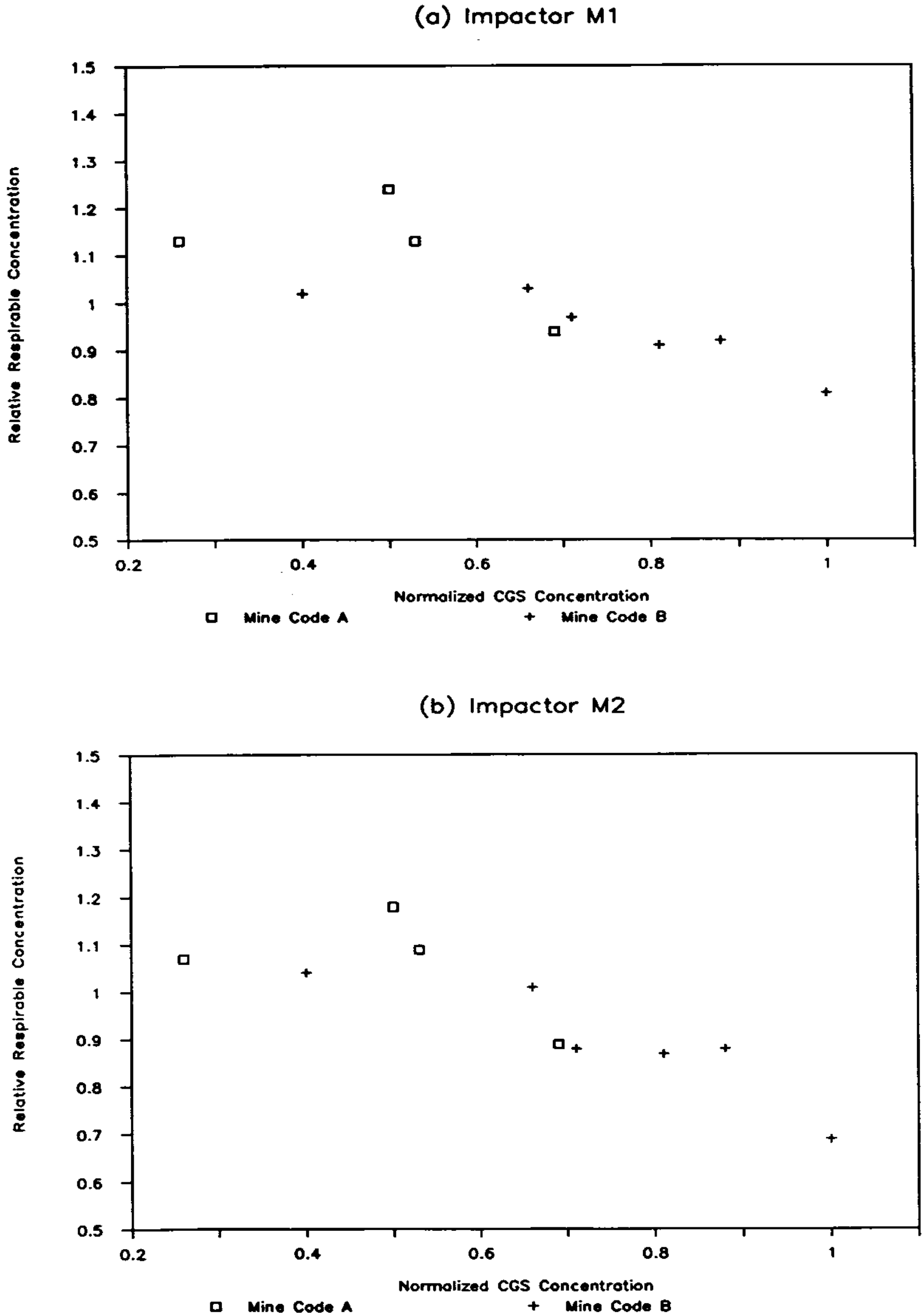


Figure 4. Relative respirable dust concentrations determined in Mine A and Mine B by the samplers (a) with the cascade impactor M1 and (b) with the cascade impactor M2.

