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COMPARISON OF DUST SAMPLING INSTRUMENTS

T. S. COCHRANE, G. KNIGHT, L. C. RICHARDS AND W. STEFANICH

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COMPARISON OF DUST SAMPLING INSTRUMENTS

by

ENVIRONMENTAL CONTROL GROUP*

SUMMARY

This report describes many comparisons between dust sampling instruments. These narrow down to the very wide range in ratio of dust concentrations indicated by any two types of dust sampling instruments in different dust clouds and, therefore, the need to consider physiological factors in applying dust sampling instruments to assess health hazards. Changes in design that are apparently minor can have a large effect on the respirable dust concentration indicated by a sampler that has an aerodynamic size selector.

Dust Sampling: Thermal Precipitator: Midget Impinger: Tyndalloscope: Gravimetric Sampling: Size Selection: Respirable Dust.

* G. Knight, Project Leader,
L. C. Richards,
W. Stefanich,
T. S. Cochrane, Program Coordinator,
Mining Research Centre, Mines Branch, Department of Energy, Mines and Resources.

Direction des mines

Rapport de recherches R 250

LA COMPARAISON DES INSTRUMENTS POUR L'ÉCHANTILLONNAGE DES POUSSIÈRES

par

Le Groupe de Contrôle de l'Environnement*

RÉSUMÉ

Dans ce rapport, les auteurs décrivent plusieurs comparaisons entre les instruments pour l'échantillonnage des poussières. Celles-ci se limitent à un champ étendu dans le rapport des concentrations de poussière indiquées par deux de n'importe quels genres d'instruments pour l'échantillonnage des poussières dans les différents nuages de poussière et, de là, le besoin de considérer les facteurs physiologiques dans l'application des instruments pour l'échantillonnage des poussières en vue d'évaluer les dangers pour la santé. Les changements de dessin qui sont apparemment mineurs peuvent avoir un grand effet sur les concentrations de poussière respirable indiquées par un échantillonnage qui a un sélecteur de taille aérodynamique.

L'Échantillonnage des poussières: Précipitateur thermique: "Midget Impinger": Tyndalloscope: L'Échantillonnage gravimétrique: Sélection de taille: Poussière respirable.

*G. Knight, Chef de projet; L.C. Richards, W. Stefanich, T.S. Cochrane, Coordonnateur de programme, Centre de recherches minières, Direction des mines, ministère de l'Énergie, des Mines et des Ressources.

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CHAPTER 1
AIRBORNE DUST SAMPLING

INTRODUCTION

Airborne dust sampling is done in mines because it is a hazard to health. Dust sampling in mines is normally directed to one or more of the following objectives:

- assessment of the health hazard to which miners are exposed;
- control of dust sources;
- characterization of the dust cloud and relating to clinical observations.

PHYSIOLOGICAL BACKGROUND

Because the main hazard is pneumoconiosis in its many forms such as silicosis and anthracosis, dust sampling should be directed toward estimating the potential pneumoconiosis hazard of airborne dust. To do this, it is essential to consider the physiological processes involved in pneumoconiosis and to measure the appropriate parameters of the dust. The dust cloud is related to the onset of pneumoconiosis by:

the deposition of dust in the lungs,
the clearance of dust from the lungs, and
the biologic activity of dust in the lungs.

Deposition of Dust in the Lungs

The only dust that can be deposited in the alveolar region of the lung is that remaining in the inhaled air after passing through the respiratory tract (mucous-swept airways). Three physical mechanisms - impaction, gravity settlement, and diffusion - are instrumental in the deposition of dust in both the respiratory tract and the alveolar region. One property of a particle that is common to these three mechanisms is its 'aerodynamic size'. The aerodynamic size is defined as the diameter of a unit-density sphere having the same settling velocity as the particle in question.

The general dependence of alveolar and respiratory tract deposition on size and breathing rate is shown in Figure 1-1; however, the precise values vary with the breathing pattern and with the individual (1). There is, in general, a minimum deposition of 0.5-μm particles. Impaction and gravity-settlement deposition increase with increasing particle size and are responsible for most of the deposition at sizes above the minimum. Diffusion deposition increases with decreasing size and is the main mechanism below the 0.5-μm size.

In order to define the alveolar-deposition potential of an airborne dust cloud, the size distribution should be specified in terms of the aerodynamic size. Other measures of particle size may give misleading results; for example, coal particles with an aerodynamic size of 5 μm may have projected areas equivalent to those of 5- to 15-μm-diameter circles (2).

Clearance of Dust from the Alveolar Region of the Lungs

The mechanisms of clearance are not as clearly understood as are those of deposition. Experimental studies, reviewed by Hatch and Gross (1), have suggested that clearance is dependent on the composition, size distribution, shape, and concentration of the deposited dust.

Experimental studies (1) have suggestsd that the clearance mechanism has a half-life of 20 days or more, and only at extremely high dust concentrations has there been a suggestion of a breakdown in this mechanism. This slow rate of clearance suggests that the average dust exposure over a period of at least 20 days would be more important than peak exposures, unless they were extremely high.

Biologic Effect of Dust in the Lungs

The physical and chemical factors determining the biologic effects are: concentration, size distribution, composition, shape, and residence time. The parameters in which these factors should be expressed are not known. There is considerable support for the view (3,4) that the mass of coal dust is the appropriate concentration parameter in coal miners' pneumoconiosis and that the surface area of silica dust is applicable to silicosis. However, some recent work (5) has suggested that a parameter intermediate to surface area and mass would be most closely related to the health hazard. For other materials and for mixed dusts, no recommendations have been made as yet. Therefore, in research applications, fairly comprehensive specifications of the dust clouds need to be made because of the uncertainty in both clearance and biologic effects.

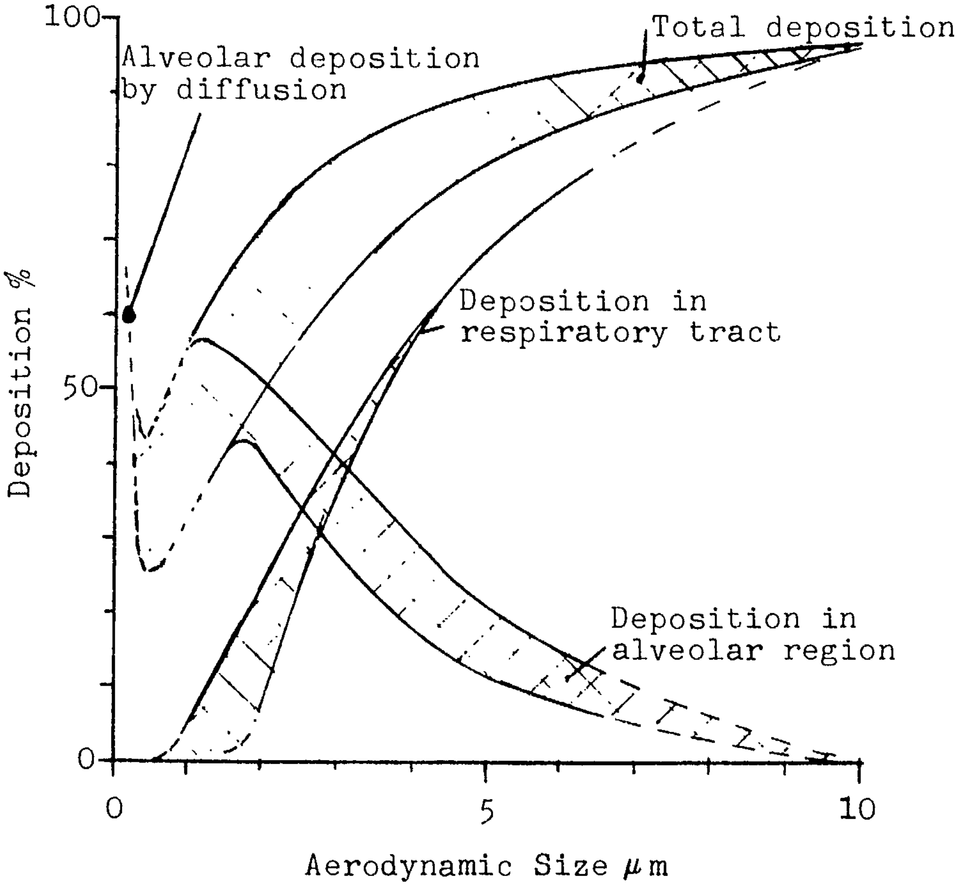

FIGURE 1.1 Dust deposition in the lungs showing range of variation with the breathing rate after Hatch and Gross (1).

SCOPE OF THIS PROJECT

Many comparisons of dust sampling instruments have been made in most parts of the world. Most of these comparisons have been restricted to a few working places or to laboratory dust chambers using just a few types of dust cloud. Per Odelycke (6) and Landwehr (7) have made two such studies, of wider range than most, which reveal very wide differences in the comparison of dust sampling instruments.

The object of the first part of this project was to investigate the range of dust concentrations obtained when a wide range of dust sampling instruments - in current and projected use - were exposed to a wide range of dust clouds prepared in the laboratory dust chamber. The dust clouds were prepared from five minerals and one synthetic material to cover the range of particle density from 1.4 to 5 gm/cm^3 and of particle shape from near cubic through plate to fibrous. The clouds were dispersed by five techniques to give a range of size distribution and different states of aggregation.

In these studies, particular attention was paid to the extent of variations - both random and systematic - in the relationship between systematic variations and measurable properties of the dust cloud. A number of subsidiary investigations are also reported which examined the collection efficiency of certain dust sampling instruments and compared aerodynamic respirable-dust size selectors.

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CHAPTER 2
EXPERIMENTAL TECHNIQUES

DUST CHAMBER

The laboratory dust chamber is 6x8x6 feet high inside. It is fitted with an inlet duct which distributes the incoming air evenly throughout the length of the chamber and with exhaust ducts. The chamber has an air circulating fan which has been arranged so that the dust laden air passes through the main 2x2x2-foot sampling space at low velocity (50 to 150 ft/min), through the fan, and around the walls to the sampling area again. The layout used in the main comparison experiment is shown in Figure 2-1. Most of the sampling instruments were placed, in the main sampling area, with their air inlets facing upstream.

DUST SAMPLING INSTRUMENTS

A number of important factors enter into the classification and description of dust sampling instruments, as follows:

1. property of the dust particles assessed - number, light scatter and mass;

2. method of collection - electrostatic or thermal precipitation, filtration, impaction, settlement, etc.

3. method of defining size range of dust assessed - instrument characteristics, assessment method characteristics, modification of instrument characteristics by fitting a primary dust collector to reject coarse non-respirable dust from the assessment;

4. method of assessment - weighing, microscopy, densitometry, tyndall effect, etc.

The range of instruments in this report covers the three properties and all the collection methods mentioned.

The methods of assessment used have been weighing for mass and microscope counting for number throughout. The tyndalloscope assesses the intensity of scattered light from the dust particles, and this is dependent on the surface area and the optical properties. Other methods for determination of mass and number have been used to a limited extent in parts of the world, i.e. the calibration of densitometric measurements of the Long Period Dust Sampler (1) in terms of both mass and number, by the National Coal Board, U.K., but have not been included in this study.

The classification of the instruments below follows the above list with the main sections corresponding to 1. The information given on each instrument comprises, a) manufacturer and description, b) installation in chamber and modifications, c) airflow and method of control, and d) method of assessment.

Figure 2-1 is an isometric representation of the position of the instruments in the chamber with indicating lines and crosses marking the projected position of each instrument air intake on the front wall of the chamber. The circulating fan is also shown.

The dust chamber is fitted with a 500 ℓ/min vacuum pump, to draw air through some of the filter type dust sampling instruments and the midget impingers.

To ease operation of the many dust sampling instruments, the vacuum pump and all the electrically operated instruments except the 113D dust sampler are switched on and off through a timer and relay.

Instruments Assessing Dust by Number

These instruments use three methods of dust collection: thermal precipitation, settlement, and impaction. Two types of instruments, the thermal precipitator and the konimeters, collected dust directly on glass slides which are later examined under the microscope. The impingers collect dust as a liquid suspension which is assessed by microscopic examination of settled dust.

Thermal Precipitators

The precipitators were made by Casella (2) Ltd., London, U.K., and are designated the T12500 thermal precipitator and the N.C.B. M.R.E. Long Period Dust Sampler Type 112A. The T12500 collects dust by thermal precipitation in a thin strip on two cover glasses. The type 112A is a modified thermal precipitator fitted with a battery operated air pump, inhaling and exhaling 2 cc of air through the sampling head every minute. The main modification is that the coarser respirable dust is permitted to settle on the glass cover slip prior to the thermal precipitation zone, thereby

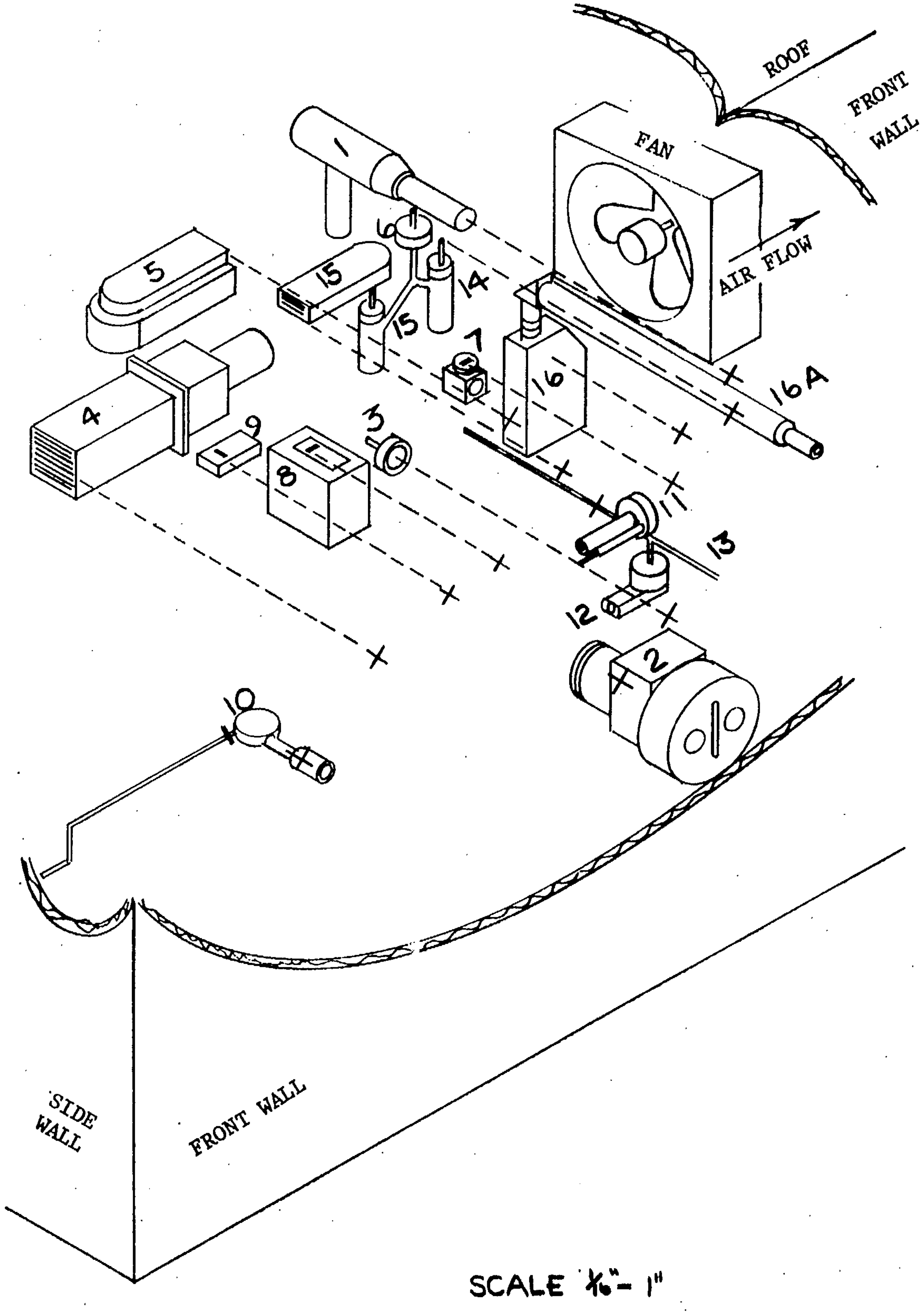

FIGURE 2-1: POSITION OF DUST SAMPLERS IN CHAMBER (ISOMETRIC PROJECTION)

Captions for Figure 2-1

Figure Reference	Dust Sampler
1	Electrostatic Precipitator
2	Open Filters - Staplex
3	Gelman
4	Respirable Dust Filters - Hexhlett
5	N.C.B. M.R.E. Type 103D (Note this sampler has, for clarity, been drawn 16 inches further from front wall)
6	Impinger Secondary Filter
7	Thermal Precipitators - Standard Thermal Precipitator, T 12500
8	- Long Period Dust Sampler, Type 112A
9	- Spare Head
10	Konimeters - Gathercole
11	Sartorius
12	Haslam
13	Suction Line
14	Impingers - Open Inlet
15	Fitted with Elutriator
16	Tyndalloscope
16A	Fitted with Remote Reading Telescope
X	Projected Position of Sampler Intakes on Front Wall

decreasing overlap and permitting eight hour samples to be collected. The sampler is also fitted with a horizontal elutriator (3, 4, 5) to remove the coarse, non-respirable dust. A spare 112A sampling head without the elutriator was also used.

The batteries were replaced by a battery charger operated from the mains with sufficient rheostats and ammeters to control the heater and motor currents.

The airflow of 2 cc/min through the Long Period Dust Sampler was obtained from its pump and calibrated by a bubble flowmeter. The airflow for the T12500 thermal precipitator was obtained from the standard aspirator and jet. The total volume of water displaced was measured for each run. The airflow of about 5 cc/min for the 112A spare head was obtained from a constant head aspirator, again the volume of water was measured for each run.

The thermal precipitator samples were counted using a light field projection microscope with a 2-mm oil immersion objective at 3000 times magnification in a number of size ranges:

a. greater than 5 μm by projected area*;
b. 1 - 5 μm*;
c. 0.5 - 1 μm;
d. all visible particles less than 0.5 μm**;
e. all visible fibres (fibres being defined as particles with a length breadth ratio greater than 3 to 1).

Midget Impingers

Three glass impingers (6) were used, one of which was fitted with a horizontal elutriator (2, 3) size selector to reject the non-respirable, coarse dust particles. The samples, after settlement for 30 minutes in 1-mm deep cells, were counted on a light field projection microscope with

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* For the L.P.D.S. with a size selector, range a is included as an estimate of respirable dust in range b.

** This size range was counted only on two slides from each dust cloud using a light field binocular microscope fitted with a 1.3 N.A. oil immersion objective because the projection screen decreased the resolution slightly.

a 16-mm objective at a magnification of 1000 in two size ranges, greater and less than 5 µm*, and all visible fibres. The techniques used were those recommended by the United States Bureau of Mines (7) except that butyl alcohol was used to reduce evaporation and permit sampling times up to 2 hours. The impingers were selected to pass between 0.0975 and 0.1025 ft^3/min at 12-inch water gauge suction and the three together were operated with a back-up filter at 0.3 ft^3/min.

Konimeters

Three konimeters were used: Gathercole (Ontario), Haslam (South Africa), and Sartorius (Germany). The first two took 5 cm^3 snap samples while the third took both 2.5- and 5-cm^3 samples. These instruments, while basically the same, differ in size of and air velocity through the jet. These samples were counted, both before and after acid and heat treatment, at 160 times magnification on a dark-field microscope in two size ranges, greater and less than 5 µm, and all visible fibres. The preparation, heat treatment, and counting techniques used are those recommended by Mines Accident Prevention Association of Ontario (8). Comparisons with other instruments were made using the counts on untreated slides only.

The Haslam and Sartorius konimeters could not readily be placed in the chamber and operated remotely and they were set up to sample from tee pieces on a tube through which dust-laden air was drawn from the chamber continuously.

Instruments Assessing Dust by Light Scatter

The Leitz Tyndalloscope is the only instrument assessing dust by light scatter which is used to any extent in mining. The tyndalloscope (Leitz Germany, Model T II) was used. Non-respirable coarse particles were rejected by a settlement period of 20 seconds as recommended by the manufacturer. The instrument was modified for remote operation by fitting a telescope viewer and a rack and pinion drive. This modification required more elaborate calibration than the manufacturers suggest. This was done by using the Leitz intensity standard by itself and with each of the 0.7 and 1.0 density discs. These three calibration standards were cross-checked

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* On the impinger fitted with an elutriator, all particles were classified as being in the respirable size range and included with particles fewer than 5 µm.

with our instrument in normal operation and on a number of other tyndalloscopes, giving close agreement between all the instruments. The rack and pinion drive was then calibrated with all three intensity standards. It is believed that these modifications may have reduced the sensitivity slightly but they did not affect the accuracy. The dust concentration is expressed as the square of the sine of the angle between the polarizing screens ($\sin^2 \theta$).

Instruments Assessing Dust by Mass

The mass of dust is greatly influenced by the coarse non-respirable particles in the dust cloud; therefore the instruments assessing dust by mass can be split into two classes: total-dust samplers and respirable-dust samplers with which size selectors (section below - Respirable Dust Size Selection) are used to remove coarse non-respirable particles.

Total-dust samplers - an electrostatic precipitator and open filters were used. The MSA (9) portable electrostatic precipitator collects dust on the inside of an aluminum tube. A number of open filters have been used at a wide range of flow rates. The dust was assessed by weighing and, in some cases, was dispersed in liquid for assessment by other techniques (Appendix A).

Respirable-dust samplers - three samplers, the Casella (2) Hexhlett (50 ℓ/min), the Casella Gravimetric sampler (2.5 ℓ/min), and a laboratory-build model (2.83 ℓ/min) with horizontal elutriator size selectors (MRC specification (3)) were used in the comparison with other instruments. In the work described in Chapter 5, a number of samplers fitted with cyclone and horizontal elutriator size selectors were compared with each other at various flow rates.

RESPIRABLE DUST SIZE SELECTION

Rejection of coarse non-respirable dust particles is included in most dust sampling techniques and is particularly important in gravimetric assessment.

The techniques available and where used are:

1. size assessment in the microscope - used in most number assessment techniques - 5-μm top size limit by projected area;

2. settlement chamber - a 20-second settlement period is recommended prior to using the tyndalloscope;

3. horizontal elutriators - the United Kingdom Medical Research Council produced a standard specification for respirable-dust size selection; horizontal elutriators to this standard specification have been used in the bulk of the work and were fitted to the Long Period Dust Sampler, one of the impingers, and all the respirable dust samplers used to obtain the results obtained in Chapter 3; horizontal elutriators to other specifications have been used to obtain some results given in Chapter 5;

4. cyclones - cyclone size selectors have been recommended because they are smaller, are independent of orientation and give a size selection curve closer to the average lung than does a horizontal elutriator. Comparisons between different models of cyclone size selectors (10, 11) are given in Chapter 5.

AIRFLOW CONTROL AND CALIBRATION

All sampling instruments with airflows of more than 1 ℓ/min have been calibrated against wet test gas meters either directly or through a tapered tube rotating float type airflow meter. The wet test gas meters used have been calibrated in a Fuels Division Laboratory in Ottawa.

The airflow control and monitoring, if any, used have either been that of the manufacturer or they have been added here. The instruments, in which no modifications to the manufacturer's airflow control and monitoring were made, are:

Electrostatic Precipitator,
Hexhlett (in the main experimental work, but was modified later - see Chapter 5),
Gravimetric Sampler,
T12500 Thermal Precipitator,
Long Period Dust Sampler,
Konimeter,
Tyndalloscope.

The Staplex was modified by reducing motor speed by voltage control and increasing the sensitivity of the airflow meter by reducing the area of the associated orifice.

The airflow for the other filters and the impingers was obtained by connection to a vacuum manifold through a control valve and a critical orifice (12) with a vacuum gauge on its upstream side. The airflow through a critical orifice (with a tapered kinetic to static pressure, recovery section) is dependent only on its area and the upstream pressure as long as the pressure drop across it is greater than 10% of the absolute pressure on its upstream side.

THE DUST CLOUDS

Comparative dust measurements were made in a large number of dust clouds chosen to study the effects of concentration, size distribution, density, shape, and aggregation. Some subsidiary experiments on collection efficiency were carried out in dust clouds prepared by a compressed air atomizer from a dilute latex of uniform sized plastic spheres.

The effect of concentration was examined by preparing three to six dust clouds of each of twenty-two types covering a concentration range of between 4 to 1 and 10 to 1; the lowest concentration used was high enough to avoid excessive contamination by atmospheric dust. Some further comparisons were made at lower concentrations in three types of dust cloud after fitting a filter to the chamber air inlet.

Dust clouds differing in size distribution were prepared from each material by four dry methods of dust dispersion:

1. laboratory twin-jet fluid-energy mill (13),
2. rotating plate pulverizer (14),
3. compressed air ejector followed by a cyclone,
4. as 3, but bypassing the cyclone.

The feed material for methods 1 and 2 was fairly coarse, larger than 200 mesh, but that for methods 3 and 4 was prepared from coarse material by breaking in the rotating plate pulverizer. The dust clouds prepared by methods 3 and 4 from glass fibre and asbestos were not used because they contained very low concentrations of fibrous particles.

Dust clouds were prepared from coal, silica, and pyrite to study the effect of particle density; these clouds consisted of particles of near cubical shape. To study shape, clouds prepared from the minerals silica, mica, and asbestos were used. Because many of the asbestos fibres were very fine and could not be resolved in an optical microscope, glass fibre (diameter 0.25 - 0.50 μm) dust clouds were also examined.

Two types of aggregated coal dust clouds were prepared by using a spinning disc sprayer to atomize two strengths (full strength - 0.11 gm/ml, 1.4×10^{10} particles/ml; dilute - 1/10 full strength) of suspensions of coal dust in ethyl alcohol. The coal dust was prepared in the jet mill. Attempts to prepare aggregated silica dust clouds by a similar technique were unsuccessful. The preparation and properties of the dust clouds are described in detail in Appendix A.

TECHNIQUES FOR ANALYSIS OF RESULTS

The analysis is described in detail in Appendix B.

It can be expected that the relation between the dust concentrations measured by two types of instrument in one type of dust cloud should be given by the equation,

$$y = kx \qquad \text{(Eq. 1)}$$

where y and x are the dust concentrations measured by the two instruments and k is a constant.

The value of k can be expected to differ in the various types of dust clouds; this can be allowed for by using dummy variables (15). Then,

$$y = x(1+k_1 x_1)(1+k_2 x_2) \ldots (1+k_n x_n) \qquad \text{(Eq. 2)}$$

where x_2 to x_n are the dummy variables taking the value $x_i = 1$ if the measurement is made in the ith dust cloud and $x_i = 0$ if it is not. k_1 to k_n are simply related to the coefficients in each type of dust cloud as shown by reducing equation 2 to fit one dust cloud,

$$y = x(1 + k_1 \cdot 1) \qquad \text{(Eq. 3)}$$

All the other brackets reduce to 1 as, $x_2 = x_3 = \ldots = x_n = 0$.

In order to perform a regression analysis and meet the requirements for a valid statistical analysis based on least squares, it is necessary to transform this equation to a more suitable form. The most suitable form was found to be,

$$\ln \frac{y}{x} = b_0 + b_2 x_2 + \ldots + b_n x_n \qquad \text{(Eq. 4)}$$

where $\ln \frac{y}{x}$ is the dependent variable,
x_2 to x_n are the independent variables, and
b_0 to b_n are the regression coefficients.

This equation was solved using a computer with the IBM program REGRE (16).

In solving this equation it was found that checks for linearity could readily be made. Those checked showed that all relationships were linear except those between the konimeters and the other instruments. In these cases the modified relationship was used.

$$\ln \frac{k^S}{x} = b_0 + b_2 x_2 + \ldots + b_n x_n \qquad \text{(Eq. 4a)}$$

where k is the dust concentration measured by the konimeter and
S is a coefficient of non-linearity determined by the methods given in Appendix B.

The value of the coefficient S in the relationship between x and y is first determined by methods given in Appendix B. Only in comparisons with the konimeters was S found to differ significantly from unity.

The computer program was used to study the relationship between each pair of instrument types (for example, one type being the four konimeters). In this, values were given for:

1. the geometric mean ratio between the dust concentrations estimated by a pair of instrument types in all the dust clouds;
2. the difference between the mean ratio in each type of dust cloud and the overall mean;
3. the standard error of 2 above;
4. the linearity of 1 and 2 with dust concentration.

The computer program can be used to compare the dust concentration estimated by the individual instruments of one type with its mean; this gives:

5. the mean differences in the estimates of the dust concentration by the two to four instruments of each type;

6. the standard error of a dust concentration estimate by a single instrument.

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CHAPTER 3
COMPARISONS BETWEEN INSTRUMENTS ASSESSING DUST BY NUMBER OF PARTICLES

All dust concentrations by number are expressed as particles per cubic centimetre (p/cm^3).

The results presented in this chapter are abstracted and analysed to demonstrate the conclusions that have been drawn from this work. The detailed results of each test are given in Appendix C.

This section describes the results obtained in comparisons made between instruments assessing dust by number.

A typical comparison between two sampling instruments of different types is shown in Figure 3-1. This shows the wide range of results obtained, for instance, in dust clouds with concentrations estimated at 1000 p/cm^3 by a konimeter; the impinger estimates the concentration to be 100 to 500 p/cm^3. The range would be even wider if the results obtained in fibrous dust clouds had been included.

ACCURACY OF DUST ESTIMATES

The computer analysis of the dust measurements made within each group of instruments calculated the departure of the concentration estimated by the individual instruments from the group mean and the standard error for a single observation. The results obtained in the coal, silica, pyrite, and mica dust clouds are shown in Table 3-1.

The mean difference between instruments in the same group is due mainly to differences in collection efficiency and to systematic counting errors. The first probably accounts for most of the differences between the Haslam, Gathercole, and Sartorius 5-cm^3 sample konimeters, while the second accounts for the low estimates on the standard thermal precipitator as compared with the long period dust samplers and on the Sartorius 5 cm^3 as compared with the 2.5 cm^3. The konimeters give less reproducible dust concentration estimates than do the impingers and thermal precipitators.

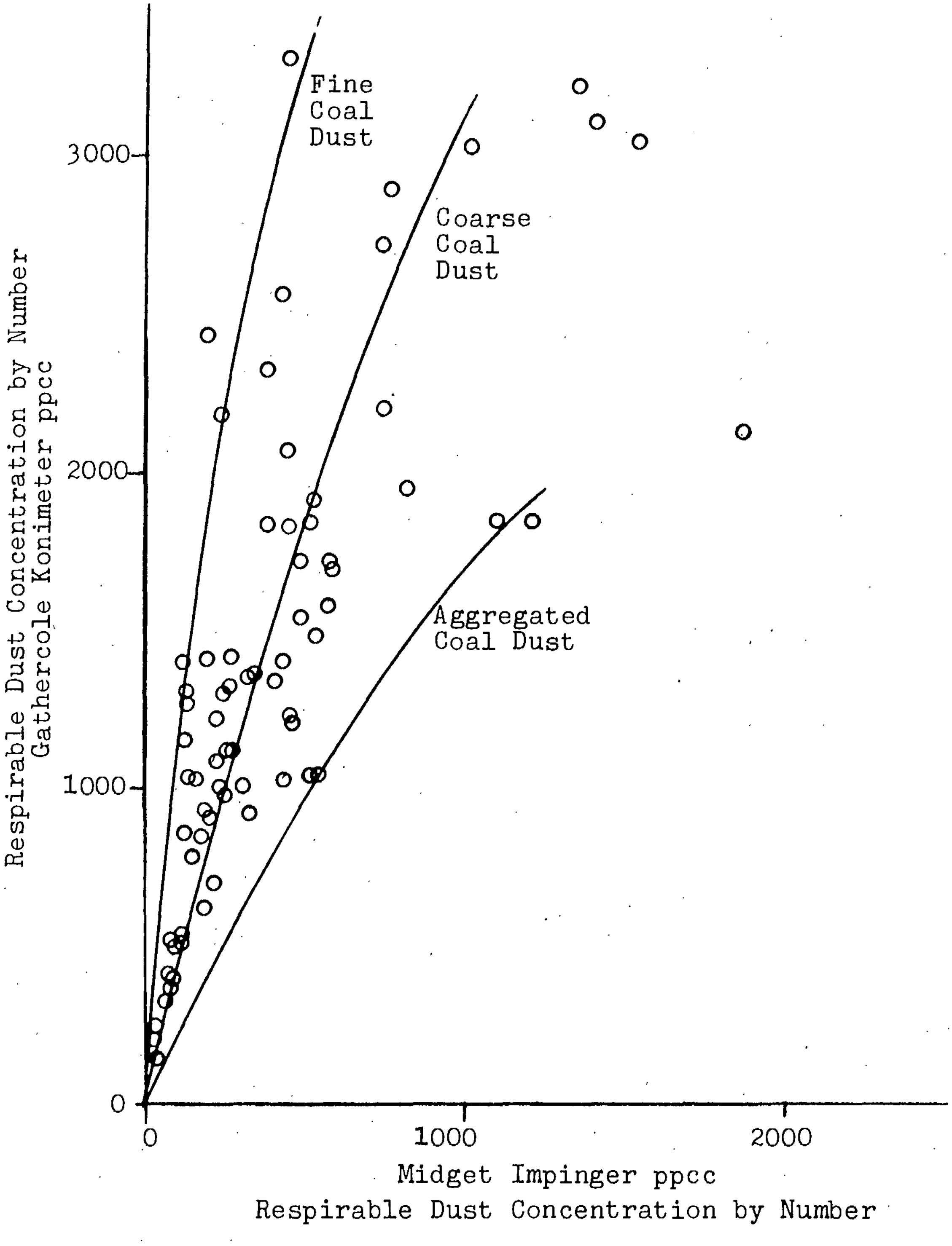

FIGURE 3.1 COMPARISON BETWEEN INSTRUMENTS ASSESSING DUST BY NUMBER with 'best fit' lines by statistical regression.

TABLE 3-1

Accuracy of Dust Estimates

Group Instrument	Ratio of Individual Instrument to Group Mean	Geometric Standard Error for Single Observation
Thermal Precipitators 1-5 μm Size Range		1.24
Standard	0.89	
Long Period (Head Only)	1.03	
Long Period	1.06	
Thermal Precipitators 0.5-5 μm Size Range		1.21
Standard	0.91	
Long Period (Head Only)	1.01	
Long Period	1.06	
Impingers		1.19
1	1.03	
2	0.98	
Elutriated	0.99	
Konimeters		1.32*
Haslam	0.84	
Gathercole	0.93	
Sartorius 5 cc	1.0	
2.5 cc	1.21	

* This is for the mean of five samples taken in each run. Normal practice is to take the mean of three samples.

THE INSTRUMENT COMPARISON INDICES

The instrument comparison indices are the geometric mean ratios of the dust concentrations measured by a pair of instruments in one type of dust cloud. The values for the comparisons between the number counting instruments are shown in Table 3-2, together with the range of the standard error of the index in each of the coal, silica, pyrite, and mica dust cloud types. It can be seen that the range of each comparison index is very high - 3.7 to 8.4 in the coal, silica, pyrite, and mica clouds - reaching 250 to 1 when the fibrous dust clouds are included. The differences in the index between dust clouds are mostly much larger than the standard error of the index in any one cloud.

THE EFFECT OF CONCENTRATION

The main comparison was carried out over a range of concentrations between 4 to 1 and 10 to 1 in each type of dust cloud. The non-linearity in the comparisons between each pair of instruments was examined by comparing the coefficients b_1 and $1/b_1'$ in the two regression equations:

$$\ln y = b_0 + b_1 \ln x + b_2 X_2 + \ldots + b_n X_n$$

and

$$\ln x = b_0' + b_1' \ln y + b_2' X_2 + \ldots + b_n' X_n$$

as described in Appendix B. It was found that this coefficient had a statistically significant value only in the comparisons with the konimeters. The relationships between the other instruments can thus be assumed linear.

The Non-Linearity of the Comparisons with the Konimeter

The regression analysis carried out on the main set of experiments showed that the comparisons between the konimeters and the other instruments were not linear with concentration. The regression analysis can be used to produce a power law of the form:

$$y = aK^S$$

where y is the dust concentration measured by another instrument; K is that

TABLE 3-2

Instrument Comparison Indices: Number/Number

Material and Dispersion Method	Instrument Comparison Index (Non-dimensional)				
	TP* 1-5 µm / Impinger	TP* ½-5 µm / Impinger	TP* 1-5 µm / Konimeter	TP* ½-5 µm / Konimeter	Impinger / Konimeter
Coal					
Aggregated					
Full Strength	0.51^{+}	0.83^{+}	0.34	0.56	0.67^{+}
Dilute	0.85^{+}	1.74^{+}	0.36	0.74	0.42^{+}
Jet Milled	1.75	5.5	0.19	0.65	0.115
Pulverised	2.3	6.2	0.30	0.88	0.14
Cyclone	1.8	3.2	0.42	0.74	0.22
No Cyclone	1.7	3.1	0.52	0.90	0.28
Silica					
Jet Milled	1.5	4.8	0.27	0.91	0.19
Pulverised	1.25	3.8	0.32	0.99	0.25
Cyclone	1.26	2.7	0.39	0.83	0.30
No Cyclone	1.28	2.8	0.32	0.72	0.24
Pyrite					
Jet Milled	0.62	5.25	0.13	1.12	0.24
Pulverised	1.03	6.95	0.30	2.05	0.28
Cyclone	1.04	2.0	0.32	0.68	0.31
No Cyclone	.99	1.9	0.30	0.63	0.31
Mica					
Jet Milled	1.26	3.7	0.28	0.86	0.255
Pulverised	1.18	4.9	0.19	0.83	0.175
Cyclone	0.93	3.0	0.22	0.80	0.27
No Cyclone	0.96	3.1	0.22	0.74	0.26
Geometric Standard Error Max.	1.18	1.28	1.16	1.18	1.22
Min.	1.17	1.15	1.14	1.14	1.15
	Non Fibrous and Fibrous Particles				
Glass Fibre					
Jet Milled		1.95		0.24	0.088
Pulverised		5.7		0.28	0.051
Asbestos					
Jet Milled		4.7		0.47	0.095
Pulverised		3.3		0.51	0.155
	Fibrous Particles Only				
Glass Fibre					
Jet Milled		0.62		2.1	2.95
Pulverised		2.1		3.9	1.22
Asbestos					
Jet Milled		7.3		63	10.1
Pulverised		4.25		15.7	3.0

* Thermal precipitator with size range.

\+ These results exclude the impinger fitted with an elutriator (see Section 5.8).

estimated by the konimeter; a is a constant dependent on the cloud type; and S is the exponent. The best values of the exponent are between 1.1 and 1.4 for comparisons with the four konimeters in the main set of experiments.

However, this equation is only valid over a limited range of concentrations and an alternative presentation of the results obtained in three types of dust cloud is shown in Figure 3.2. This figure shows the dependence of the konimeter comparison index* on the dust concentration. It appears that four major phenomena occur:

1. an apparent difference in the type of relationship for the Haslam konimeter and the others;
2. a sharp increase in the instrument comparison index at low concentrations on three of the four konimeters;
3. a gradual decrease in the index at concentrations by mass above a few milligrams per cubic meter;
4. a marked difference in the comparison index with some konimeters in some dust clouds between the main set of experiments and the later set; this appears to be akin to the 'wandering bias' described by Beadle (1).

The reasons for these phenomena are not clear. Beadle (1) has described non-linear and erratic behaviour of konimeters. The Haslam konimeter clearly differs from the Gathercole and Sartorius konimeters in having a much weaker pump action.

THE EFFECT OF PARTICLE SIZE DISTRIBUTION

Data on the size distributions of the dust clouds determined by a number of techniques are given in Appendix A. These have been used as size classifications and a correlation analysis with the value of each comparison index was carried out. It was found that the comparisons between all these instruments showed a significant correlation with one or more of the size classifications.

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* The comparisons were made with respirable mass (mg/m^3) as the Hexhlett gave the most reproducible estimate of concentration over such a wide range.

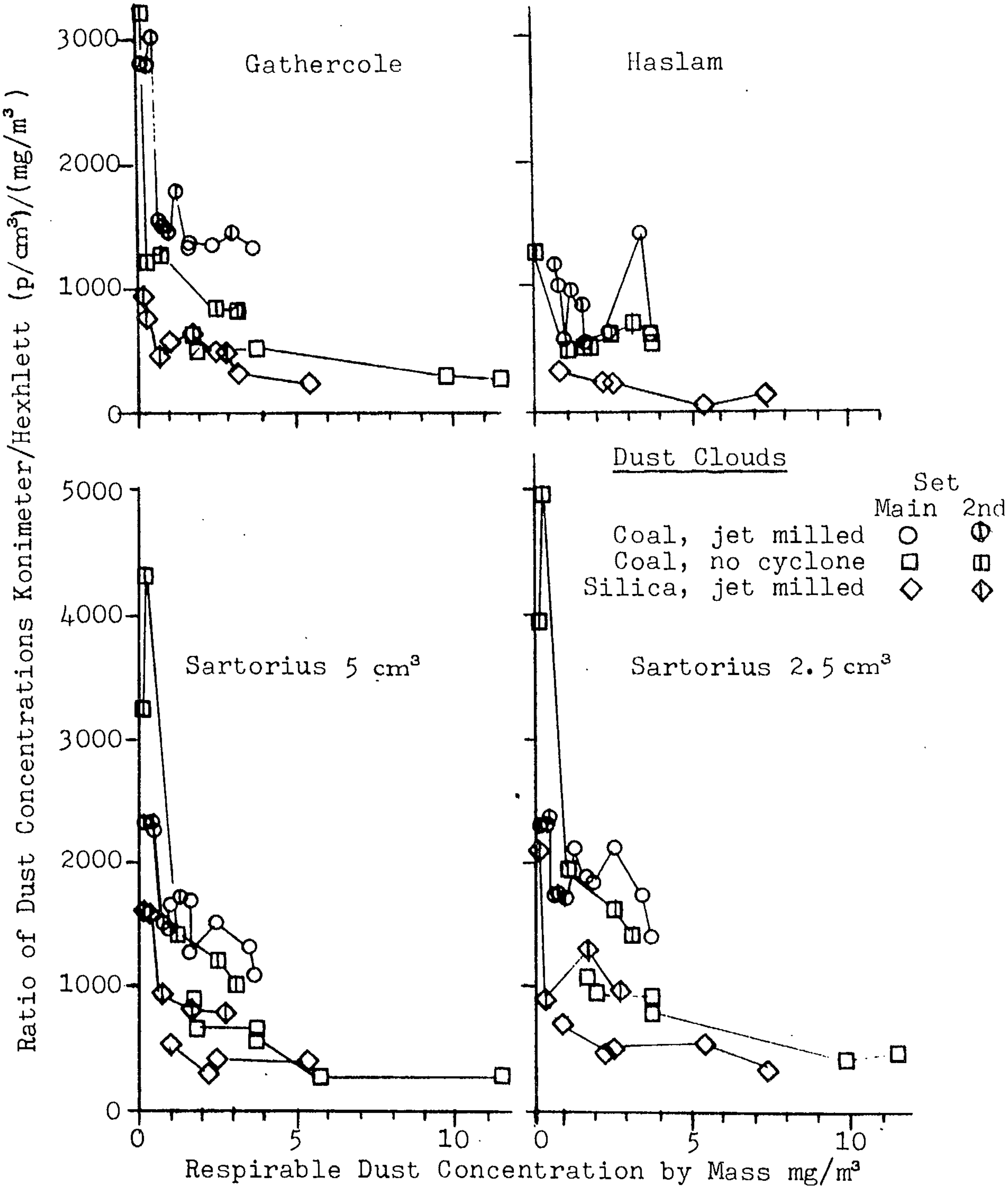

FIGURE 3.2 THE EFFECT OF DUST CONCENTRATION ON THE RELATIVE CONCENTRATIONS ESTIMATED BY THE KONIMETER.

The comparison indices are shown in Figure 3.3, plotted against the size classification by projected area obtained by microscopic examination of the thermal precipitator samples. It can be seen that there are apparent marked changes in index with size distribution in most of these comparisons. It can be seen that the concentration estimates made by the impingers and konimeters in comparison with the thermal precipitators (1 to 5-µm size range) tend to fall in the coarser dust clouds, while in comparison with the 0.5to 5-µm size range they tend to rise.

EFFECT OF DENSITY

The materials, coal, silica, and pyrite, were chosen to cover a range of densities with particles of similar near-cubic shape. There are suggestions of differences between these three materials as can be seen in Figure 3.3, particularly in the comparisons with the impinger. It appears that the relative count by the impinger increases with density in the order, coal (density 1.4 g/cm^3), silica (2.6 g/cm^3), and pyrite (5 g/cm^3).

EFFECT OF PARTICLE SHAPE

The materials, silica, mica, glass fibre, and asbestos, were chosen to give particles of different shapes; near cubic, plate, coarse fibre and fine fibre respectively. Most of the glass fibres were 0.25 to 0.5 µm in diameter but many of the asbestos fibres could not be resolved.