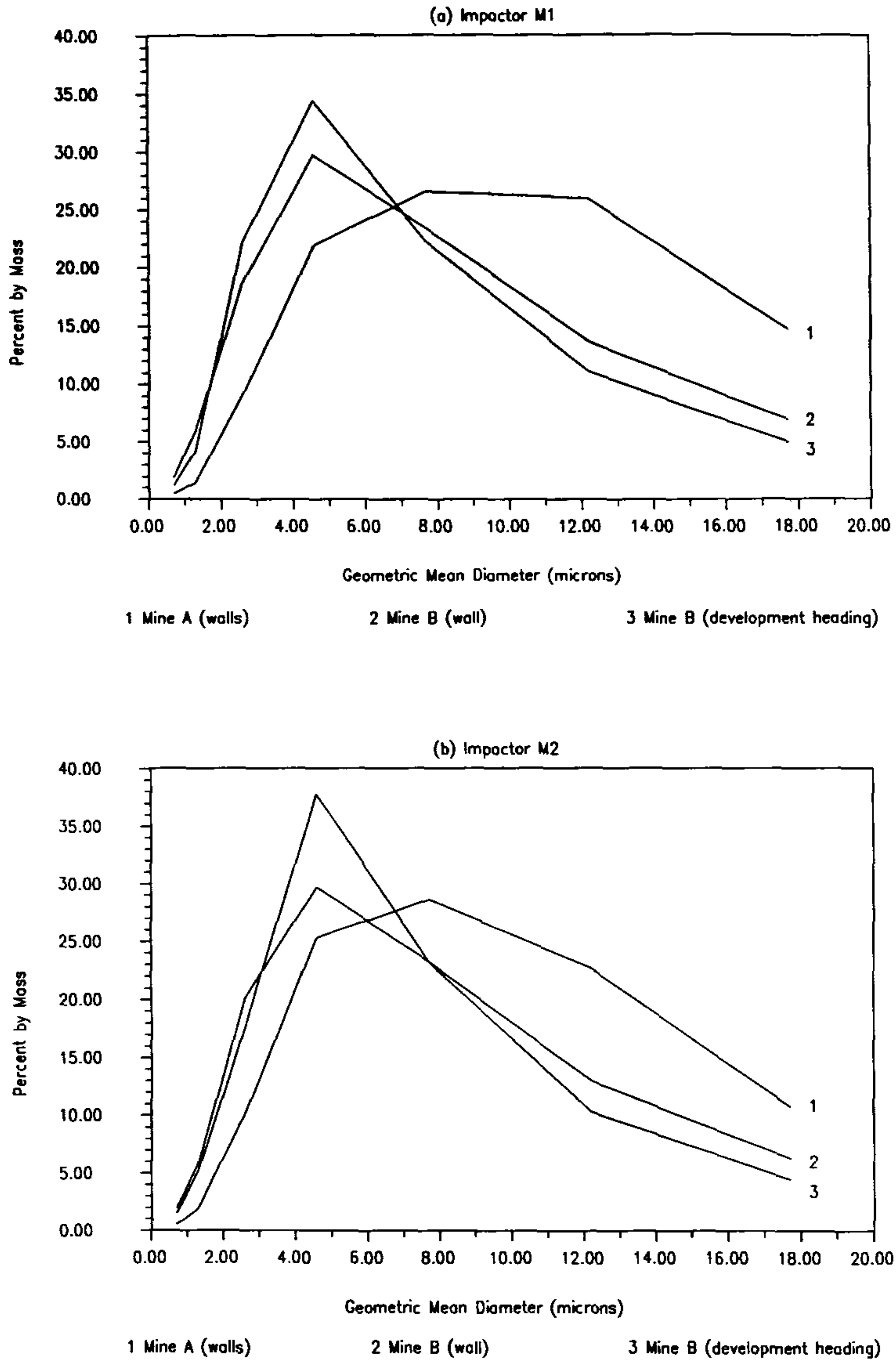


Figure 5. Average size distributions of airborne dust measured by (a) impactor M1 and (b) impactor M2 in Mine A and Mine B.