Only minor differences were found between silica and mica, as shown in Figure 3.3. Extreme values of the comparison index were found in some of the fibrous dust clouds, particularly in the assessment of fibrous particles alone (Table 3.2). The 'shape' effect cannot be distinguished from possible size distribution effects because the size distributions of the fibrous dust clouds differ greatly from those of the other dust clouds. The fibrous dust clouds have three components; fine particles less than 1 µm, fine fibres, and a coarse non-respirable portion of matted fibres, while there are very few particles of intermediate size. The other dusts have a smooth distribution from 0.5 to 10 µm.

EFFECT OF AGGREGATION

Dust clouds containing aggregated particles were prepared by spraying coal dust suspensions; the particles in each liquid drop remained attached to each other after evaporation. Two types of cloud were prepared from full strength and dilute suspension respectively. The

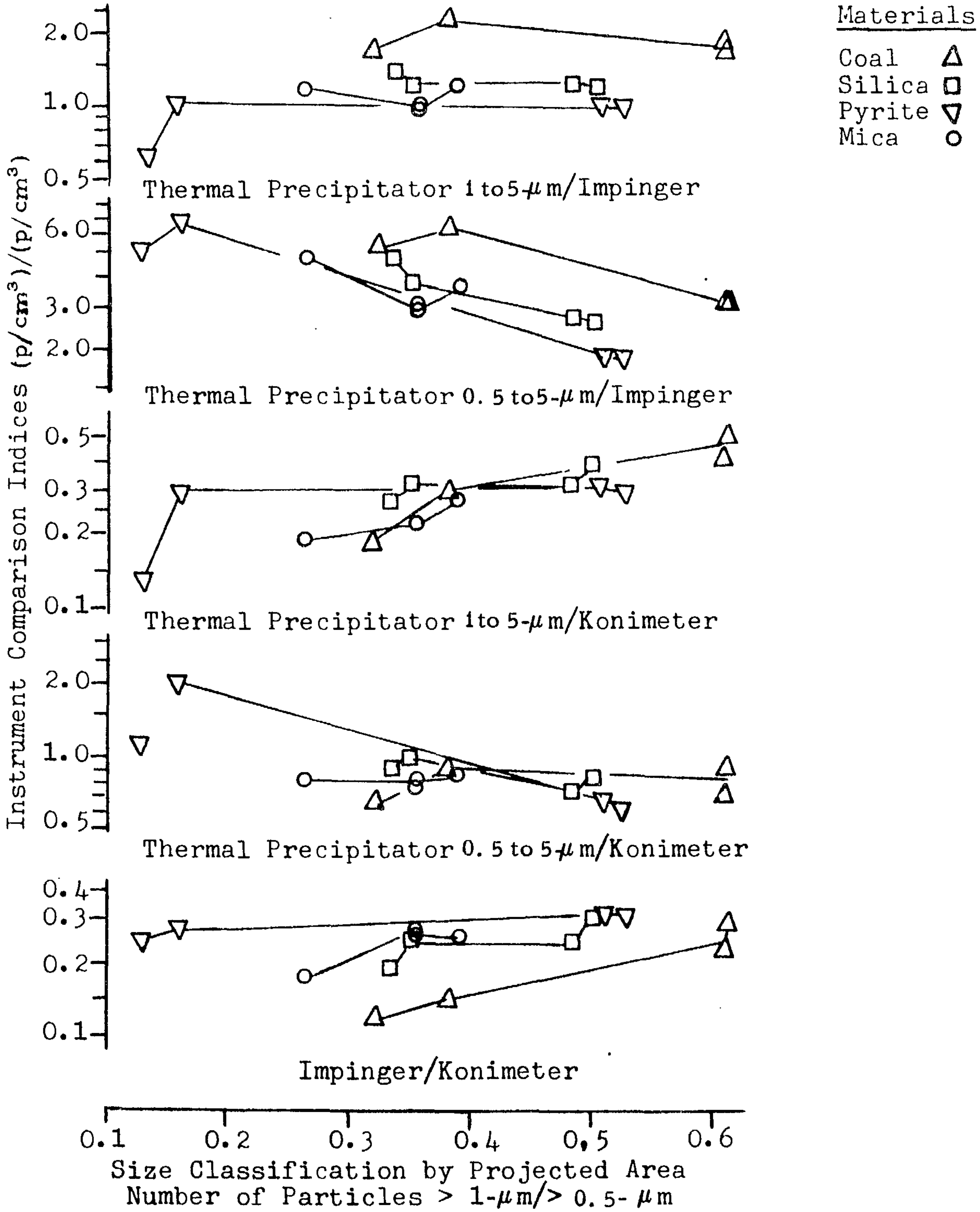

FIGURE 3.3 EFFECT OF PARTICLE SIZE AND DENSITY ON COMPARISON INDICES OF DUST SAMPLING INSTRUMENTS.

distribution of particles among the aggregates is shown in Table 3-3. It was not possible to distinguish particles and identify aggregates in the 0.5 to 1-μm size range. In contrast, there were very few aggregates in the coal, silica, pyrite, and mica dust clouds prepared by dry dispersion. The number concentration for the thermal precipitator samples was obtained by following the NCB rule of one count for each set of touching particles.

The instrument comparison indices for the aggregated dust clouds were given in Table 3.2. The index in the aggregated dusts extends outside the range of those for the other non-fibrous dust clouds for the comparisons with the impinger and for the comparison between the thermal precipitator (0.5 to 5-μm size range) and the konimeter.

TABLE 3-3

Distribution of Particles in Aggregated Dust Clouds

	Individual Particles %	Relative Number of Aggregates Containing 2 or 3 Particles %	Relative Number of Aggregates Containing 4 or more Particles %
Full strength suspension			
> 5-μm size range	47	40	13
1 to 5-μm size range	80	20	0.3
Dilute suspension			
> 5-μm size range	52	30	18
1 to 5-μm size range	81	19	.1

The midget impingers gave relatively high counts because the dust particles forming the aggregates are dispersed in the collecting liquid and counted separately. The impinger, fitted with an elutriator, gave a count 0.7 times those of the other two impingers, suggesting that the coarse non-respirable aggregates contained a sufficient number of small particles to increase the count by 40%.

COMPARISON OF MICROSCOPE TECHNIQUES

The wide variations in the instrument comparison index, particularly in the fibrous clouds, led to a minor study in which two thermal precipitator (Long Period Dust Sampler) slides from each type of dust cloud were counted using the impinger and konimeter microscope assessment techniques. The geometric means of the ratios from each pair of slides are shown in Table 3.4 as the microscope comparison index. These results show considerable scatter; the T.P./Impinger microscope comparison has a range of 7 to 1, the T.P./Konimeter 6.7 to 1, and the Impinger/Konimeter 4.3 to 1. The most extreme values occur in the finest dust clouds, jet-milled pyrite and asbestos fibres. Apparently neither the impinger microscope technique with its medium-resolution light field nor the konimeter microscope with its medium resolution dark field see or count particles less than 0.5 μm in size. Also the impinger and konimeter microscope techniques are not nearly as effective as the high-resolution thermal precipitator microscope in distinguishing fine fibres.

COMPARISON OF THE COLLECTION EFFICIENCIES

The collection efficiency of the instruments was examined using three techniques:

1. in dust clouds prepared from uniform-sized spheres;
2. by using the same microscope technique on samples taken by the different techniques;
3. for impingers only, weighing the dust in the air passing through the impingers after collection on a filter.

The clouds of uniform-sized spheres were prepared by atomizing with compressed air a dilute aqueous latex (Dow Chemical Co.) of polystyrene spheres. The size used is that given by the maker and measured by electron microscopy; however, the surface active agent used to disperse the spheres is hygroscopic and forms a thin liquid film over each sphere. It is believed that the film is less than 0.1 μm thick, i.e. the diameter of the spheres is between the stated size, d, and d + 0.2 μm. Because high-resolution microscopy is needed to distinguish and count the finer spheres, 0.2-mm settling cells were used for the impinger and the konimeter spots were collected on cover slips. Because the density of the spheres, about 1.0 g/ml, was not much greater than that of the alcohol, 0.9, the settling periods in the impinger cells were increased to permit full settlement.

TABLE 3-4

Comparison of Microscope Techniques on Thermal Precipitator Slides

Dust Cloud	Microscope Comparison Index		
	T.P.* / Impinger	T.P.* / Konimeter	Impinger / Konimeter
Coal			
Jet Milled	1.3	1.35	1.05
Pulverised	1.5	1.15	0.75
Cyclone	1.55	1.0	0.67
No Cyclone	1.25	1.4	1.1
Silica			
Jet Milled	1.6	1.4	0.88
Pulverised	1.7	1.2	0.71
Cyclone	1.3	1.0	0.80
No Cyclone	1.4	1.1	0.63
Pyrite			
Jet Milled	0.84	2.9	3.8
Pulverised	1.6	1.5	0.86
Cyclone	1.3	1.1	0.85
No Cyclone	1.0	1.0	1.0
Mica			
Jet Milled	1.55	1.4	0.9
Pulverised	1.4	1.0	0.75
Cyclone	2.3	1.1	0.53
No Cyclone	1.8	1.45	0.98
	Non Fibrous and Fibrous		
Glass Fibre			
Jet Milled	1.15	1.5	0.96
Pulverised	1.4	1.1	1.0
Asbestos			
Jet Milled	3.9	2.4	0.62
Pulverised	2.7	3.2	0.80
	Fibres Only		
Glass Fibre			
Jet Milled	1.6	3.75	2.3
Pulverised	3.0	6.7	2.2
Asbestos			
Jet Milled	6.0	3.8	0.87
Pulverised	2.4	4.5	1.75

* The thermal precipitator technique counts are in the 0.5 to 5-μm size range and/or all visible fibres.

The results obtained are summarized in Figure 3.4. While it is generally (2) accepted that thermal precipitators have a very high efficiency, these results show that they collect less than do the impingers in the 1 to 2-μm size range. This is believed to be due to the deposition of some of the spheres in the metal intake channels of the thermal precipitators due to an electrostatic charge on the spheres, charge separation having occurred during atomization. Efforts to neutralize the charges with an ionizer were only partly successful.

Figure 3.4 shows that the comparative collection efficiency of the impingers falls rapidly for spheres less than 1 μm in diameter. The konimeters, with the normal adhesive layer (prepared from 2% petroleum jelly in xylene), show low collection efficiencies for spheres of all sizes. The spheres were also spread over an area much larger than the normal spot, suggesting that bouncing occurred. However, when using a thick adhesive layer (10% petroleum jelly), the spheres were only found in the normal spot area and the collection efficiencies were much higher, rising to slightly more than that of the thermal precipitators. A steep fall in collection occurred below 0.7 μm on the Gathercole and Sartorius konimeters but for the Haslam, with its much softer action, the fall occurred between the 1.8 and 1.3-μm-diameter spheres.

In the second technique, the results obtained by normal counting of impinger and konimeter samples were compared with special counts of the thermal precipitator samples using the impinger and konimeter microscope techniques. This technique, of course, compares the thermal precipitator with the impinger and its associated settling and counting cell. The results obtained are shown in Table 3-5. It can be seen that the thermal precipitator collects 1.2 to 7.5 times more dust than does the impinger, the effect being particularly noticeable in the fine dust clouds - jet-milled pyrite and fibres. Thus, the lower size limit is defined by the collection and settlement characteristics of the impinger and its cell. The konimeter gives a much higher count, up to five times except for fibres only, than the thermal precipitator; this again is most marked in the clouds containing fine particles. As the thermal precipitator is reputed to have a very high collection efficiency, these results suggest that the konimeter can produce spurious particles, or countable impressions, in the adhesive layer with fine dust particles. It is clear that the impinger and the konimeter are poor at collecting fine fibrous particles.

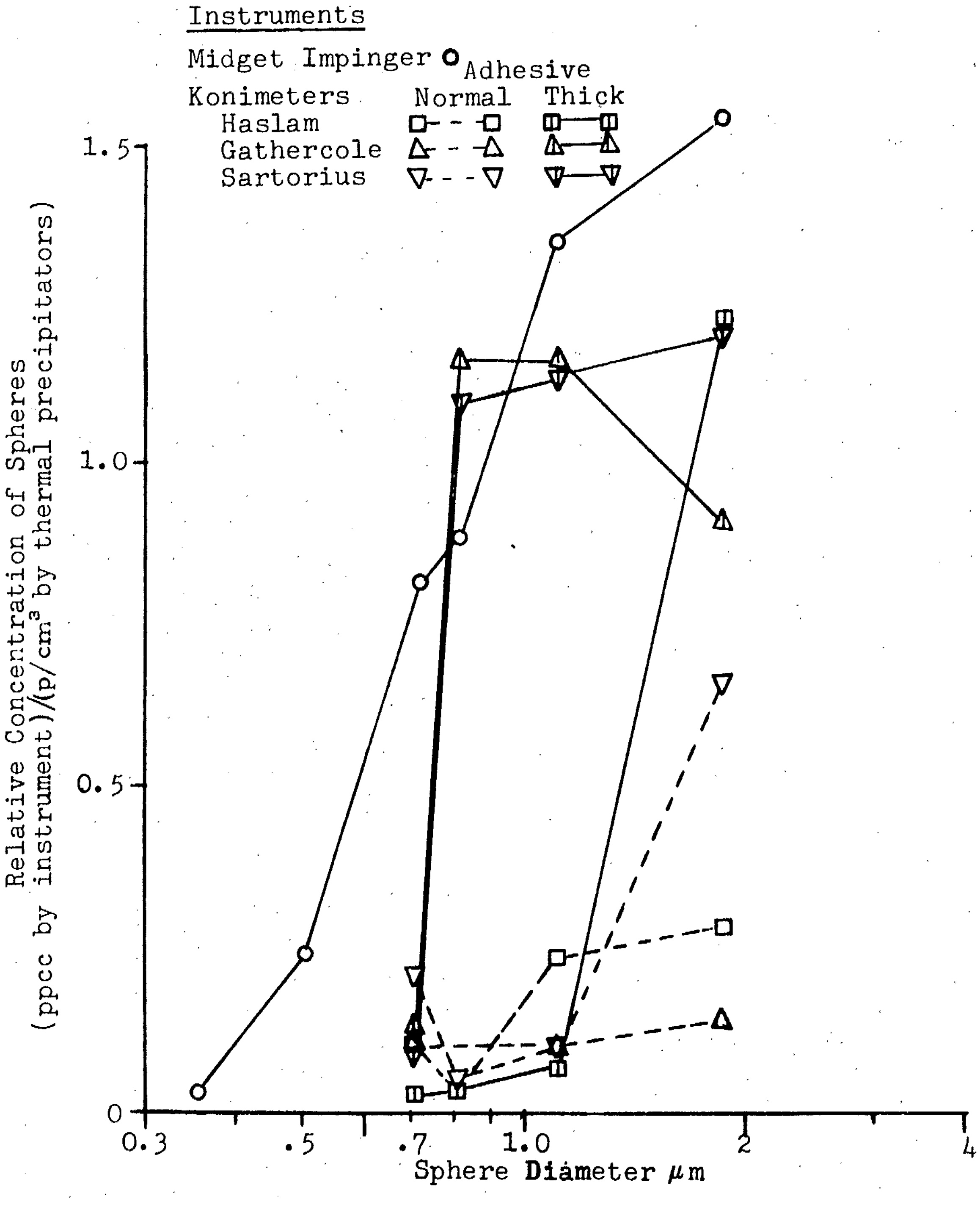

FIGURE 3.4 COLLECTION EFFICIENCIES OF IMPINGERS AND KONIMETERS COMPARED TO THAT OF THERMAL PRECIPITATORS.

TABLE 3-5

Comparison of Thermal Precipitators with the Impingers and Konimeters using the Impinger and Konimeter Microscope Techniques Respectively

Dust Cloud	Collection Comparison Index	
	T.P.* / Impinger**	T.P.+ / Konimeter
Coal		
Jet Milled	3.7	0.39
Pulverised	5.5	0.79
Cyclone	2.4	0.56
No Cyclone	3.1	0.62
Silica		
Jet Milled	3.9	0.74
Pulverised	2.45	0.64
Cyclone	2.05	0.6
No Cyclone	1.7	0.44
Pyrite		
Jet Milled	5.4	0.23
Pulverised	5.0	1.05
Cyclone	2.6	0.53
No Cyclone	1.75	0.46
Mica		
Jet Milled	1.7	0.48
Pulverised	3.9	0.89
Cyclone	1.2	0.53
No Cyclone	1.5	0.46
	Non Fibrous and Fibrous	
Glass Fibre		
Jet Milled	2.65	0.2
Pulverised	5.4	0.26
Asbestos		
Jet Milled	1.25	0.21
Pulverised	1.5	0.19
	Fibres Only	
Glass Fibre		
Jet Milled	2.3	4.2
Pulverised	4.1	2.3
Asbestos		
Jet Milled	3.1	61
Pulverised	7.5	33

* Thermal precipitator assessed by impinger microscope.

\+ Thermal precipitator assessed by konimeter microscope.

** Includes effects due to both collection and counting cell settlement.

In the third technique the filter. placed in the exhaust air from the impingers, collected between 4 and 20% of the mass of respirable dust (Hexhlett) present in the dust cloud, i.e., the collection efficiency of the impingers was 80 to 96% by mass in the respirable size range. The low values occurred in the fine dust clouds and the high in the coarse.

THE COMPARISON OF COUNTING SIZE RANGES ON THERMAL PRECIPITATOR SAMPLES

There is general agreement throughout the world that the top limiting size of respirable dust is 5 μm and that particles with a projected area larger than a 5-μm-diameter circle are not counted; however, widely different lower limiting sizes have been used: 1 μm, 0.5 μm and all visible (A.V.) particles with various microscope techniques. Table 3-6 shows the relative increase in number concentrations that are found with the thermal precipitator when the 1to5-μm counting range is extended to finer sizes.

THE EFFECT OF HEAT TREATMENT AND ACID WASH ON KONIMETER DUST ESTIMATES

The incineration and acid wash treatment of konimeter slides was introduced in South African gold mines to emphasize the silica content in dust assessment, and the treatment is also recommended by the MAPAO (3) for use in high-silica mines in Ontario. The counting of konimeter samples in this study was done both before and after treatment. All the results given elsewhere in this report refer to counts on untreated slides. The effect of treatment expressed as the mean ratio of treated to untreated counts for each material was 0.05 for coal, 1.04 for silica, 0.91 for pyrite, 0.96 for mica, 0.61 for glass fibre, and 0.41 for asbestos. The variability of these ratios was high, the standard error of a single observation (mean of 5 spots) being about 70%.

REFERENCES

1. Beadle, D.G., "An Investigation of the Performance and Limitations of the Konimeters", J. Chem. Met. Min. Soc. S.A., Vol. 51, pp 265-283 (1951).

2. Anon., "Air Sampling Instruments for Evaluation of Atmospheric Contaminants", Amer. Conf. of Gov. Ind. Hyg., p. B-5-3 (1966).

TABLE 3-6

Comparison of Counting Size Range on Thermal Precipitator Slides

Dust Cloud	Counting Size Range Comparison Index	
	$\frac{0.5 - 5\ \mu m}{1 - 5\ \mu m}$	$\frac{A.V.^{*} - 5\ \mu m}{1 - 5\ \mu m}$
Coal		
Jet Milled	3.1	7.2
Pulverised	2.9	6.2
Cyclone	1.8	2.5
No Cyclone	1.8	---
Silica		
Jet Milled	3.3	12
Pulverised	2.7	3.5
Cyclone	1.6	2.4
No Cyclone	2.1	2.6
Pyrite		
Jet Milled	8.9	23
Pulverised	5.7	35
Cyclone	2.2	3.0
No Cyclone	2.05	---
Mica		
Jet Milled	3.1	16
Pulverised	5.5	16
Cyclone	3.3	5.5
No Cyclone	3.15	---

* All particles visible using a high-resolution microscope (2 mm oil immersion, light field, N.A. ≃ 1.0) were counted.

3. Anon, "Konimeter Dust Sampling as Practised by MAPAO Engineers", Mines Accident Prevention Association of Ontario (1959).

CHAPTER 4

COMPARISON BETWEEN INSTRUMENTS ASSESSING DUST BY NUMBER, BY LIGHT SCATTER AND BY MASS

This chapter summarizes the comparisons between instruments assessing dust by number, by light scatter, and by mass. The detailed results are given in Appendix C. All dust concentrations by number are expressed as particles per cubic centimetre (p/cm^3). The mean number is introduced here as the geometric mean of the concentrations assessed by the three types of instruments - thermal precipitators, impingers, and konimeters.

Light-scatter is measured with the tyndalloscope and is given in the relative unit - $\sin^2\theta$ where θ is the angle between the polarizing screens. All mass concentrations are expressed in milligrams per cubic metre (mg/m^3).

Many references are made in this chapter to comparisons between estimates of dust concentration by various physical parameters of the dust particles as well as by various types of instrument. The ratios of the two dust concentrations being compared are termed 'comparison indices'. When comparing two physical parameters, these will be abbreviated to 'mass/number' index, 'mass/light scatter index', or 'number/light scatter' index. These are given as straight ratios of the measured dust concentrations or 1000 times greater or less than these, whichever gives a convenient range of numbers. The mass/number index follows European usage where it is defined as $(mg/m^3)/(10^{-3}. p/cm^3)$.

To assist in understanding the analysis and presentation of results, the comparison between respirable mass, as estimated by the Hexhlett, and number count, as estimated by the Gathercole konimeter, is shown in Figure 4-1. In this, the concentrations estimated by each instrument in each dust cloud are shown plotted against each other. The very wide spread can be seen; at a number concentration of about 1200 p/cm^3, the mass concentration varies from 0.6 to 5.4 mg/m^3 or over a range of 9 to 1. Also shown are the 'best fit' relationships for selected types of dust cloud.

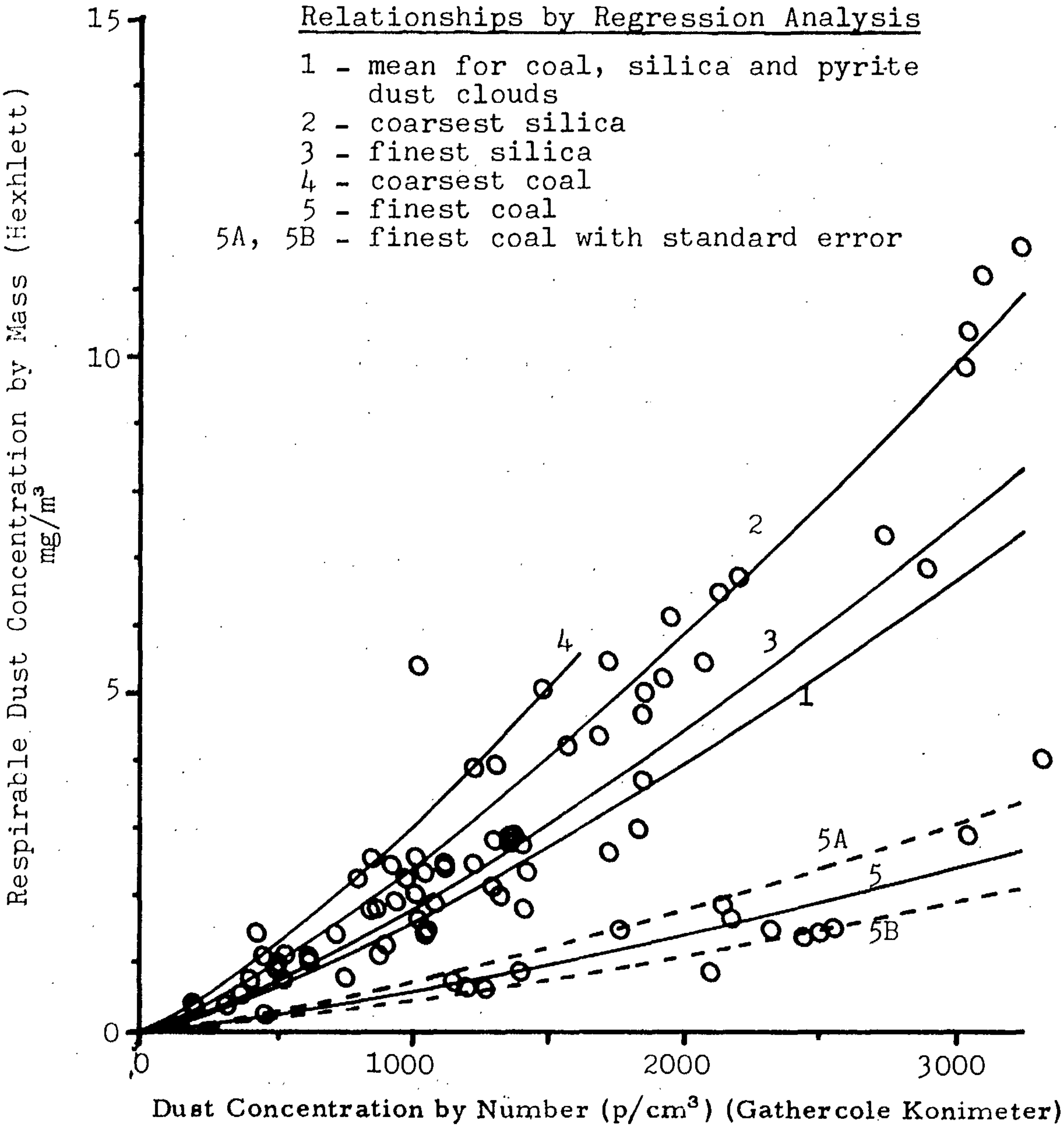

FIGURE 4. 1: COMPARISON OF DUST ASSESSMENTS BY MASS AND BY NUMBER.

TABLE 4-1

Accuracy of the Dust Estimates by Each Instrument

Group	Ratio of Individual Instrument to Group Mean	Geometric Standard Error for Single Dust Estimate
Respirable Mass		1.16
Hexhlett	0.98	
NCB MRE	1.02	
Mean Number Range		1.19 to 1.32+
Light Scatter		1.15*
Tyndalloscope		
Total Mass		1.20
Electrostatic	0.97	
104 ℓ/min Open Filter	1.02	
23 ℓ/min Open Filter	1.01	

\+ Detailed results for the instruments assessing dust by number were given in Chapter 3.

* This estimate is based on the mean of twenty readings and the variability of the calibration.

ACCURACY OF MEASUREMENT BY EACH INSTRUMENT TYPE

Table 4-1 shows the mean differences between the instruments of each type and the standard error of a single estimate of the dust concentration. Also given in this table are the results obtained for gravimetric samplers measuring the total dust, i. e. that including the coarse non-respirable particles.

The standard error for an estimate of respirable mass is large because of errors due to the low weights collected on the 2. 5 ℓ/min samples.

THE COMPARISON INDICES

The mean ratios obtained between estimates of respirable dust by mass, number and light-scatter are shown in Table 4-2. Also given is the ratio of total to respirable mass. It can be seen that the range of each index is very large: 4. 8 to 1 for mass/number, 13. 4 to 1 for mass/light-scatter and 16. 5 to 1 for number/light-scatter. This is much greater than the standard error of the estimate of the comparison index in any one dust cloud - 5 to 25%.

Tables 4-3 and 4-4 show, for reference, the comparisons of mass and light-scatter with the separate types of instrument assessing dust by number.

THE EFFECT OF CONCENTRATION

The main experiments were done over a concentration range of between 4 and 10 to 1 in each type of dust cloud and tests for non-linearity, i. e., variation in the comparison index with concentration, were made using the techniques described in Appendix B. It was found that the comparisons between total mass, respirable mass, thermal precipitators, impingers, and light-scatter ($\sin^2\theta$) on the tyndalloscope were linear within the limits of statistical error, though the comparisons between these instruments and the konimeters showed significant non-linearity as discussed in Chapter 3.

In the further comparisons at lower concentrations, linearity was maintained between respirable mass, total mass, and number, by impingers and thermal precipitators. The light-scatter instrument was too insensitive to measure these low dust concentrations.

THE EFFECT OF PARTICLE SIZE DISTRIBUTION

Data on size classifications of these dusts, in terms of falling speed (comparison of total and respirable mass), are given in Table 4-2 and, in terms of projected area on thermal precipitator slides, are given in Appendix A. Correlation analysis showed that there is a statistically significant effect of dust size classification on the instrument comparison index between most pairs of instruments. Figures 4-2, 4-3, and 4-4 show plots of the comparison indices against three size classifications for the dust clouds prepared from coal, silica, pyrite, and mica. These show a marked increase in mass/number and mass/light-scatter indices with increasing coarseness of the dust cloud, while the number/light-scatter index shows no definite trend.

THE EFFECT OF DENSITY

Figures 4-2, 4-3, and 4-4 show the effects of size classification on the mass/mean-number, mass/light-scatter, and mean-number/light-scatter comparison indices respectively. It can be seen that there are marked differences between the plots for different minerals in some of the figures but not in others.

However, only for the two top figures in Figure 4-2 is there a definite grading with density thus confirming the expected effect of density on the mass/number index. Figures 4-3 and 4-4 suggest that there may be an effect due to opacity rather than density on the mass/light-scatter and number/light-scatter indices as the minerals if anything, split into the two groups, coal-pyrite and silica-mica.

THE EFFECT OF PARTICLE SHAPE

Silica, mica, glass fibre, and asbestos were chosen to give clouds with near-cubical, plate-like, fibre, and fine-fibre particle shapes respectively. The plots against size classification in Figures 4-2 to 4-4 suggest that the effects of the differences between silica and mica are small. The fibrous dust clouds, particularly those of glass fibre, tend to give extreme values of the comparison indices (Tables 4-2, 4-3, and 4-4). It is difficult, however, to separate shape effects from those due to the great differences in size distribution. The fibrous dusts consist of three components: fine particles, fine fibres, and coarse matts of fibre with very few particles in the 2 to 10-μm size range, whereas the other clouds have a smooth distribution from 0.5 to 10 μm.

TABLE 4-2

Instrument Comparison Indices between Mass Number and Light Scatter

	$\frac{\text{Respirable Mass}}{\text{Mean Number}}$ $\frac{(\text{mg/m}^3)\cdot 10^{3*}}{(\text{p/cm}^3)}$	$\frac{\text{Respirable Mass}}{\text{Light Scatter}}$ $\frac{(\text{mg/m}^3)}{(\sin^2\theta)}$	$\frac{\text{Mean Number}}{\text{Light Scatter}}$ $\frac{(\text{p/cm}^3)\cdot 10^{-3}}{(\sin^2\theta)}$	$\frac{\text{Respirable Mass}}{\text{Total Mass}}$
Coal				
Aggregated				
Full Strength	4.6	591	128	0.61
Dilute	3.8	296	76	0.70
Jet Milled	1.8	95	57	0.84
Pulverised	2.0	190	80	0.64
Cyclone	5.0	420	80	0.61
No Cyclone	5.3	390	69	0.39
Silica				
Jet Milled	3.15	95	31	0.74
Pulverised	2.9	270	91	0.47
Cyclone	3.5	170	48	0.57
No Cyclone	3.8	150	40	0.37
Pyrite				
Jet Milled	1.25	150	132	0.80
Pulverised	2.5	135	56	0.60
Cyclone	4.05	330	79	0.44
No Cyclone	3.9	350	87	0.24
Mica				
Jet Milled	3.8	125	35	0.84
Pulverised	2.55	130	49	0.83
Cyclone	3.3	140	44	0.71
No Cyclone	3.85	160	44	0.71
Glass Fibre				
Jet Milled	6.0	51	9	0.28
Pulverised	6.0	44	8	0.60
Asbestos				
Jet Milled	1.8	75	43	0.64
Pulverised	2.1	120	60	0.74

* referred to as the Mass Number Index in U.K. Publications.

TABLE 4-3

Instrument Comparison Indices: Mass/Number

Material and Dispersion Method	Mass Number Index $(mg/m^3) . 10^3/(p/cm^3)$				
	Total Mass TP* 1-5 μm	Hexhlett TP* 1-5 μm	Hexhlett TP* 1.2-5 μm	Hexhlett Impinger	Hexhlett Konimeter
Coal					
Aggregated					
Full Strength	16.7	9.7	6.0	4.8	3.3
Dilute	10.3	7.3	3.6	6.1	2.6
Jet Milled	3.8	3.5	1.1	6.5	0.74
Pulverised	6.4	3.7	1.35	8.3	0.74
Cyclone	12.0	7.2	3.9	12.3	2.7
No Cyclone	18.8	7.2	3.8	12.0	3.2
Silica					
Jet Milled	9.3	6.3	1.95	8.9	1.8
Pulverised	13.2	5.5	1.9	7.3	1.8
Cyclone	10.9	5.9	2.75	7.4	2.15
No Cyclone	18.5	6.7	3.0	8.45	2.1
Pyrite					
Jet Milled	7.0	5.5	0.68	3.3	0.87
Pulverised	12.4	6.95	1.0	7.1	2.2
Cyclone	17.1	7.6	3.6	7.6	2.3
No Cyclone	32.2	7.8	3.7	7.2	2.2
Mica					
Jet Milled	9.4	7.65	2.6	8.4	2.5
Pulverised	10.0	7.5	1.75	8.2	1.6
Cyclone	13.1	8.35	2.6	6.7	2.15
No Cyclone	12.9	9.6	2.9	7.9	2.5
Glass Fibre					
Jet Milled			7.2	19	1.25
Pulverised			4.8	34	1.3
Asbestos					
Jet Milled			1.35	6.9	0.66
Pulverised			1.75	5.6	0.96
Geom.+ Stan. Error Max.	1.12	1.12	1.14	1.18	1.26
Min.	1.11	1.11	1.10	1.12	1.20

* Thermal precipitator with size range.

\+ In dust clouds prepared by dry dispersion from coal, silica, pyrite and mica.

TABLE 4.4

Instrument Comparison Indices: Number/Light Scatter

Material and Dispersion Method	Instrument Comparison Index $(p/cm^3) . 10 /(\sin^2\theta)$ TP* 1-5 μm	 TP* 1/2-5 μm	 Impinger	 Konimeter
	Tyndalloscope	Tyndalloscope	Tyndalloscope	Tyndalloscope
Coal				
Aggregated				
Full Strength	63	104	113	179
Dilute	42	83	47.5	111
Jet Milled	26	88	15.5	135
Pulverised	49	140	23	159
Cyclone	59	110	31	149
No Cyclone	53	99	30	110
Silica				
Jet Milled	14	49	11.5	54
Pulverised	46	145	35	147
Cyclone	28	63	23	76
No Cyclone	21	50	18	69
Pyrite				
Jet Milled	26	230	49	206
Pulverised	19	135	20	66
Cyclone	43	92	40	135
No Cyclone	45	96	46	152
Mica				
Jet Milled	15.5	49	16	57
Pulverised	17	75	17	90
Cyclone	16	55	22	69
No Cyclone	16	55	21	75
Glass Fibre				
Jet Milled		7.6	3	32
Pulverised		10	1.5	36
Asbestos				
Jet Milled		55	12	117
Pulverised		70	22	137
Geom.+ Stan. Error Max.	1.16	1.19	1.25	1.26
Min.	1.15	1.15	1.17	1.17

* Thermal precipitator with size range.

+ For dust clouds prepared by dry dispersion from coal, silica, pyrite and mica.

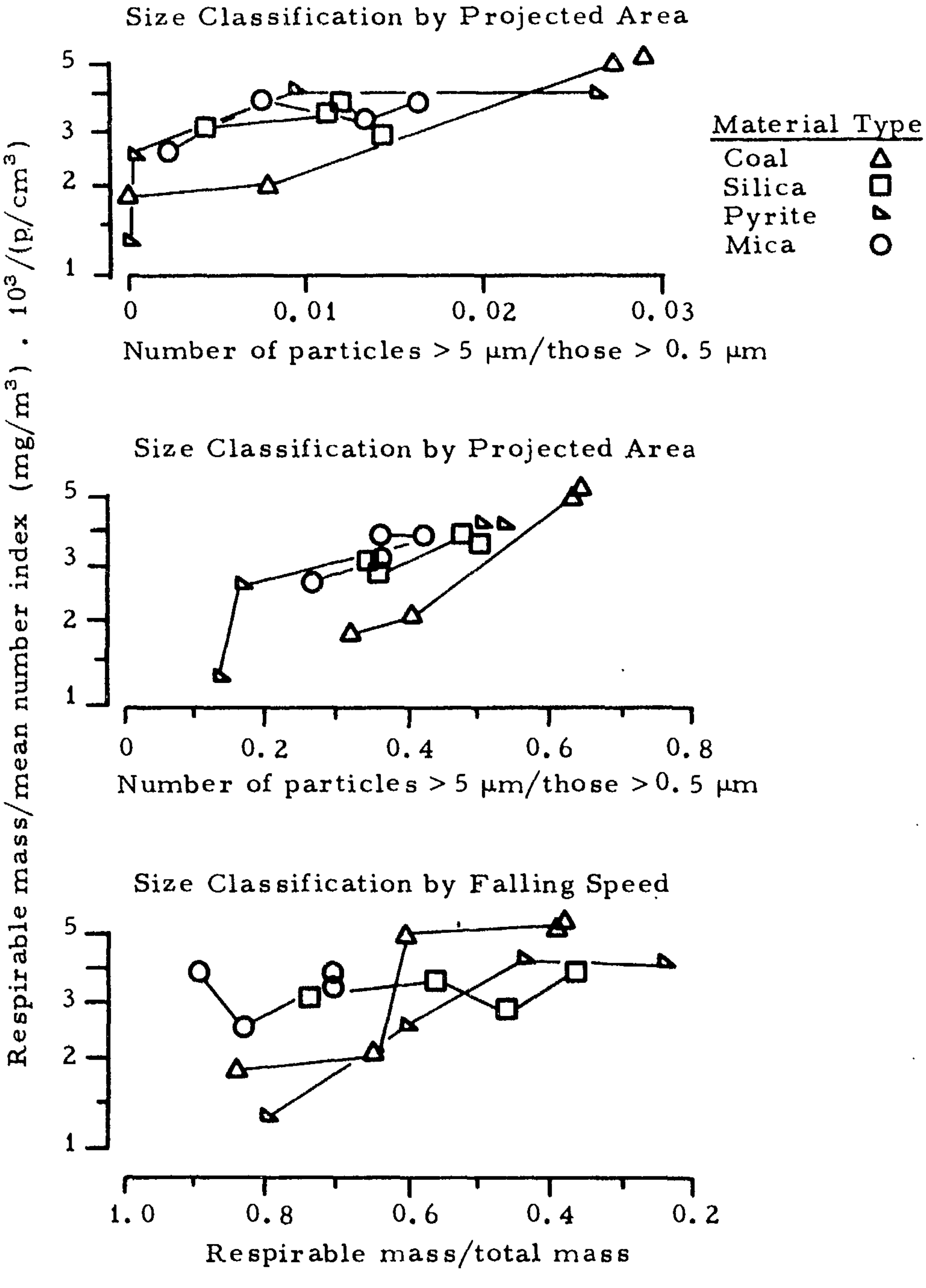

FIGURE 4-2: Effect of size classification, density and shape on respirable mass/mean number comparison index.

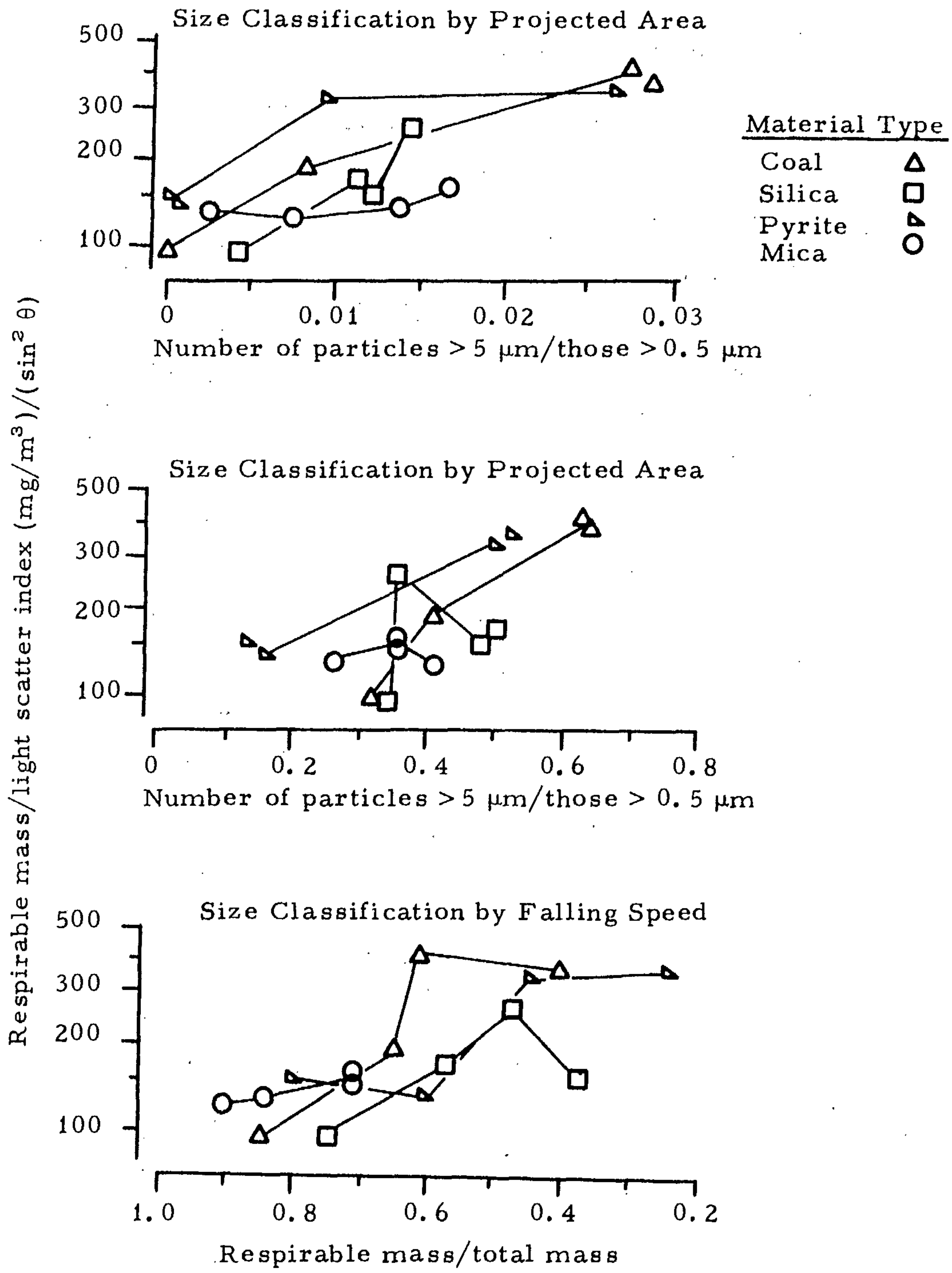

FIGURE 4-3: Effect of size classification, density and shape on respirable mass/light scatter comparison index.

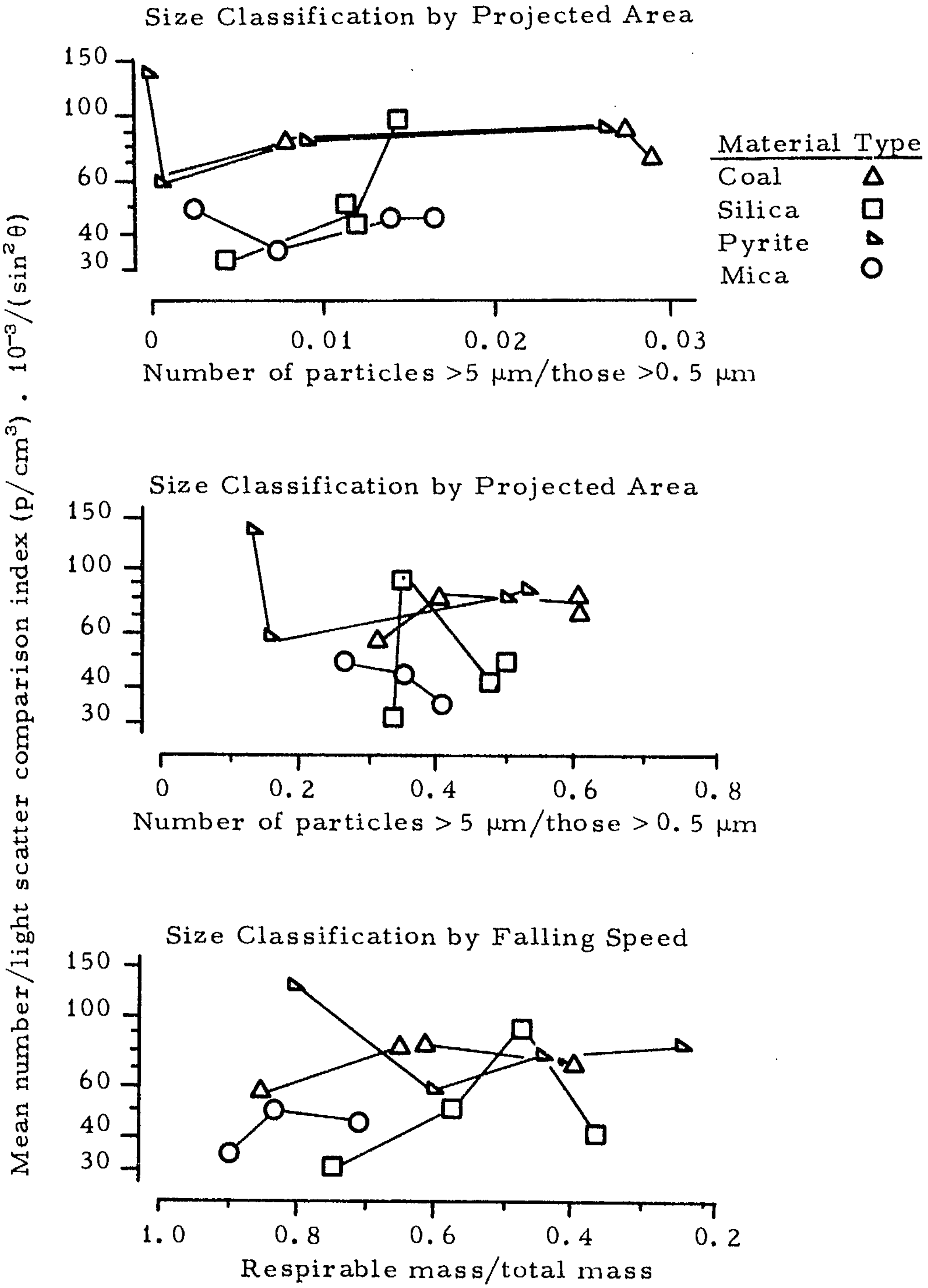

FIGURE 4-4: Effect of size classification, density and shape on mean number/light scatter comparison.