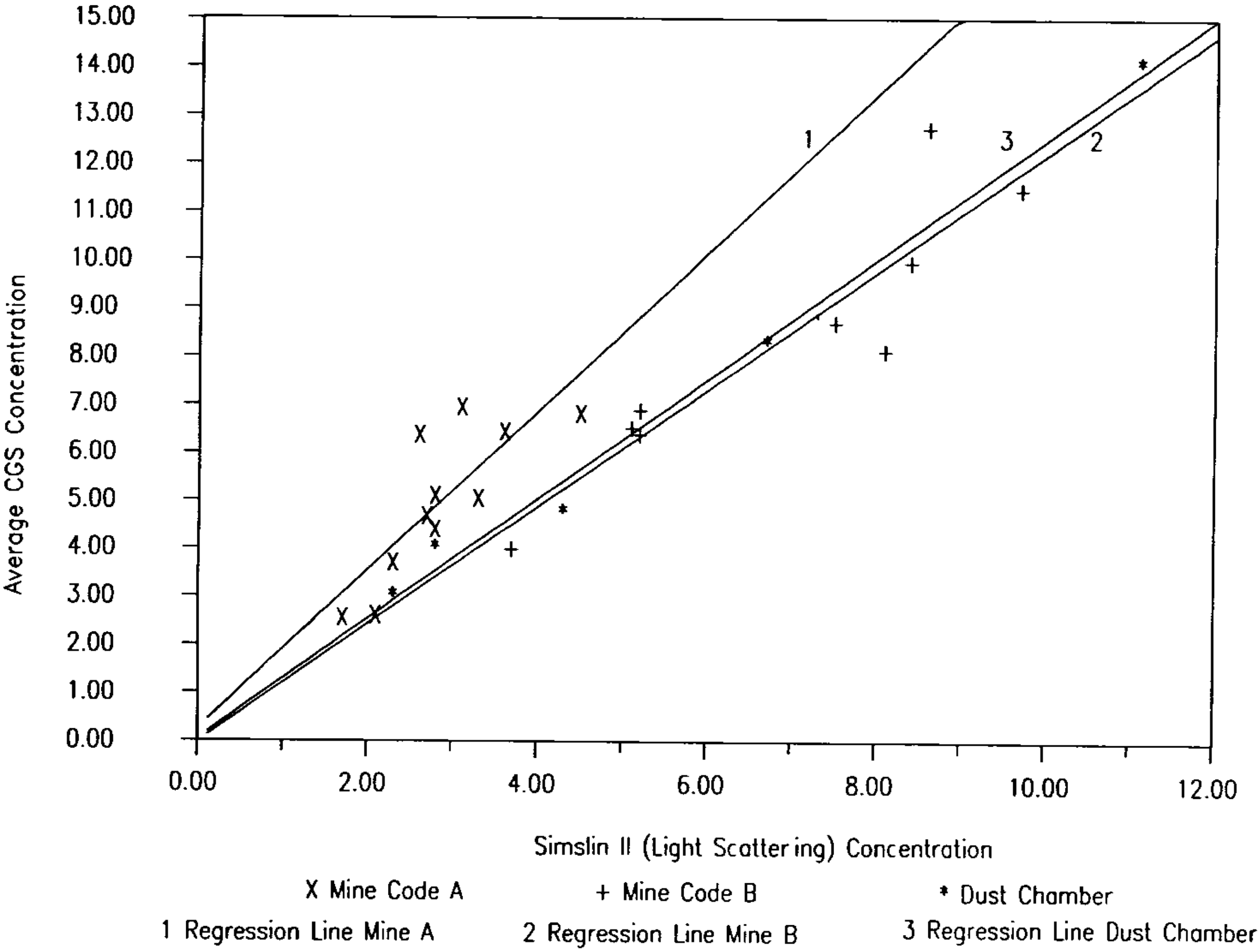


Figure 6. Linear relationships between the concentrations (in an arbitrary unit) determined by SIMSLIN II and by Casella Gravimetric Samplers (CGS) in Mine A, Mine B and in the dust chamber.

Measurements of Respirable Dust by Real-Time Dust Monitors

A factory-calibrated SIMSLIN II monitor was tested side-by-side with CGS at the control points of the longwalls of the two mines. The end of shift average concentrations determined by the SIMSLIN's light-scattering system were found to be less than the CGS concentration with an average concentration ratio 0.60 for Mine A and 0.81 for Mine B. The linear relationships between the SIMSLIN's concentration and those measured by CGS are depicted by Figure 6 for Mine A, Mine B, and the dust chamber. The regression line representing Mine A is markedly different from the line obtained in Mine B. The line derived from the tests in the dust chamber appears to be similar to the line representing Mine B.

Three shift-length tests have been carried out in Mine A in order to compare the dust concentrations determined by TM-DATA with that determined by SIMSLIN II and by CGS. Table II shows the end-of-shift average concentration relative to the CGS concentration obtained in two wall sections. The relative concentrations determined at the wall section (coded WF) by the two monitors were almost identical, but in the test at the wall WE, the relative concentration by TM-DATA was greater than that measured by SIMSLIN II. Although there are some differences at the beginning of some coal cutting periods, the concentration recordings by the two monitors appear similar (Figure 7). When a shearer started coal cutting, TM-DATA recorded a concentration peak higher than the peak registered by SIMSLIN II; such a difference may characterize TM-DATA which does not employ an elutriator as a particle size selector. TM-DATA does not have a time delay due to the fact that it has no pump and consequently no internal tubing.

DISCUSSIONS

The measurement of respirable dust concentrations by gravimetric techniques is subject to variations in the sampling flow rate of pumps, the handling of filters, and in the filter weight change caused by humidity or static electrical charges. The sampling systems, if used for personal sampling instead of fixed position sampling, are subject to more variations due to the additional movements and impacts associated with mounting the devices on mobile miners. A Casella Gravimetric Sampler's flow rate may deviate as much as 6.2%. The flow rate deviation of a personal gravimetric sampler has a maximum value of 7.1%. The overall filter weight change has been as high as 0.34 mg for a change in laboratory relative humidity of 20%.

The precision of respirable dust concentration measurements by using one type of gravimetric sampler increases with increasing mine dust levels. For the Casella Gravimetric Samplers (CGS) and the personal samplers with Casella cyclones, the percent variation may take a value as low as 1% to 3% in mine locations with a dust level above 6 mg/m^3; below 6 mg/m^3 the variation could reach a value as high as 10%. Thus, any concentration value determined by a given type of gravimetric dust sampler relative to the CGS is subject to greater percentage errors when it is employed in a lower dust level. However, the results described in this paper indicate that such variability also depends to some extent on the mine type. Retreat longwall mining generates airborne dust mainly by the shearer's cutting and face support movement while advance longwall mining generates the dust by the coal cutting activity as well as various activities in the headgate and the tailgate. It has been shown that dust particle size distributions are different between the two mines. Furthermore, the two mines work different coal seams and thus the nature of the airborne dust particles (e.g. mineralogical composition) may vary from one mine to the other.