THE EFFECT OF AGGREGATION

Tables 4-2, 4-3, and 4-4 show that the comparison indices in the aggregated coal dust clouds differ considerably from those in the non-aggregated ones and tend to extreme values when compared to all the other mineral dusts. This shows that aggregation has a great effect on instrumental assessments of dust and could be important in some mining situations.

CHAPTER 5
COMPARISONS OF 'RESPIRABLE DUST' SIZE SELECTORS

A number of tests have been carried out in the laboratory dust chamber in which the 'respirable dust' concentrations, estimated by a number of dust samplers fitted with horizontal-elutriator or cyclone size selectors, have been compared. The comparisons were intended to determine the variability of each type of size selector and to compare the various types available.

Most of the comparisons were carried out in two types of dust clouds, fine coal (jet milled) and coarse coal (pulverized, no cyclone), chosen to represent the extremes of size distribution with near-cubic particles.

All dust concentrations are given in milligrams per cubic metre (mg/m^3) or relatively to that given by one chosen instrument, usually the Hexhlett.

THE EFFECT OF DESIGN DETAIL ON THE PERFORMANCE OF THE HORIZONTAL ELUTRIATOR SIZE SELECTOR

In the course of some experiments in this laboratory, it became apparent that there were some minor differences in the performance of various respirable dust samplers fitted with horizontal elutriators. These were carefully compared at the MRC design flow rate (1) in two coal dust clouds, one fine (Dispersion Method 1) and one coarse (Dispersion Method 4).

The samplers differed in the filter holders, some having a constriction between the elutriator channels and the filter. Diagrams of the significant construction features of each elutriator and the relative respirable concentration collected are shown in Figure 5-1.

Good agreement is obtained between the respirable dust concentrations indicated by the two laboratory samplers (top and fourth) and by the modified* Hexhlett (eighth).

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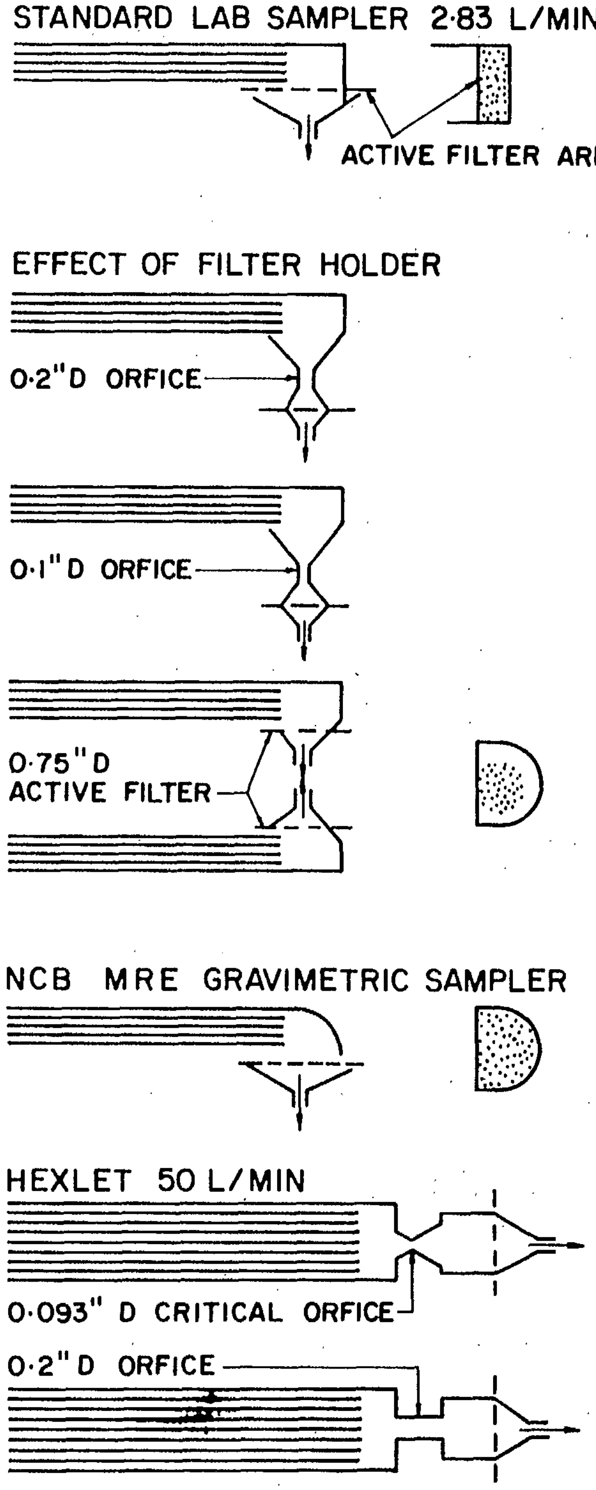
* The Hexhlett was modified by removing the flow control orifice and using the previously described (page 2-8) control valve, critical orifice and vacuum gauge.



	RELATIVE PERFORMANCE			
	FINE DUST CLOUD		COARSE DUST CLOUD	
	MEAN	SD OF MEAN	MEAN	SD OF MEAN
STANDARD LAB SAMPLER 2·83 L/MIN	1.0		1.0	
EFFECT OF FILTER HOLDER 0·2"D ORFICE	0.93	± .03	0.87	± .04
0·1"D ORFICE	0.86	± .03	0.83	± .04
0·75"D ACTIVE FILTER	1.008	± .03	0.97	± .04
	0.94	± .03	0.97	± .03
NCB MRE GRAVIMETRIC SAMPLER	0.965	± .06	1.015	± .025
HEXLET 50 L/MIN 0·093" D CRITICAL ORFICE	0.945	± .02	0.94	± .05
0·2"D ORFICE	1.00	± .035	1.0	± .04

FIGURES 5-1: SCHEMATIC DIAGRAMS AND RELATIVE PERFORMANCE OF RESPIRABLE-DUST SAMPLES

The Casella NCB MRE gravimetric sampler (sixth) is in fair agreement with those mentioned above. However, the flow rate is slightly higher at 2.55 ℓ/min than the design flow rate (2.5 ℓ/min), and the results suggest that the turned-up ends of the plates collect a part of the airborne dust leaving the elutriator. However, for practical application, the error is within a reasonable tolerance.

The Hexhlett (seventh), supplied with the flow-control orifice between the elutriator and the filter, indicates a respirable dust concentration that is about 5% low. This is apparently due to dust precipitation near the flow restriction and has been found on the laboratory samplers (second and third) which also have orifices. These orifices were introduced to smooth the dust distribution over the surface of the filter for X-ray assessment of quartz, unfortunately an invalid approach.

VARIATIONS IN PERFORMANCE OF CYCLONE SIZE SELECTORS

During the course of these studies three types of cyclones have been examined:

1. the Dorr Oliver 10-mm nylon hydroclone of which eight samples have been included;
2. the Casella chrome-plated brass cyclone (personal gravimetric sampler, type no. T13040) of which ten samples have been included;
3. the 0.5-inch stainless steel (Unico) of which two samples have been included.

Three of the nylon cyclones were fitted, in this laboratory, with 1-inch-diameter aluminum filter holders by pushing them over a rubber seal on the extension of the vortex finder, and three were similarly fitted with plastic filter holders. The other two units were assembled by M. S. A. and Unico respectively.

Some variations, between the samplers of each type, were found and are given in Table 5.1.

It can be seen that there are small differences between the six nylon cyclones A to F using a smooth airflow with B and C significantly lower than E and F. These differences are probably due to small differences in the assembly of the cyclones and filters.

TABLE 5. 1

Cyclone Size Selectors: Variations in Dust Collection

		Flow	Coarse Coal Dust				Fine Coal Dust			
	Pump	ℓ/	Set 1		Set 2		Set 1		Set 2	
Cyclone	type	min	RDC[1]	SD[2]	RDC	SD	RDC	SD	RDC	SD
10mm nylon										
A	CO[3]	1. 7	. 78	. 07			. 79	. 08		
B	CO	1. 7	. 735	. 06			. 8	. 07		
C	CO	1. 7	. 755	. 04	. 84	. 05	. 845	. 05	. 9	. 06
D	CO	1. 7	. 77	. 06	. 89	. 035	. 84	. 05	. 91	. 035
E	CO	1. 7	. 84	. 08	. 76	. 06	. 84	. 07	. 85	. 04
F	CO	1. 7	. 815	. 09			. 83	. 06		
Statistical significance of difference between extreme and mean(A-F)			0. 1		0. 05		--		0. 1	
F	PS[4]	1. 7	. 74	. 05						
Unico	P[5]	1. 7	. 63	. 05						
MSA	P	1. 7	. 49	. 05						
MSA	PS	1. 7	. 67	. 05						
Casella										
1	PS	2. 0	. 92	. 02			. 95	. 04		
2	PS	2. 0	. 76	. 04			. 88	. 04		
3	PS	2. 0	. 85	. 06			. 94	. 05		
4	PS	2. 0	. 93	. 06			1. 02	. 07		
5	PS	2. 0	1. 02	. 06			1. 03	. 05		
6	PS	2. 0	. 96	. 06						
7	PS	2. 0	1. 06	. 06						
8	PS	2. 0	1. 06	. 06						
9	PS	2. 0	1. 03	. 06						
10	PS	2. 0	1. 03	. 06						
statistical significance of difference between extreme and mean			0. 02				0. 1			
1/2 " steel										
1	CO	8. 15	1. 25	. 09			. 935	. 05		
2	CO	8. 15	1. 23	. 07			. 90	. 05		
1	CO	16. 15	1. 0	. 06			. 84	. 02		
2	CO	16. 15	1. 07	. 12			. 80	. 05		

Footnotes:

[1] RDC - Dust concentration relative to the Hexhlett.

[2] SD - Standard deviation.

[3] CO - Smooth flow controlled by critical orifice.

[4] PS - Diaphragm pump with pulsation damper.

[5] P - Diaphragm pump, no damper.

It can be seen that the M. S. A. and Unico samplers used did not give the same size selection as the 10-mm nylon cyclone used with a smooth flow. Of the ten Casella cyclones, only one (No. 2) showed a statistically significant difference from the others. Examination of this cyclone showed that the entry slot was narrower than on the other cyclones, 0. 058 as compared with 0. 062 to 0. 064 for the others. This dimension is outside the tolerance permitted.

The difference between the two 0. 5-inch stainless-steel cyclones was not statistically significant; however, it should be noted that these are assembled by hand and should always be checked.

COMPARISON OF CYCLONE AND HORIZONTAL-ELUTRIATOR SIZE SELECTORS

A number of tests comparing cyclone and horizontal-elutriator size selectors have been done. The first set of comparisons was made between four 10-mm nylon cyclone and four horizontal-elutriator size-selective samplers. For these tests, the cyclone size-selective samplers were made up from the nylon cyclone and a 1-inch diameter filter holder mounted directly over the outlet end of the vortex finder and operated at 1.3, 1.65, 1.95, and 2.6 ℓ/min respectively, using constant flow, controlled by critical orifices. The horizontal-elutriator size-selective samplers consisted of a 2. 5-ℓ/min Casella, a 2. 83- ℓ/min laboratory model, a 50- ℓ/min standard Hexhlett, and a Hexhlett run at 25 ℓ/min. The first three were intended to operate at the standard Medical Research Council (1) top cuts of 7. 1 µm for unit density spheres, and the fourth had a theoretical top cut of 5. 0 µm.

The comparisons were carried out in thirty dust clouds of thirteen types chosen to cover the range of the standard laboratory types. The results are given in detail in Appendix D and are summarized in Figures 5. 2 and 5. 3. Figure 5. 2 shows a plot of the ratios of dust concentrations - estimated by samplers fitted with cyclone size selectors (operated at a range of flow rates) - to those estimated by samplers fitted with horizontal-elutriator size selectors. This graph shows both the mean and the standard deviation of all the measurements at each flow rate. Figure 5. 3 shows the relationship between the ratio and a measure of the dust particle size in the dust clouds.

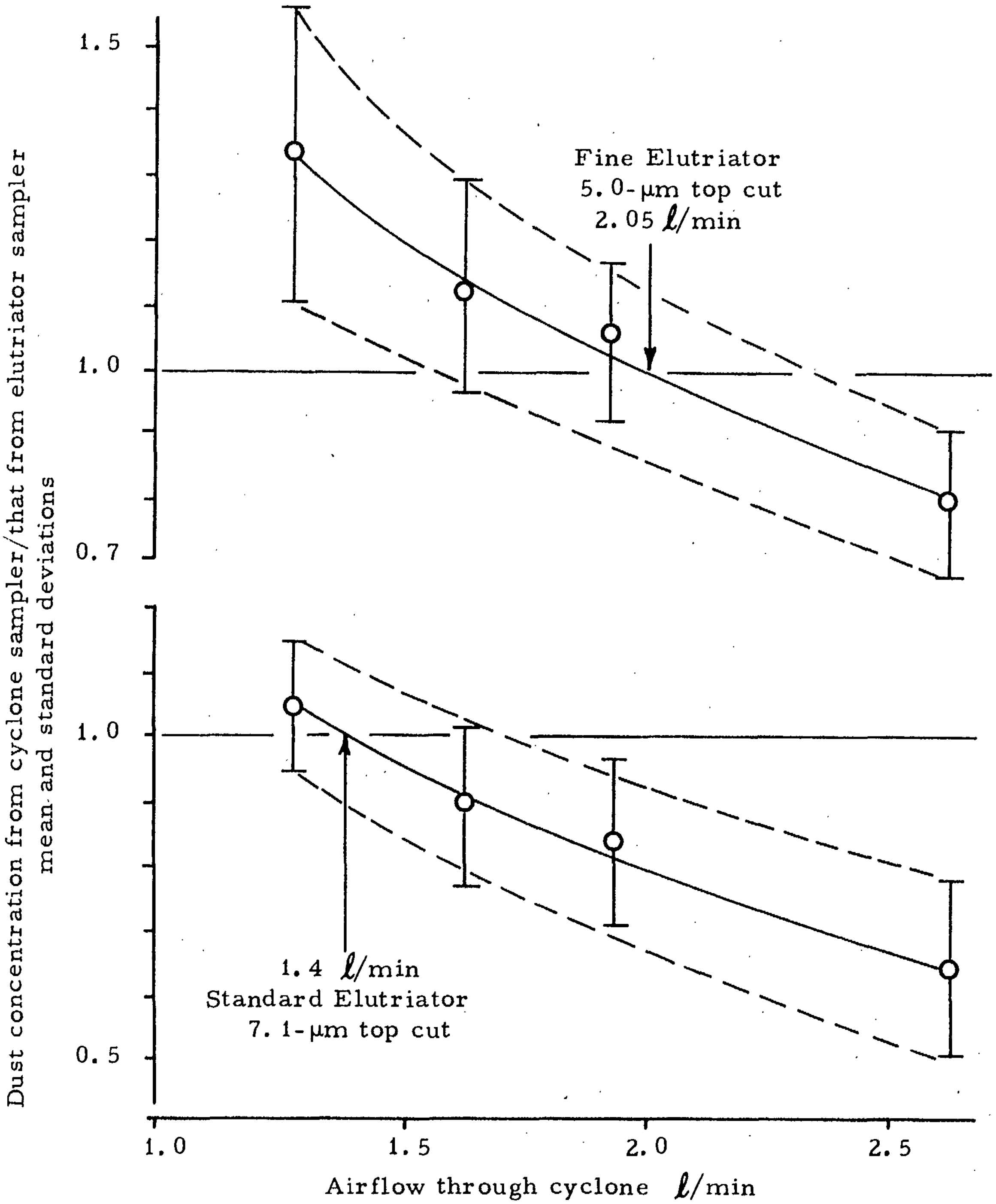


FIGURE 5-2: Effect of airflow on respirable dust concentration estimated by samplers with cyclone size selector.

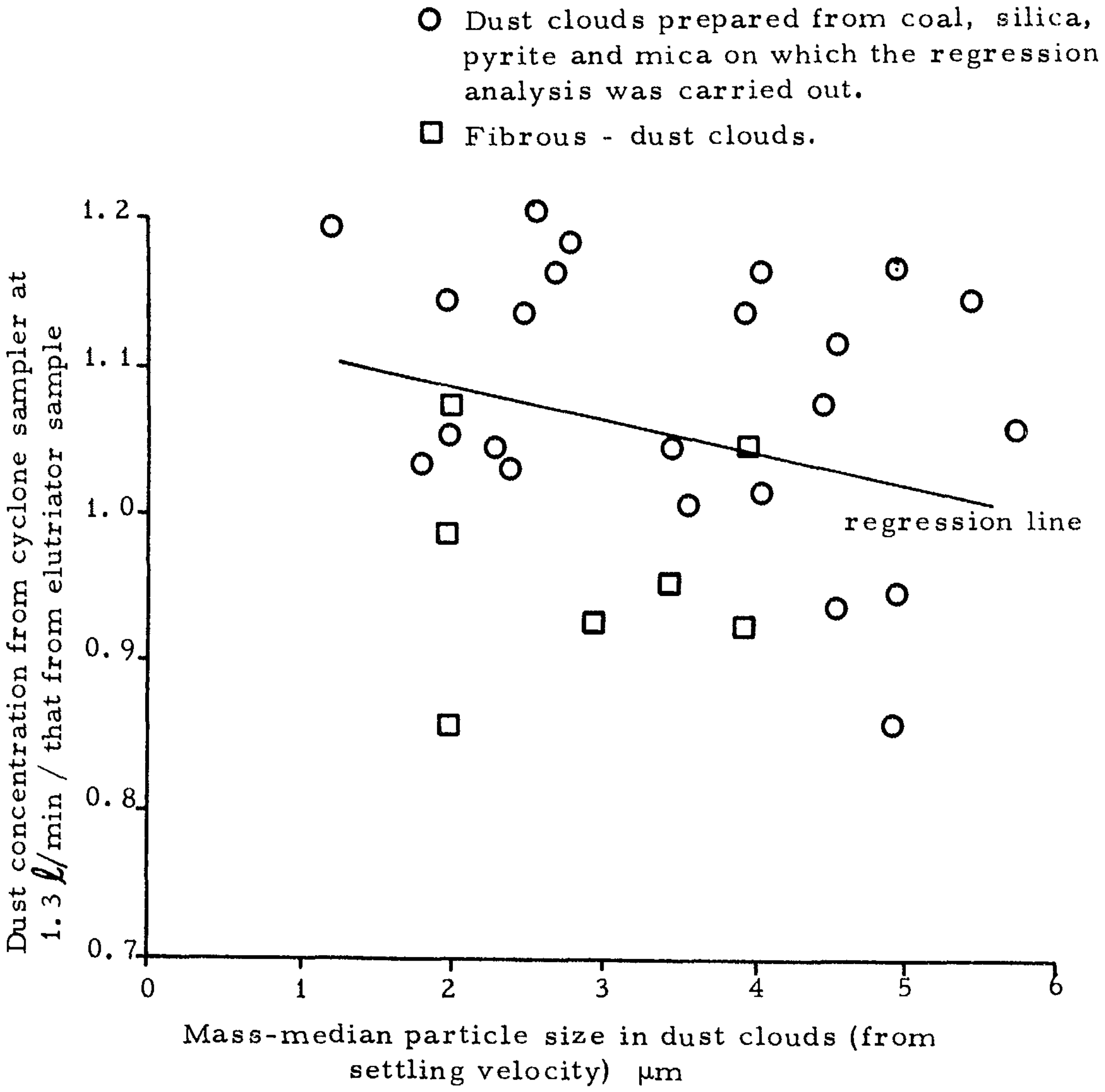


FIGURE 5-3: The effect of dust size distribution on comparison between cyclone and horizontal-elutriator size selectors.

In the second set of comparisons, three types of cyclones, recommended for size selective sampling, were compared with the modified Hexhlett (critical orifice placed after the filter) in the fine and coarse types of coal dust cloud. The results are given in Appendix D and are shown in Figure 5.4 as plots of the relationship between dust concentration relative to the Hexhlett and the airflow through the cyclone. Log-log scales are used so that the curves have the same appearance for each cyclone.

It is apparent that there are differences in behaviour between the three types of cyclone with changes in airflow and dust size distribution.

The cyclones differ in material, which could affect the conductivity and collection characteristics for charged particles, and in aspect ratio of the entrance slit; the nylon has a square slit (0.080 x 0.080 inch), the Casella has a long slit (0.060 x 0.375 inch), and the 1/2-inch cyclone has a double entry long slit (0.15 x 0.75 inch).

For the 10-mm nylon cyclone, best agreement with a sampler fitted with a horizontal elutriator (Medical Research Council specification) is found at a flow rate of 1.0 to 1.2 /min in the second set of comparisons, whereas in the first it was at 1.4 /min. The differences are due to changes in experimental technique, permitting the collection of larger samples, to the more accurate operation of the horizontal elutriator samples, and to elimination of some errors as discussed in the first section of this chapter.

The Casella cyclones give best agreement at a flow rate of 2.1 /min which is in fair agreement with Higgins and Dewells calibration of 1.9 /min to agree with the Hexhlett, which presumably reads low because of its critical orifice.

The 0.5-inch stainless-steel cyclones show very different calibrations, 6 and 15 /min, in the fine and the coarse coal dust clouds respectively. The results obtained suggest that this type of cyclone has a size collection characteristic that is markedly different than those of the other cyclones and that, in routine sampling, appreciable differences could be found if this and other types of cyclone are used together.

The advantages and disadvantages of the various types of cyclone size selectors are laid out below.

Advantages

Nylon - most consistent within limited number of specimens,
- low price (injection moulded).

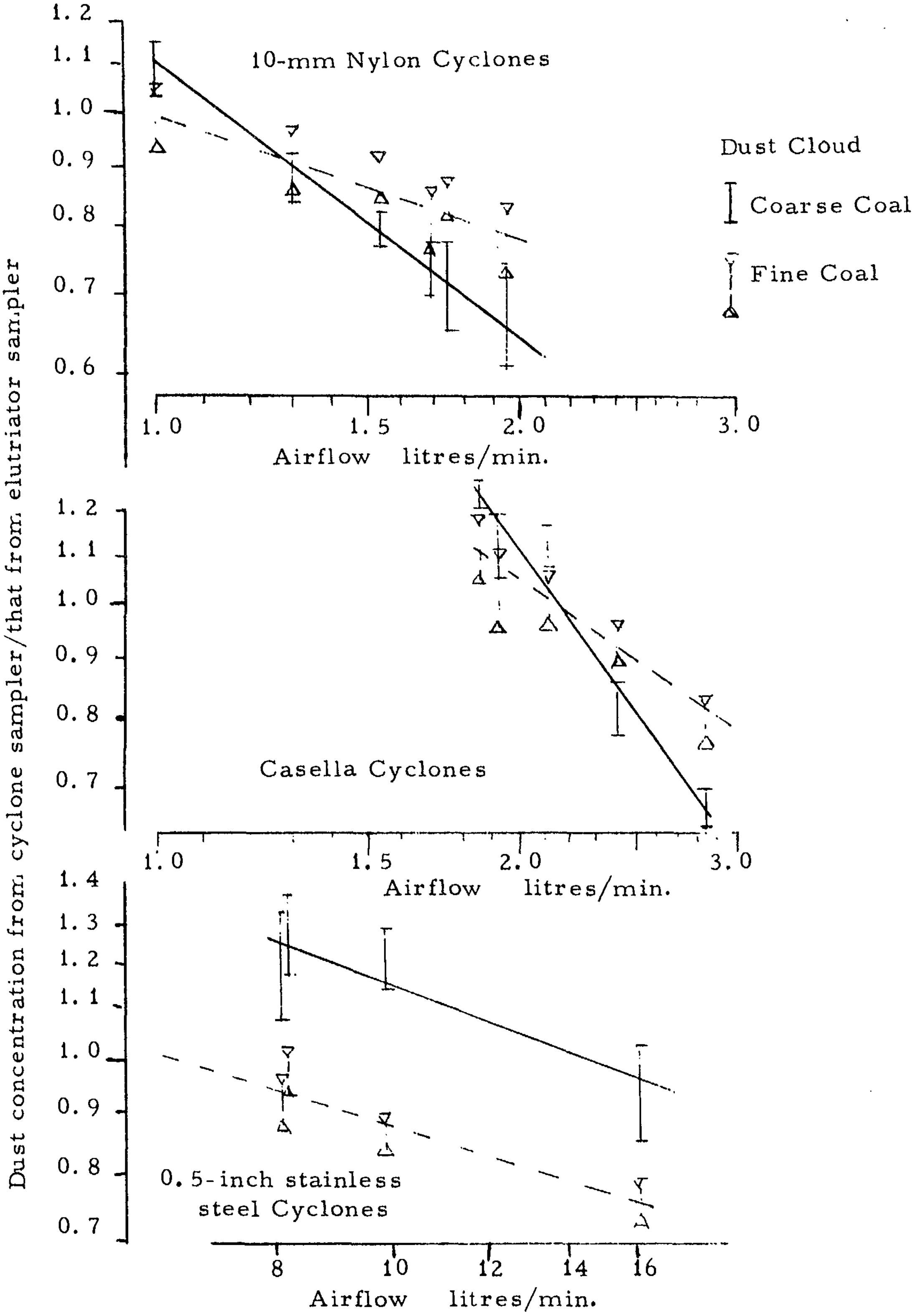


FIGURE 5.4: Effect of airflow and dust size on the 'respirable dust' concentration estimated by samplers using cyclone size selectors.

Casella - most suitable flow rate for personal sampler,
- mass collected has least dependence on flow rate,
- conductivity of metal surfaces closest to that of the wet bronchial passages.

0.5-inch - high flow rate suitable for compositional samples,
- conductivity of metal surfaces closest to that of the wet bronchial passages.

Disadvantages

Nylon - low flow rate,
- low conductivity.

Casella - inaccuracy of manufacture?,
- cost.

0.5-inch - variation with size distribution.

DISCUSSION

It has been shown in this chapter that relatively small changes in construction can affect respirable dust size selection appreciably and it is therefore recommended that all aerodynamic size selecting dust samplers should be checked against a 'standard' instrument prior to use. This can most conveniently be done in a dust chamber with a dust cloud containing about 50% respirable dust.

REFERENCES

1. Hamilton, R.J. and Walton, W.H., "The Selective Sampling of Respirable Dust", in 'Inhaled Particles and Vapours', C.N. Davies (Ed.), Pergamon Press, Oxford (1961).

A good review of the literature on size selective sampling is,
Lippmann, M., "Respirable Dust Sampling", A.I.H.A. Journal, Vol. 31, March-April (1970).

APPENDIX A
DUST CLOUD PREPARATION AND PROPERTIES

INTRODUCTION

The laboratory dust chamber was originally erected in Ottawa by L. Richards. The chamber was moved to Elliot Lake in 1965, and has since been used mainly on the program, "Comparison of Dust Sampling Instruments". The requirements of this program led to considerable extensions of some of the dust chamber ancillary apparatus. This section describes the preparation, sizing, feeding, and dispersion of material and some properties of the resulting pure mineral dust clouds such as uniformity in time and space and size distribution.

The preparation of a dust cloud can be separated into a number of stages: preparation of the material, feeding, and dispersion.

DUST SOURCES

A limited selection of minerals was chosen to cover the main range of density and particle shape found in Canadian mines. These were - for density- coal, silica, and pyrite and -for shape - silica, mica, and asbestos. Because asbestos gives very fine fibres less than 0.1 μm in diameter and below the resolving power of a microscope, a glass fibre about 0.5 μm in diameter was also examined. The resulting dust clouds are regarded as standard for laboratory purposes and stocks of material are available for future requirements.

The materials were received from the sources in the forms stated below:

1. Coal:
   Source: Princess Colliery, Nova Scotia.
   Designation: Washed nuts S13 1.75 to 0.75-inch ring size.

2. Silica:
   Source: Ottawa Silica Company, Illinois.
   Designation: ASTM C-109
   Size: 16 to 100-mesh.

3. Pyrite:
   Source: Nordic Mine, prepared by flotation at Stanleigh Research Lab.
   Purity: 95%; quartz is main impurity.

4. Mica:
   Source: A Quebec molybdenite mine, supplied through Q. M. M. A. P. A. by courtesy of Mr. Grassmuck.
   Purity: The mica contained quartz and molybdenite lumps.
   Sorting: Flakes of visibly pure mica were hand sorted from the partially crushed source material.
   Size: 1 to 2 inches.

5. Asbestos:
   Source: Californian asbestos deposits; a fine fibre received through the Department of National Health and Welfare by courtesy of Dr. Villiers. Various Canadian asbestos samples were tried out but none gave a dust cloud with as high a proportion of fibrous particles as this particular material.

6. Glass Fibre:
   Source: Gelman (filter material manufacturers), Michigan.
   Designation: Type GF/A glass fibre filter paper.

DUST PREPARATION

The equipment available in this laboratory for dust preparation is:

1. laboratory crusher, 4. 5 x 3. 25-inch opening, Denver Fireclay Co.;
2. pulverizer, type VD, Bico Inc.;
3. wet grinding mill, M. 18, SWECO;
4. twin jet fluid energy mill, Helme Products Inc.;
5. sieves, 8-inch, and sieve shaker.

This equipment is used as found necessary to produce the desired dust. The glass fibre filter paper was chopped into small pieces, less than 0. 125 inch square.

For preparation of non-aggregated dust clouds, dry processes were used throughout, either the Bico pulverizer or the Helme mill being the final breakage process. For these, standard operating conditions were chosen; the Bico pulverizer plate gap was set at 0.005-inch gap, and the Helme jet air supply pressure was run at full bore ranging over 80-85 lb/in^2 dependent on the compressor cycle. For preparation of aggregated dusts, the Helme mill is used for the softer materials and the Sweco for the harder materials. The desired material is a fine slurry in alcohol and/or water.

DUST FEEDING

The methods used to feed dust can be divided into two categories, those for dust clouds of non-aggregated particles and those for dust clouds containing aggregates. As it is very difficult to separate slightly damp fine dust particles, all the processes used to produce non-aggregated dust clouds have used dry material. Dust clouds with controlled aggregation have been produced by spraying fine dust dispersed in a volatile liquid; the technique is described later. The feed problems with sprays are producing low flow rates of liquids containing high concentrations of suspended particles; they are part of the dispersion method and will be described under it.

The main requirement of the feed method is that it will give a uniform dust concentration in the chamber over the period of the run. Two factors which interfere with this in handling dry dusts are - variations in volume rate of material feed and variations in size distribution of the material. The feed material often contains a large proportion of dust, coarser than 10 μm, that gets deposited prior to the chamber; the important parameter of the size distribution of the feed is the ratio of fine to coarse material. The variations that arise are mainly due to either insufficient mixing or to size segregation in filling or operating the feeder.

A number of dust feeders have been examined and, though they all work reasonably well on free-flowing powders, the SMRE type feeder was found to be the most versatile.

USBM TYPE OF FEEDER

This feeder is based on the one at the United States Bureau of Mines, Pittsburgh and is illustrated in Figure A-1.

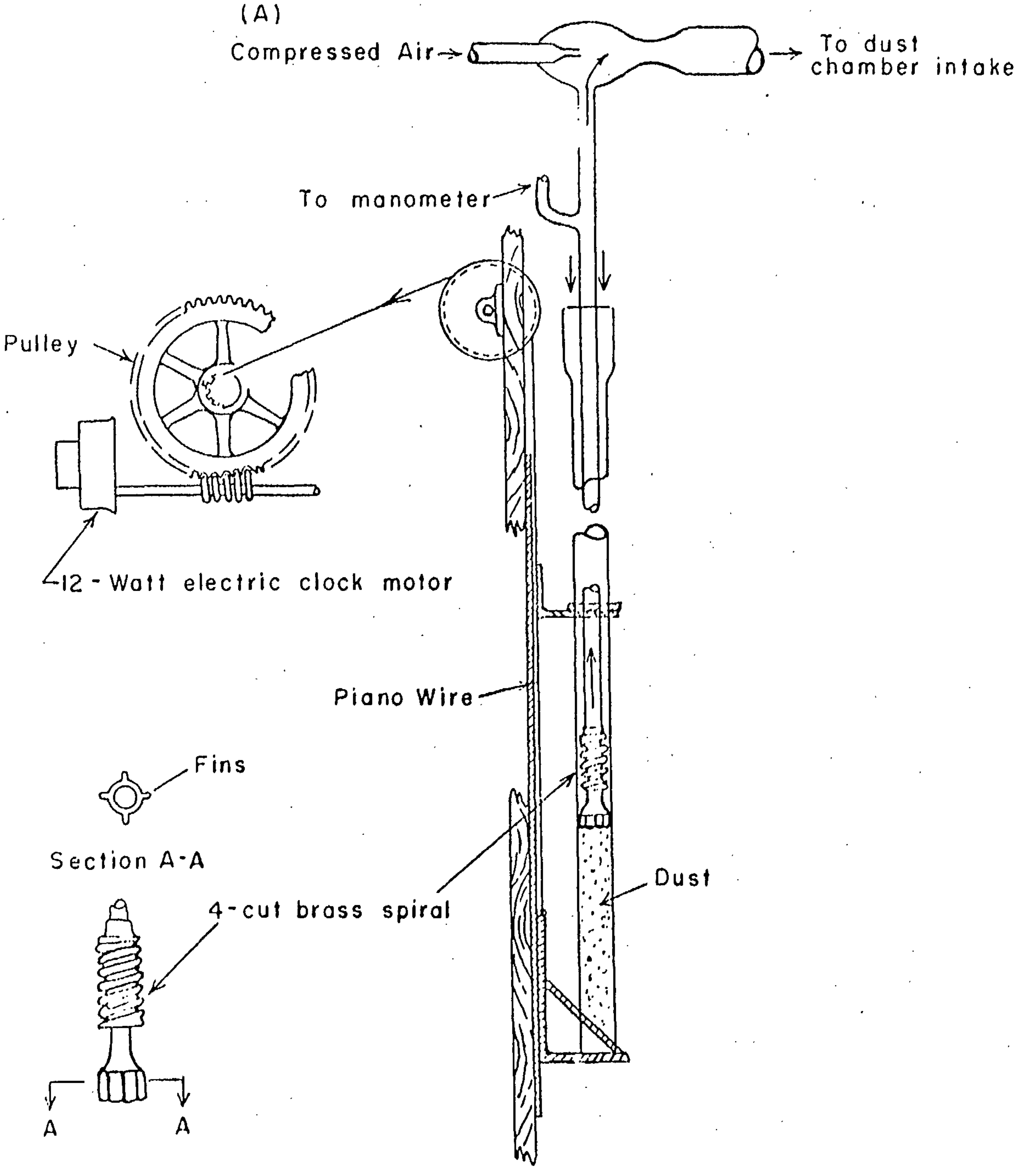


FIGURE A-1: DUST FEED APPARATUS

The dust is placed in a glass tube 34 inches long; the inner wall of this tube must be as smooth and true as possible. Inside the large tube fits a small glass tube which remains fixed; the outer tube traverses this tube. The inner tube is fitted with a brass spiral on the lower end which should be a slide fit to the inner wall of the larger glass tube. It is very important that the brass spiral has a snug fit so that most of the air passes through the spiral and swirls, giving a steady pick-up of the dust in the outer rising tube. The dust feed rate depends on the diameter of the outer tube and the rate at which it is elevated.

The following table gives the rise and dust rate for different-size pulleys, using a 1-rpm capacitor-start electric motor, geared to a 6-inch-diameter, 100-tooth gear.

TABLE B-1

Pulley Size and Hoisting Speed

Pulley Size in.	Rise Time in./hour	Dust Feed Rate cm^3/hour
4.5	8.62	102.15
2.5	4.75	56.75
1.5	2.87	34.05
1.0	1.94	22.7
0.75	1.44	17.
0.5	0.94	11.35

The difficulties with this feeder apparently are because of the dependence of the feed rate on the airflow through the feeder and because of the large area of dust exposed to the airstream as compared to the volume flow of dust. Though a satisfactory balance could be achieved for fine free-flowing powders, it could not be obtained for materials containing relatively coarse particles or for mica and asbestos. This feeder was used until the SMRE feeder was built.

WRIGHT FEEDER

The Wright (1) dust feeder was originally intended for coal and feeds dust by scraping a uniform thin layer off a lightly compacted dust bed. The feeder is commercially produced. Though the feeder is successful for free-flowing powder, it jams when used with fibrous materials like asbestos, and has been tried in only a few experiments.

SMRE TYPE FEEDER

Hattersley et al. (2) of the Safety in Mines Research Establishment, U.K., described a dust cloud producer. Essentially the feed portion of this consists of a grooved plate rotating slowly about a vertical axis, with a funnel and scraper blades to fill the groove and level the dust off flush with the plate surface. The dust is drawn out of the groove by an air operated ejector. The feed rate is controlled by the speed of rotation and the size of the groove. The Mines Branch version of this instrument is shown in Figure B-2 and the feed rates obtainable are shown in Table B-2.

TABLE B-2

Feed Rate of SMRE Type Dust Feeder

Groove Size		Feed Rate by Volume cm^3/hour at	
Diameter* Inch	Pitch Diameter Inch	1.08 rpm	0.054 rpm
0.062	4	20.5	1.025
0.094	5	57.5	2.88
0.125	6.375	132	6.6
0.25	4	323	16.1
0.375	6.375	1188	59.4

* Nominal diameter of groove of semi-circular cross section.

The feed rate has been reduced further by switching on and off for short periods, i.e., 5 seconds in 20.

This feeder worked well on free-flowing powders but, with coarse powders like sand or fluffy ones like mica, the scraper set across the groove can remove material from the groove at irregular intervals and hand scraping with a spatula was used. It was found possible to obtain a reasonably uniform feed of fibrous materials by hand-filling the groove.

The SMRE type feeder has proved to be the most versatile and the simplest to adjust over a wide range of dusts and feed rates. Dust clouds with concentrations in the range of 10 to 1,000,000 particles per cubic centimetre have been produced.

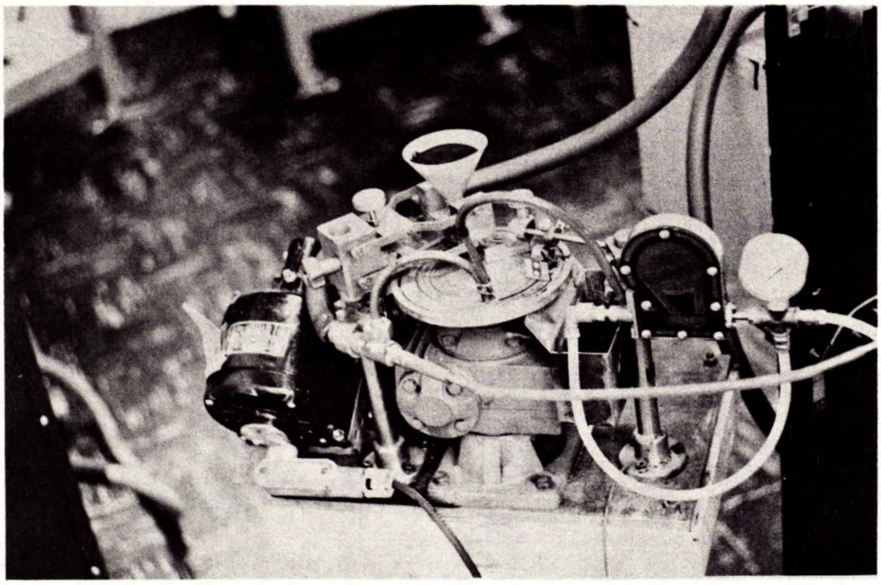


FIGURE B-2: The SMRE Type Feeder

showing:

Left:	The drive motor
Centre:	Reduction gear box with grooved plate, feed funnel, scraper blades, and suction U-tube
Right:	The Helme twin-jet fluid energy mill.

DUST DISPERSION

A number of dust dispersion methods have been used and are characterized in three ways: type of process, dry or wet; amount of fresh breakage; and intensity of air turbulence.

The first three methods are essentially for dry dusts, with the first two introducing appreciable amounts of fresh breakage on non-fibrous dusts. The intensity of air turbulence and separation of matted fibres decreases in the order given. The fourth method produces an aggregated dust cloud by atomizing a slurry of fine particles in a volatile liquid.

Jet Mill

In the jet mill (3), method 1, there are two opposed compressed air jets entering the grinding region, each drawing a dust-laden airstream, one from the feeder and the other from the cyclone chamber producing collisions between high-speed particles. The action is mainly fresh breakage of non-fibrous particles or dispersion of matted fibres.

This method produces a dust cloud having a higher proportion of fine dust than have clouds by the other methods. The jet mill is shown mounted on the right hand side of the SMRE type feeder in Figure B-2.

Pulverizer

In method 2, the material is coarser than 200 mesh; it is picked up from the feeder by a low-pressure air ejector and blown into the gap (0.005-inch) between the rotor and stator of the pulverizer. The pulverizer produces fine dust and disperses it into the air. Dust-laden air is then drawn from the pulverizer case and blown into the chamber intake airway by a second air ejector.

The main effect of the pulverizer on asbestos and glass fibre is increased dispersion of matted fibres rather than fresh breakage. For the other dusts, the fine material is broken by the pulverizer under much the same conditions as when preparing material for the third dispersion method and the main difference in the resulting dust clouds is probably due to some loss of the finest material when collecting the pulverized material prior to feeding in Method 3.

Air Ejector

In Method 3, a compressed air ejector is used to draw the dust from the feeder and blow it into the intake airstream of the chamber. The turbulence in the airstream, when supplied with air at 5 psi, is sufficient to produce non-aggregated dust clouds from coal, silica, pyrite, and mica but, even at 80 psi, it was not sufficient to separate the matted asbestos and glass fibres and gave rise to dust clouds characterized by low concentrations of mainly non-fibrous particles.

The feed material for this method of dispersion contains the fine particles which are to be dispersed in the dust cloud and all materials were prepared by pulverizing in the Bico pulverizer.

Atomization of Dust Suspension in Liquid

The object of Method 4 is to obtain dust clouds of particles with controlled aggregation. The principle is that when the liquid of a spray drop evaporates, the dust particles contained in it remain together as an aggregate. The number of particles in each drop follows a binomial distribution (4) depending on the number concentration of dust particles in the liquid and the size of the droplets. The proportion of aggregated particles increases with dust concentration and droplet size. The dust concentration in the liquid is limited by preparation and handling difficulties and the maximum drop size is limited by the problems of entrainment in the airstream and carriage into the chamber.

The experiments with compressed air atomizers were not very successful in producing dust clouds with many aggregates, because most of the droplets were too fine and gave a large proportion of single particles. Then a spinning disc generator was used. This consists of a 4-inch-diameter aluminum disc mounted on a lathe tool post grinder that turned from 7000 to 36000 rpm.

It has been found possible to obtain dust clouds in which more than 50% of the particles occur as aggregates. The optimum conditions attained have been with slurries containing 10^{10} particles, less than 5 μ in diameter, per cm^3. Dense slurries are difficult to feed slowly and steadily at a uniform rate because the jets clog frequently, therefore, the simplest technique is to spray the required amount of slurry directly into the chamber and commence sampling after the droplets have evaporated. This technique has the disadvantage that the dust cloud being sampled has a steadily decreasing concentration.

TOP SIZE CONTROL OF DUST

The dust-laden air stream from the dust dispersal mechanism can pass through an adjustable cyclone prior to joining the main intake of the chamber.

The cyclone characteristics have not as yet been ascertained because to date, only experiments, either with or without the cyclone operated at a set adjustment have been done. The effect of the cyclone was to reduce the total mass concentration of dust by 10 to 50% for coal, silica, pyrite, or mica by removing the coarser dust particles.

Even without the cyclone, very few particles larger than 10 μm are present in the chamber dust cloud. Apparently most large dust particles settle in the ducts leading to the chamber.