When a cascade impactor is used as the size selector for the measurement of respirable dust concentration, there is evidence that the measured relative concentration varies nonlinearly with increasing mine dust level. This change in the relative respirable dust concentration has been explained elsewhere.[1] The linear relationships between the SIMSLIN's data and that obtained by the CGS in the two mines are different and thus indicate that the nature of the dust particles in addition to size distribution may also play an important role in the differences resulting from the concentration measurements made by using a light-scattering technique.[2]

Errors introduced in the measurement of respirable dust concentration imply uncertainty in assessments of the risk of pulmonary diseases in miners. This problem becomes more serious if the concentrations measured in a limited number of sampling shifts are to be used retrospectively for the evaluation of occupational dust exposure of miners. The activities of mechanized long wall mining have resulted in marked variation in shift-averaged concentration measured from time to time at the same wall section. Most of the past health studies in relation to long-term dust exposure were based on the dust levels measured by the CGS samplers, which have varying degrees of precision when used in different mine sites or in dust clouds with different dust particle size distributions. If any other type of gravimetric dust sampler were chosen to measure dust levels for the purpose of indirect risk estimation, the magnitude of errors in the estimation would be greater than that based only on the CGS measurement. Although the dust concentration measurement by a light-scattering technique provides information on instantaneous and time-averaged dust levels, the measured values may not indicate precise mass concentrations for the stated reasons. Thus those measured values are less useful for an exposure assessment. However, a real-time dust monitor is useful to evaluate relative change in dust level within a short period of time in a production shift and for determining the effectiveness of a dust suppression technique.

The following is an example to illustrate the effect of respirable dust concentration measurements on the assessment of health risk of a miner. If a mean coalface concentration is 4 mg/m^3 and if an overall error of 10% (i.e. $\pm$ 0.4 mg/m^3) were introduced by concentration measurements, the probability that a miner with no pneumoconiosis (in the International Labour Organization category 0/0) is classified into the category 2/1 or higher after 35 years of dust exposure would be overestimated by 0.0096 or be underestimated by 0.0082.[3]

With sound knowledge of the relative performance of the various samplers described, we shall routinely use for fixed position and personal sampling, the gravimetric samplers

Table II
Shift-Length Side-by-Side Tests of TM-DATA and SIMSLIN II in Two Longwalls of Mine A

Wall Code	Shift Code	Concentration Relative to the Average CGS Concentration: TM-DATA	SIMSLIN II
WF	#1	0.68	0.66
	#2	0.65	0.66
WE	#3	0.78	0.65

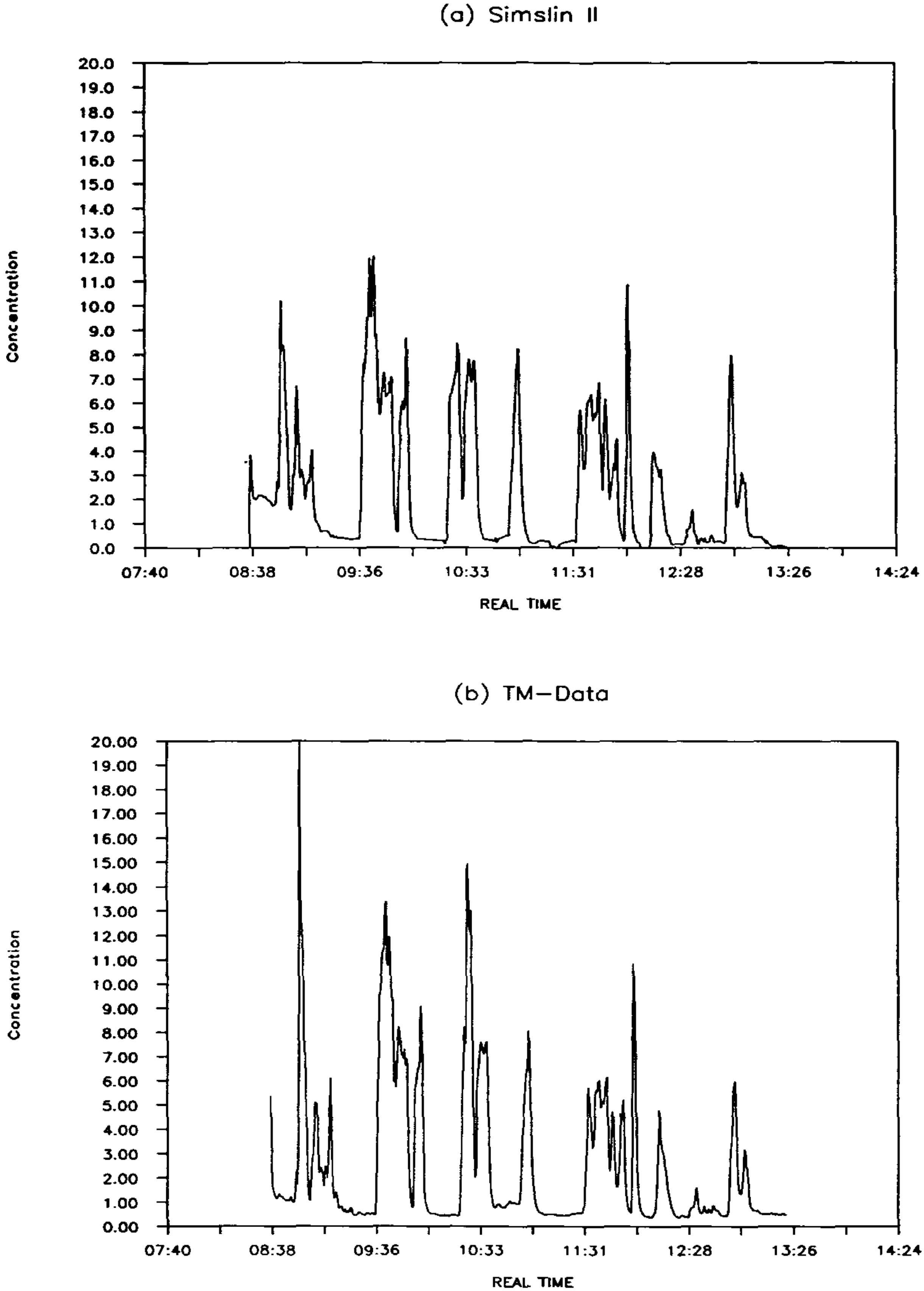


Figure 7. The shift-length concentration recordings (in an arbitrary unit) at the wall section WF of Mine A by (a) SIMSLIN II and by (b) TM-DATA. The time scales of (a) and (b) are in hours and minutes.

consisting of electronically controlled constant-flow pumps, Casella cyclones and glass fibre or the Millipore filters for respirable mass concentration measurement. Silver membrane filters have also been used for airborne dust collection for mineralogical analysis. Our dust research work will be directed more toward the assessment and promotion of dust source control technologies. For assessing the effectiveness of a dust suppression technique, a real-time dust monitor (SIMSLIN II or TM-DATA) supplemented by the gravimetric samplers chosen for our routine dust sampling work will be used.

REFERENCES

1. *Respirable Dust in the Mineral Industries: Health Effects, Characterization and Control.* 1st Ed., pp 51-59. R.L. Frantz and R.V. Ramani, Eds. The Pennsylvania State University, University Park (1988).
2. *Aerosols in the Mining and Industrial Work Environments Volume 3*, 1st Ed., pp 759-775. V.A. Marple and B.Y.H. Liu, Eds. Ann Arbor Science, Ann Arbor (1983).
3. *Inhaled Particles III Volume* 2, 1st Ed., pp 903-917. W.H. Walton, Ed. Unwin Brothers Limited, Surrey (1970).

ACKNOWLEDGEMENTS: We acknowledge the mine management and staff for providing help and support for the respirable dust research program. Technical assistance was provided by Messrs. D.J. O'Brien and L.S. O'Leary. We also thank Miss G.L. LeBlanc for assistance in the data processing.