CHAMBER AIRFLOW

There is a forced airflow through the chamber of up to 150 cu ft/min. Intake and exhaust fans are fitted to the chamber, both have dampers to permit adjustment of airflow, through, and pressure inside, the chamber. The dust-laden air enters the chamber through a perforated duct on the floor of the chamber and is exhausted through perforated ducts up the four corners and along the top of three sides of the chamber as previously described by Richards (1). The airflow is monitored by an inclined manometer across the chamber and the inlet and exhaust ducts. Figure B-3 shows the chamber airflow plotted against this pressure drop; about 100 cu ft/min or a pressure drop of 0.4 inches W. G. is a suitable setting for most experiments. A second inclined manometer is fitted to indicate the difference in pressure inside and outside the chamber. The intake and exhaust dampers are adjusted to a slight positive 0.01-inch W. G. pressure inside the chamber with all the instruments running. A slight positive pressure is used, because, with negative pressure, slight leaks of clean air into the chamber can play on a particular instrument and cause it to give a low estimate of the dust concentration. During these experiments a high-efficiency particulate filter was added to feed clean air to the chamber and to permit working in low-concentration pure-dust clouds.

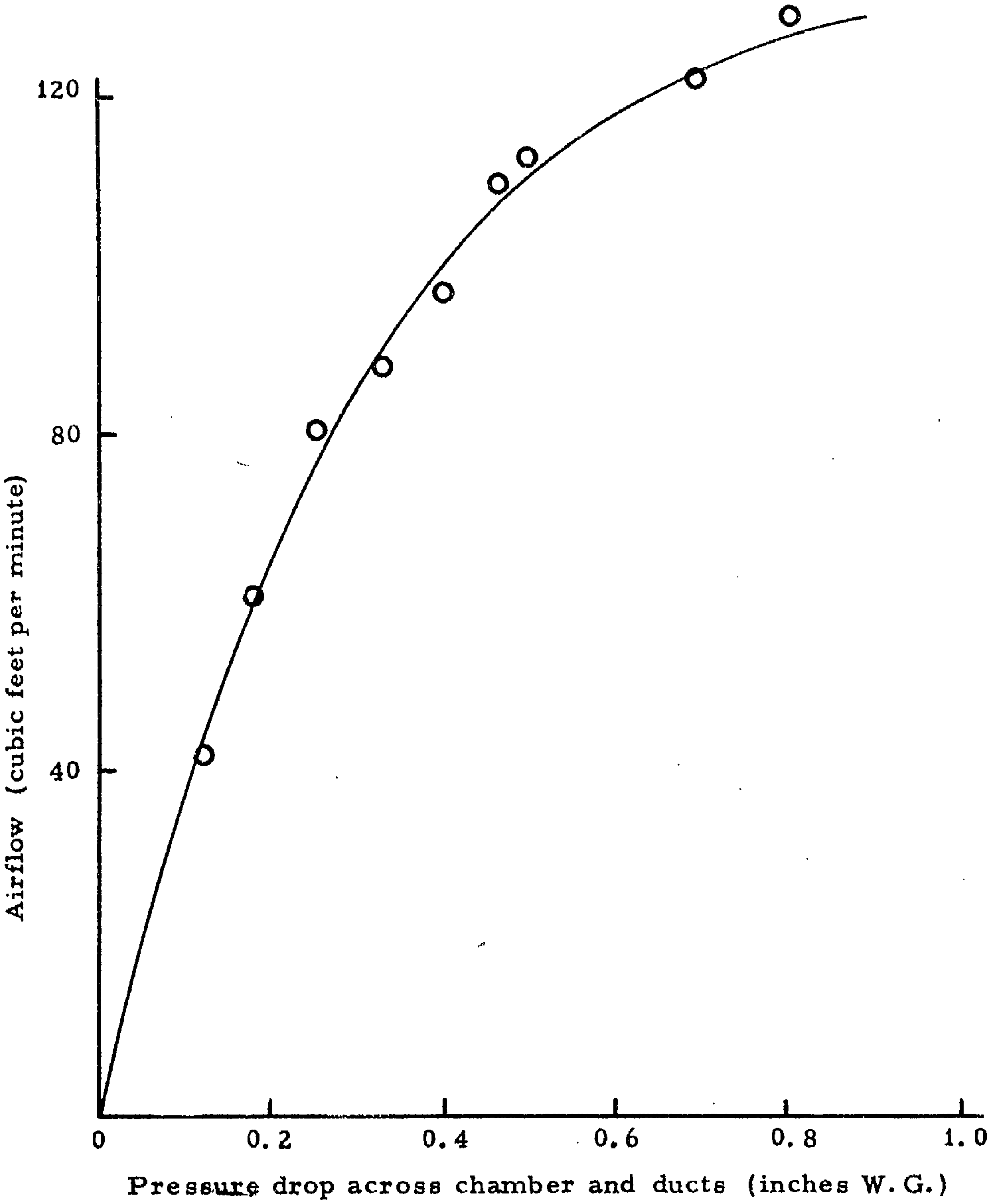


FIGURE A-3: Airflow through and pressure drop across chamber.

A circulating fan is fitted inside the chamber. The speed, position, and direction of this was adjusted so that all instruments were exposed to air velocities of 50 to 150 ft/min. This fan left only small zones of dead air in some of the corners.

CONTROL SETTINGS FOR STANDARD DUST CLOUDS

The standard non-aggregated dust clouds are all produced using the SMRE type dust feeder and three methods of dispersion with an airflow through the chamber of 100 cubic feet per minute.

Table B-3 shows the material, method of dispersion, size of feed material, feed rate and resulting dust concentration, by number of 1 to 5-μm particles (thermal precipitators) and by mass of respirable dust (Hexhlett). Only the values obtained at the middle feed rate are given here because dust concentrations are proportional to feed rate and can hence be readily determined for other feed rates.

SOME PROPERTIES OF THE DUST CLOUDS

Variations of Concentration within the Chamber

Two dust sampling instruments, a midget impinger and an open filter were placed in various parts of the chamber, and the resulting dust concentrations were compared with those obtained by similar instruments in a set position. No significant differences in concentration were found in any of these tests. There was a slight tendency for total mass concentration to rise, by less than 5%, near the chamber floor, below the position of the lowest set instrument. This is presumably due to partial settlement of coarse non-respirable dust.

Variations of Dust Concentration with Time

The variations with time can be separated into those within runs and those between runs with the same dust and feed settings. Figures B4 to B7 show the dust concentrations measured with the snap sampling instruments during a few typical runs. It can be seen that the variation in concentration is greater with asbestos than with the other minerals. This is due to both greater variations in feed rate because of difficulties of filling the groove evenly with asbestos and to the poor performance of the konimeter in sampling fibrous dusts. With the other minerals, the expected variation in sampling one dust cloud at one time with these instruments is almost as

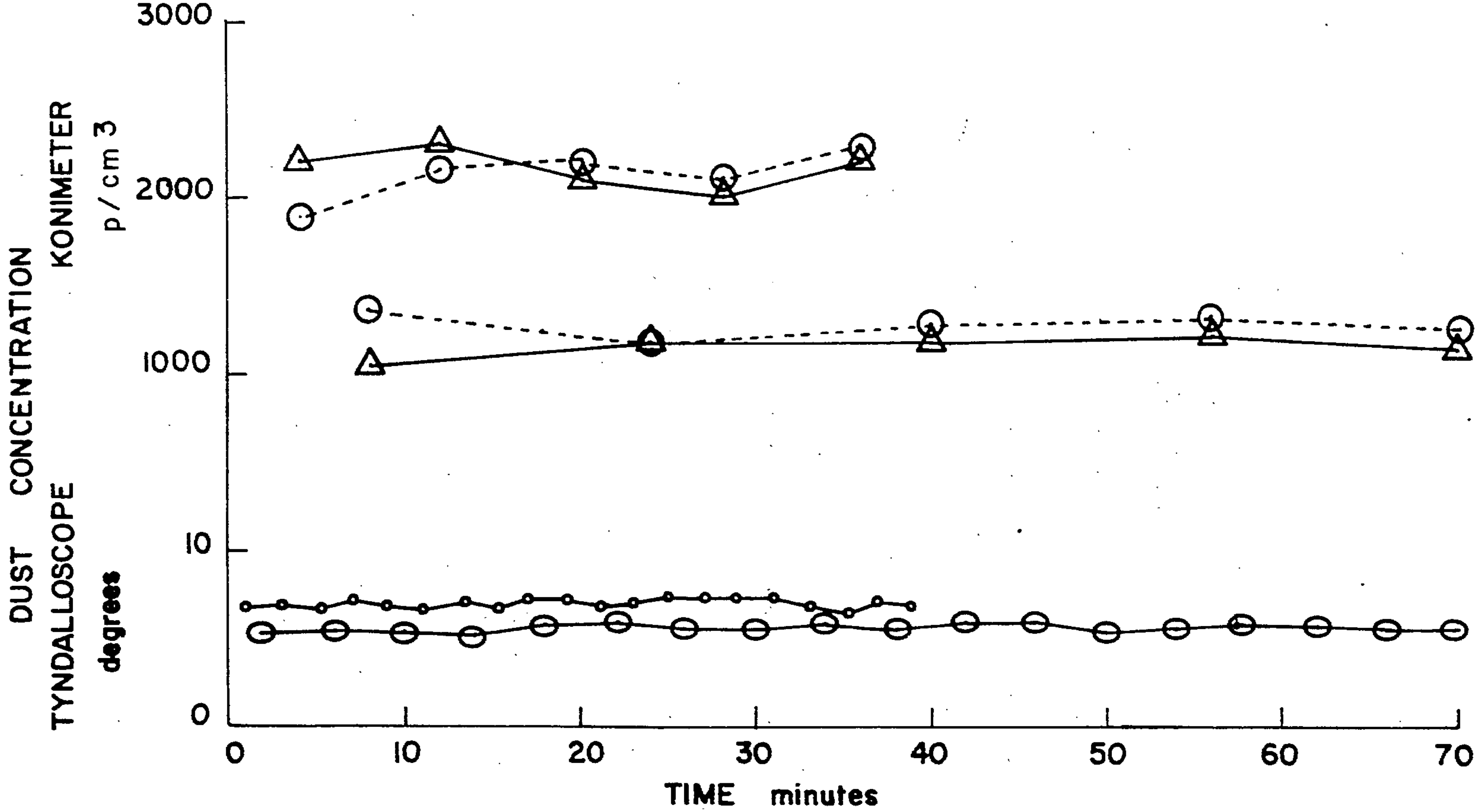
TABLE A-3

Conditions for Producing Standard Dust Clouds

Material	Disperser	Size of Feed	Feed Rate cm^3/hour	Dust Concentration p/cm^3	mg/m^3 *
Coal	Air Ejector	Pulverised	20.5	310	2.5
	Pulveriser	45-100 mesh	20.5	880	4.0
	Jet Mill	45-100 mesh	2.88	400	1.6
Silica	Air Ejector	Pulverised	20.5	410	2.6
	Pulveriser	16-100 mesh	16.1	390	2.1
	Jet Mill	16-100 mesh	2.88	750	3.7
Pyrite	Air Ejector	Pulverised	20.5	250	2.7
	Pulveriser	100-200 mesh	20.5	440	2.9
	Jet Mill	100-200 mesh	0.56	430	3.0
Mica	Air Ejector	Pulverised	6.6	430	4.0
	Pulveriser	45-100 mesh	6.6	270	2.5
	Jet Mill	45-100 mesh	6.6	1050	7.4
Asbestos	Pulveriser	As Recd	6.6	370^F	2.7
	Jet Mill	As Recd	2.88	950^F	1.7
Glass Fibre	Pulveriser	Chopped 1/8 x 1/8	16.1	140^F	1.2
	Jet Mill	Chopped 1/8 x 1/8	16.1	270^F	1.0

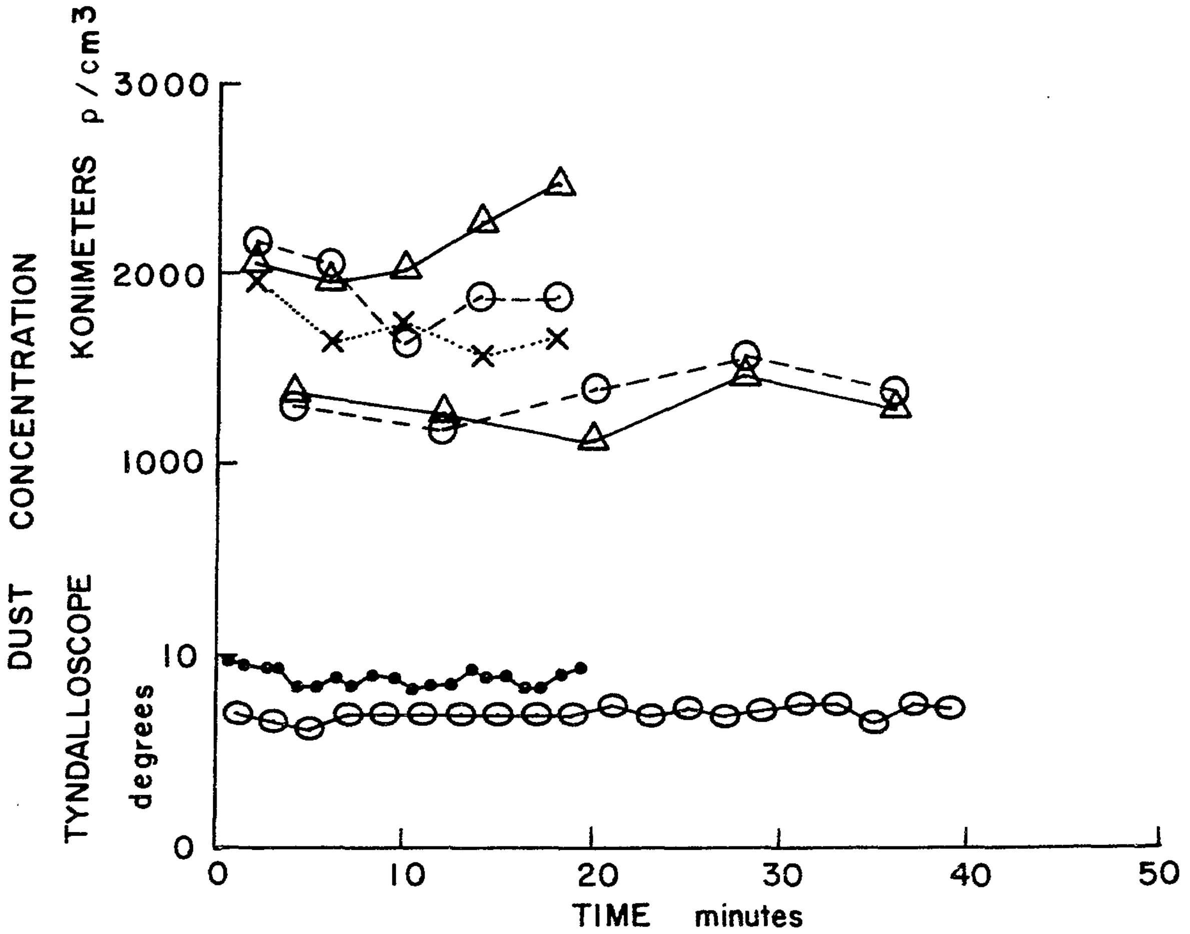
* respirable (Hexhlett)

F = fibres per cm^3



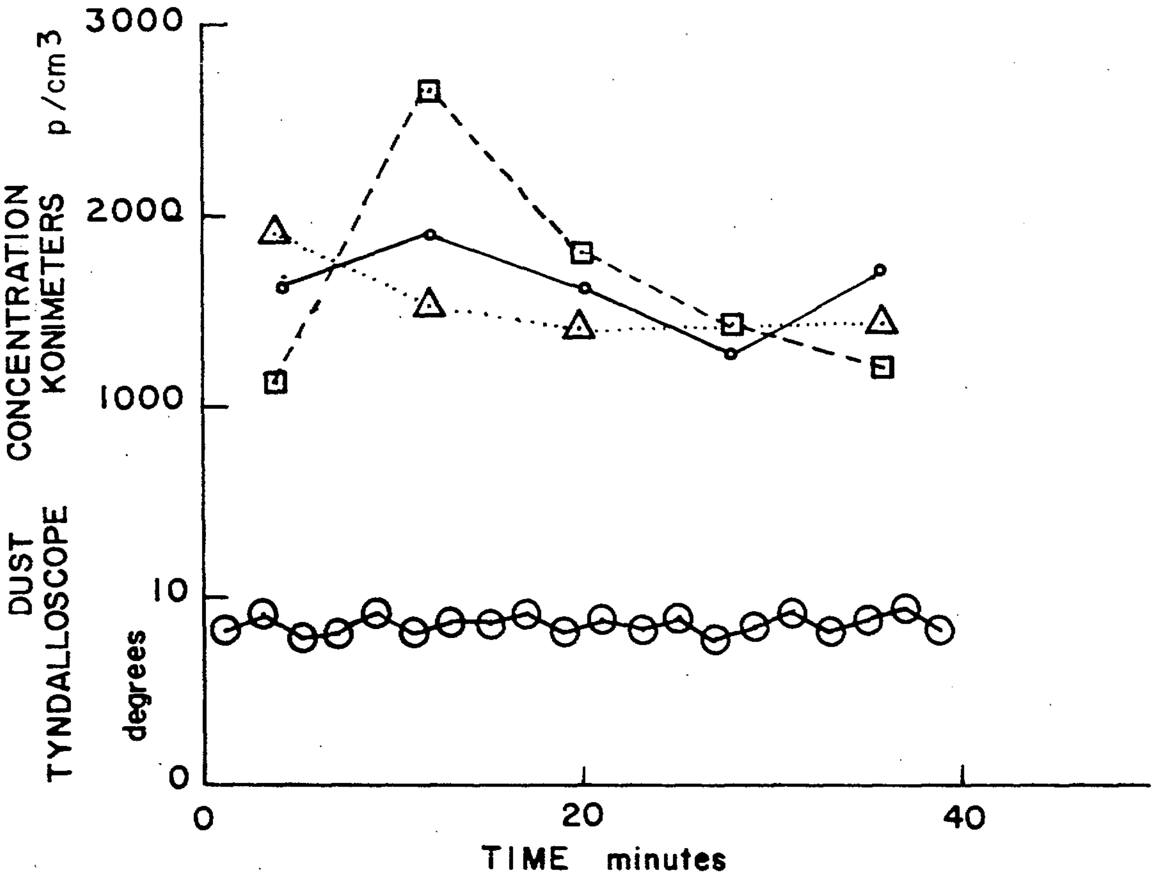
VARIATION IN DUST CONCENTRATION WITH TIME: 45 to 100-MESH COAL FED BY SMRE AND DISPERSED BY JET MILL

FIGURE A-4



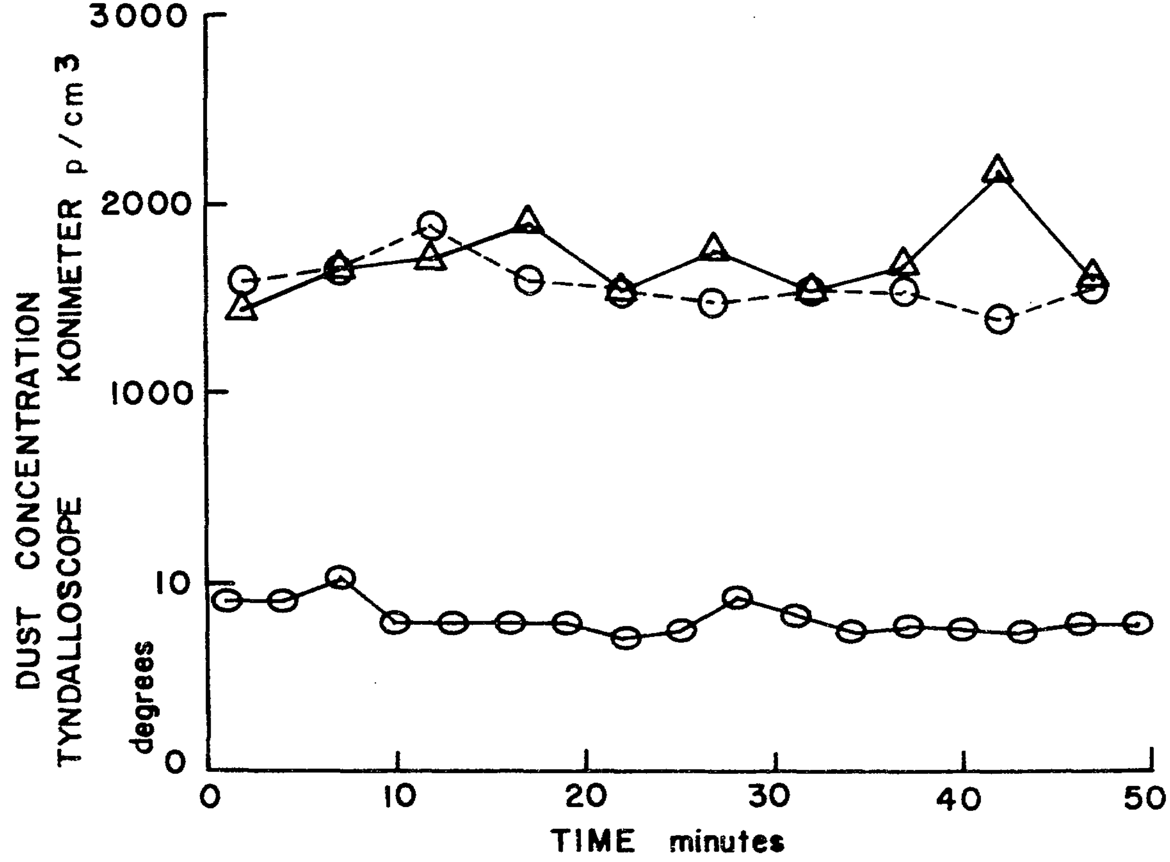
VARIATION IN DUST CONCENTRATION WITH TIME: PULVERIZED SILICA FED BY SMRE AND DISPERSED BY AIR EJECTOR

FIGURE A-5



VARIATION IN DUST CONCENTRATION WITH TIME: ASBESTOS FED BY SMRE AND DISPERSED BY JET MILL

FIGURE A-6



VARIATIONS IN DUST CONCENTRATION WITH TIME: PULVERIZED SILICA FED BY U.S.B.M. AND DISPERSED BY AIR EJECTOR

FIGURE A-7

great as the apparent variations with time; therefore, they are not necessarily as large as shown.

The difference in mean concentration for pairs of runs with the same dust at the same feed rate are shown in Table A4. The dust concentrations given were determined by the Hexhlett on a mass basis. It can be seen that the mean difference in dust concentration between two similar runs is about 10%. The results with other measures of dust concentrations, i. e., other instruments, are similar.

PARTICLE SHAPE

Some observations were made of the shape of dust particles after collection on thermal precipitator slides using a high-resolution binocular microscope. It was found that nearly all coal, silica, pyrite, and mica particles had length: breadth ratios less than 2. The thickness of small particles are difficult to determine on a microscope; however, it appeared that the breadth: thickness ratio of most of the coal, silica, and pyrite particles was less than 2 and that of most of the mica particles were greater than 4.

The asbestos and glass fibre dusts were a mixture of fibres and fine particles. The length:breadth ratio of the fibres was usually much greater than 3, the limit chosen to distinguish fibrous from non-fibrous particles. The asbestos particles frequently consisted of more than one fibre and many of the fine particles appear to be attached to the fibres.

The proportion of fibrous particles, expressed as

$$\frac{\text{Fibrous particles}}{\text{Fibres} + \text{non-fibrous particles} < 0.5\ \mu\text{m}} \quad \text{and}$$

present (5) in the four types of dust clouds produced from fibrous materials were:
- 0.77 in jet-milled asbestos,
- 0.20 in pulverized asbestos,
- 0.40 in jet-milled glass fibre,
- 0.46 in pulverized glass fibre.

TABLE A-4

Variation in Mean Dust Concentration Between Runs (Hexhlett)

Material	Disperser	Concentration mg/m^3 Run 1	Run 2	Ratio Large/Small
Coal	Jet Mill	1.64	1.38	1.19
	Air Ejector	2.28	2.48	1.09
Silica	Jet Mill	3.005	2.85	1.08
	Pulveriser	2.13	2.00	1.06
	Air Ejector	2.47	2.83	1.15
Pyrite	Jet Mill	3.72	3.78	1.02
	Pulveriser	2.83	2.91	1.03
	Air Ejector	7.43	6.31	1.18
Mica	Jet Mill	6.9	7.375	1.07
	Pulveriser	2.46	2.26	1.09
	Air Ejector	12.275	11.24	1.09
			Mean Value	1.10

SIZE DISTRIBUTION BY VOLUME: COULTER COUNTER

The results obtained for the dust clouds produced by the four dispersion methods from coal, silica, pyrite, and mica are shown in Figures A8 to A11. It can be seen that the departure from straight lines is small except near the toe, where large errors, due to the small number of large particles counted, can occur. The lines for the dust clouds from the four materials are nearly parallel except for the dust clouds produced by the jet mill from coal and silica, Figures A8 and A9. This may indicate that the breakage produced by the jet mill and the pulverizer is different for these two materials. Because the states of dispersion of these four materials, after they were prepared for the Coulter, were nearly complete and because only a few aggregates were seen on the thermal precipitator slides, the results are likely to be representative of the airborne dust clouds.

For the fibrous dust clouds, the results obtained by the Coulter Counter, Figures A12 and A13, are unreliable. There are two reasons for this: one, the state of dispersion; and two, the electrical response to a fibre passing through the orifice. Microscope examination shows that asbestos fibres are aggregated on the thermal precipitator slides and different results are obtained on the Coulter by different dispersion treatments; thus, the state of dispersion in the airborne dust cloud and in the Coulter electrolyte are most unlikely to coincide; this will render interpretation difficult. There is a large difference in the size distribution obtained using the two orifices for each of the fibrous dust clouds, whereas the difference between the orifices was within the accuracy of calibration for the other dust clouds. This difference leads to the suspicion that the Coulter Counter does not size long, thin particles or that there is an abnormal coincidence correction to be applied. Many of the fibres are longer than the zone of electrical sensing and must pass through the orifice aligned to the flow, thus only a portion of the fibre is in the sensing zone at any one time.

The values of the median size by volume and by number as well as the standard deviation for a log normal size distribution are given in Table A5.

SIZE DISTRIBUTION: OPTICAL MICROSCOPE

The size distribution of non-fibrous particles obtained by microscope examination of thermal precipitator slides were analyzed on a computer by a regression analysis technique (Appendix B). The results obtained are given in Table A6 for each of the twenty dust clouds. Further

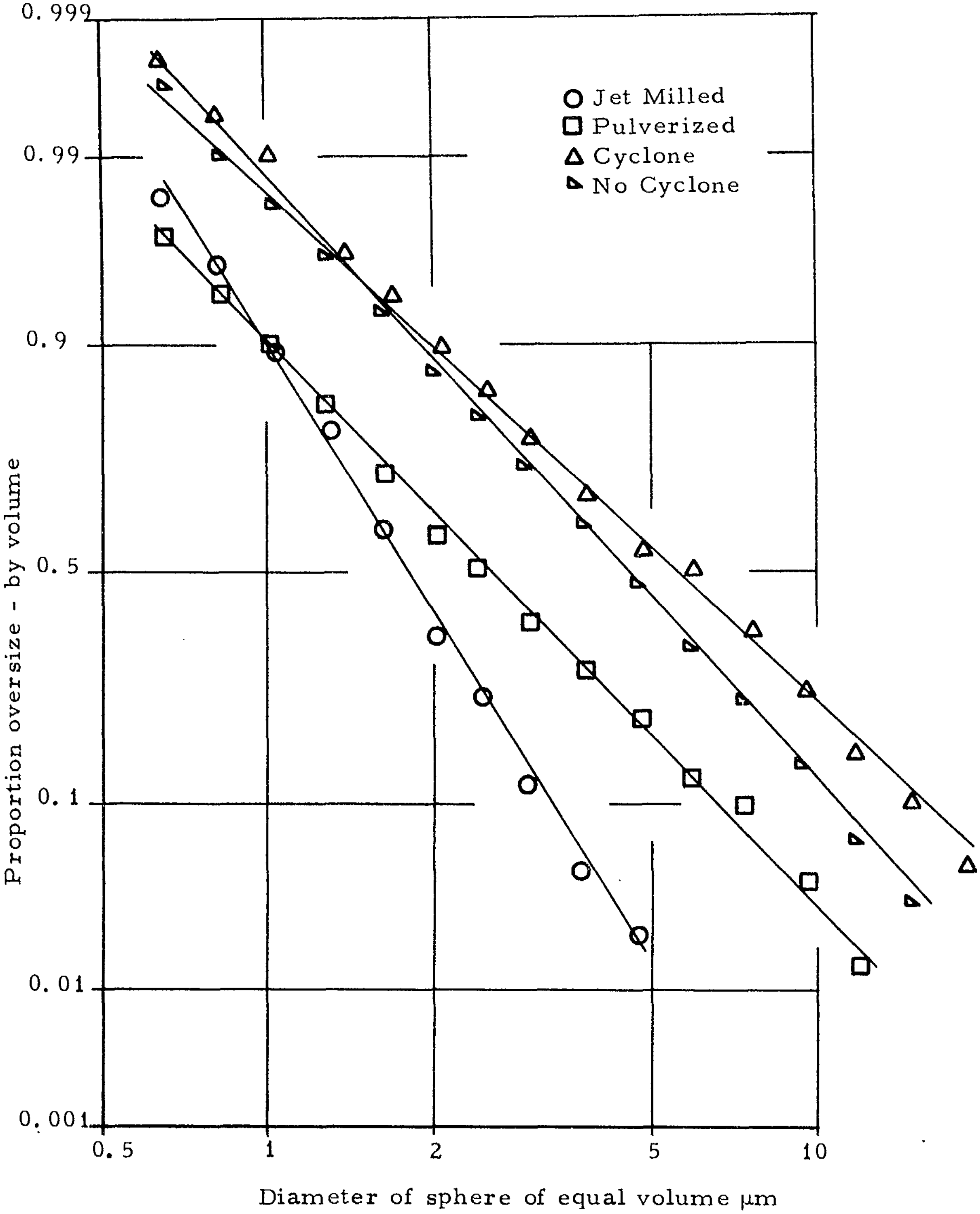


FIGURE A-8: Size distribution of the coal dust clouds - Coulter Counter.

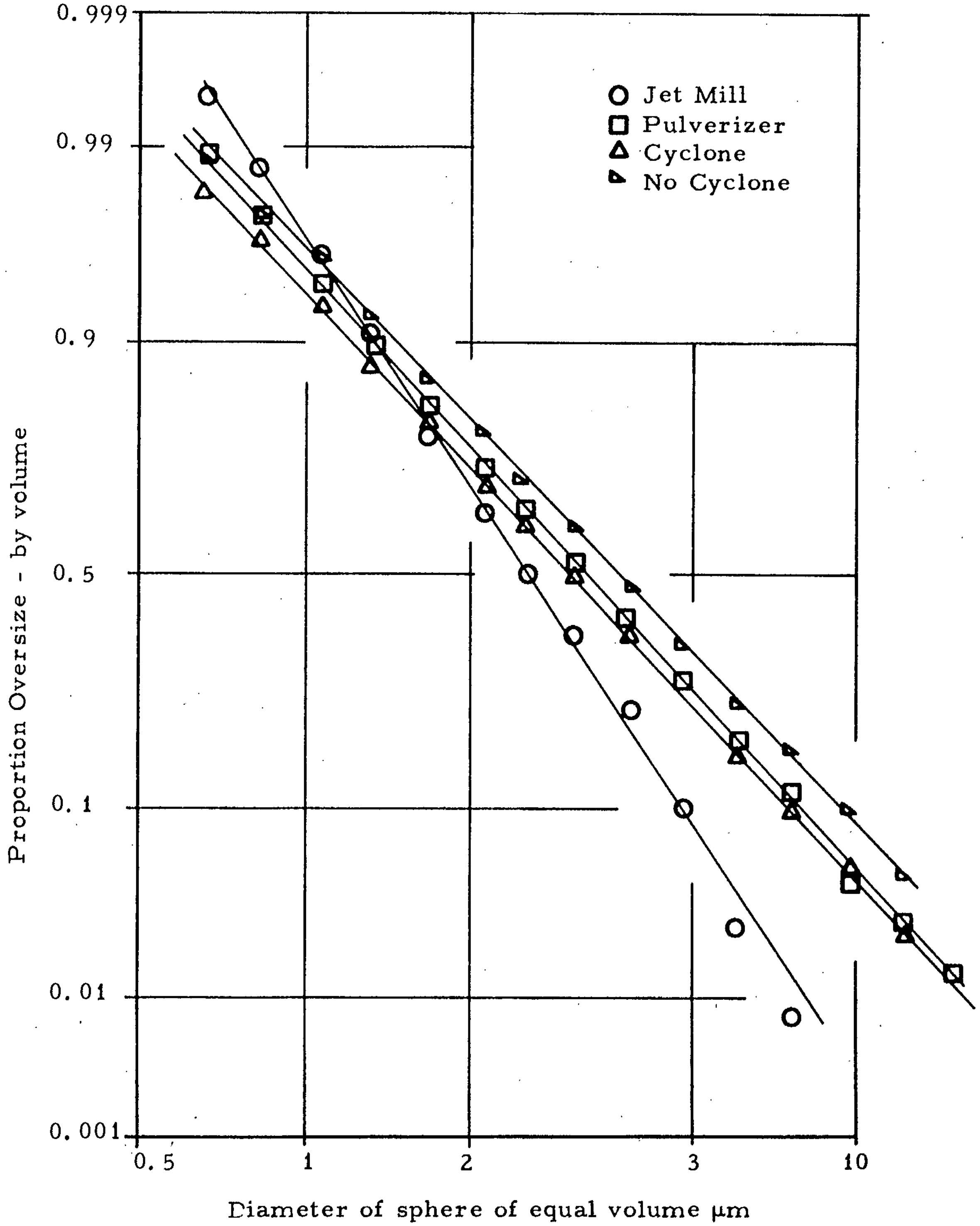


FIGURE A-9 Size distributions of the silica dust clouds - Coulter Counter.

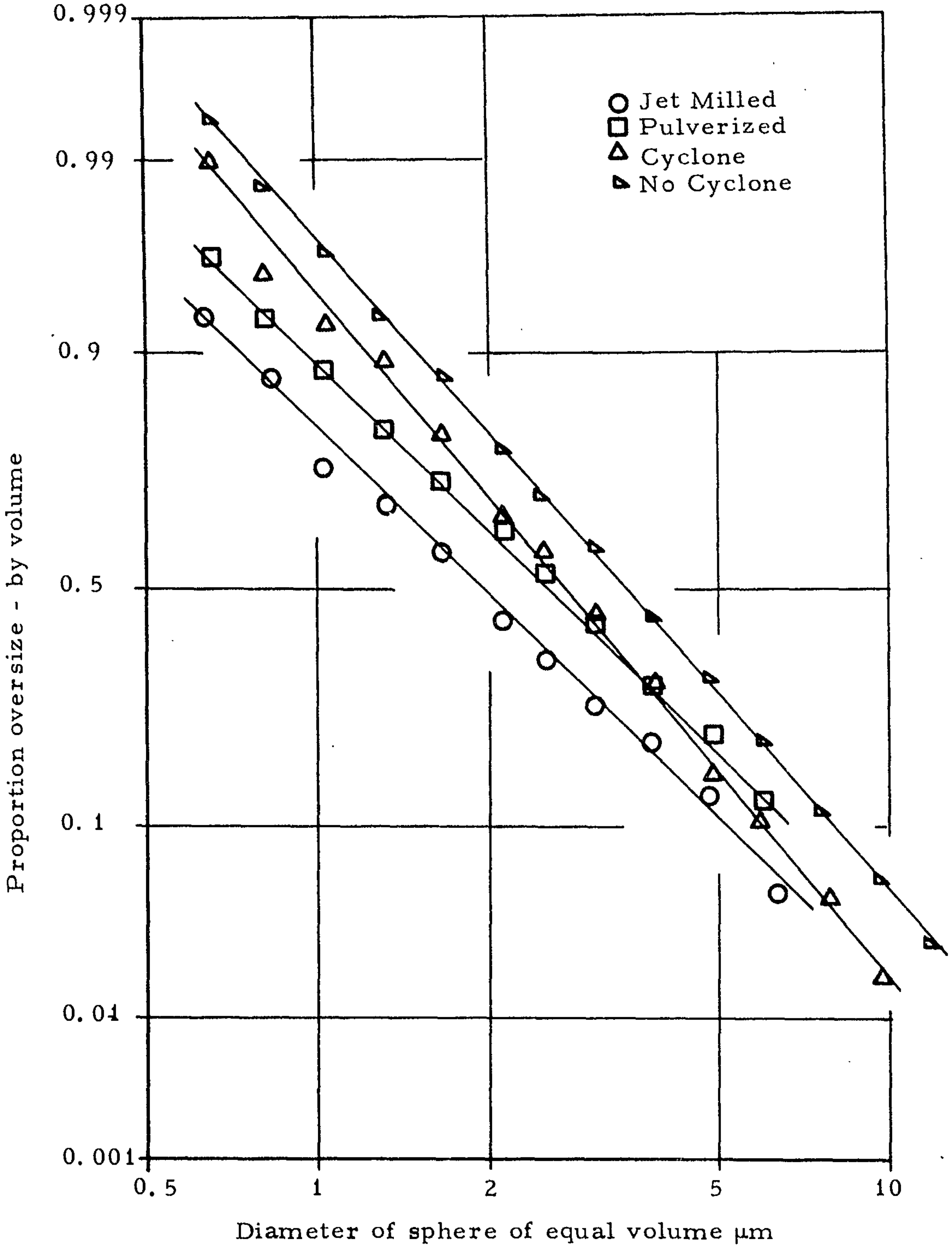


FIGURE A-10: Size distributions of pyrite dust clouds - Coulter Counter.

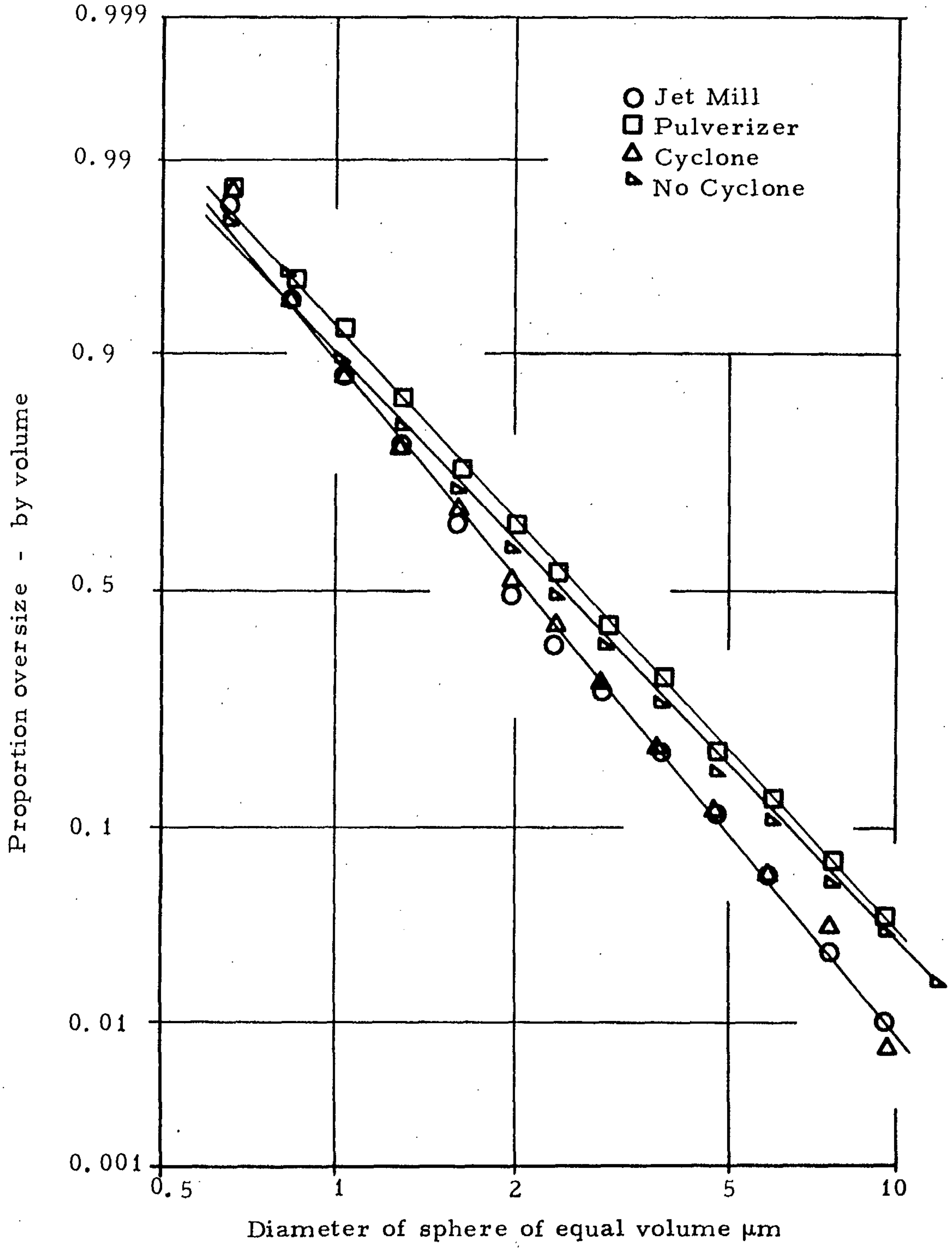


FIGURE A-11: Size distributions of the mica dust clouds - Coulter Counter.

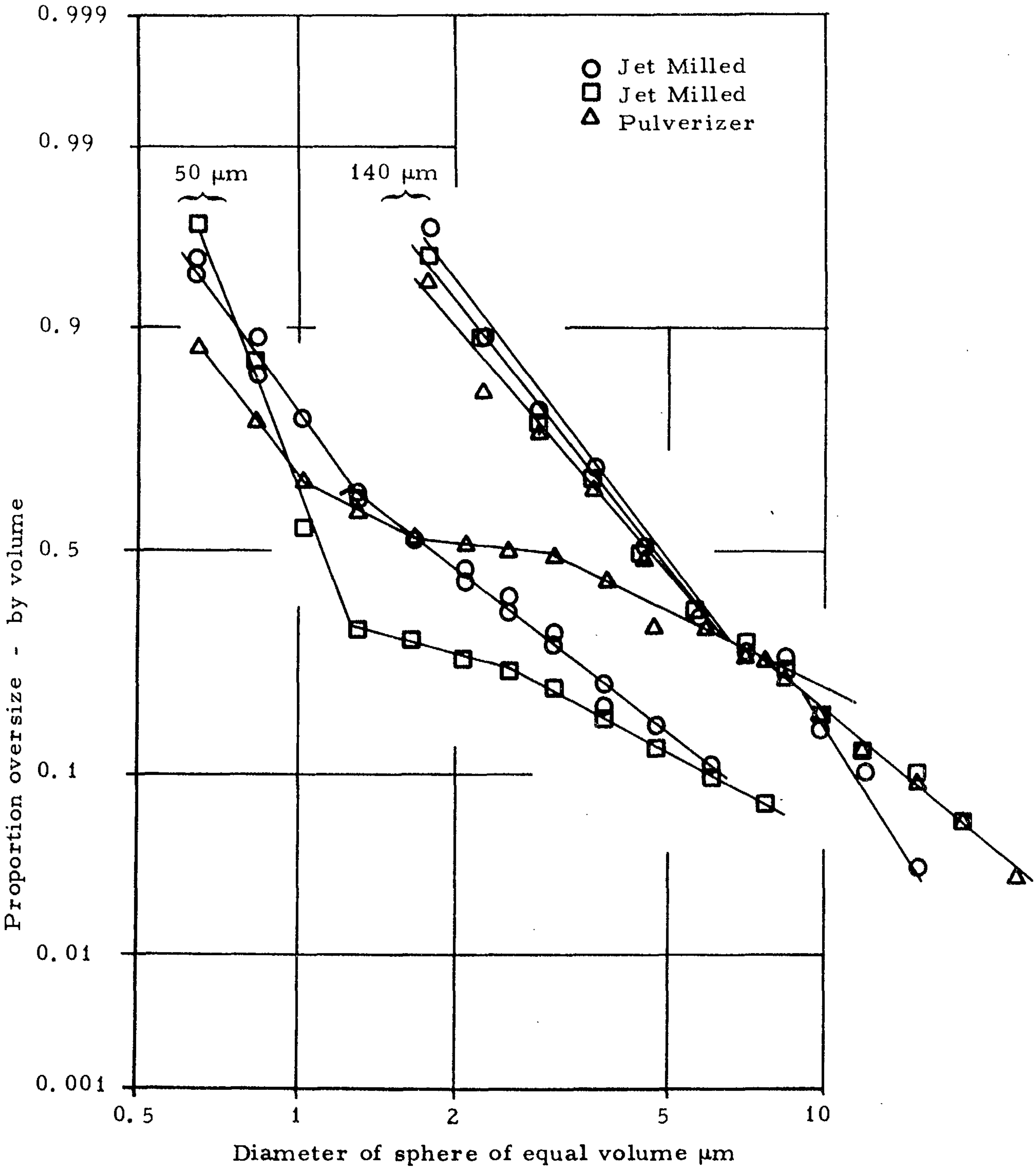


FIGURE A-12: Size distributions of asbestos dust clouds - Coulter Counter - 140- and 50-µm-diameter orifices.

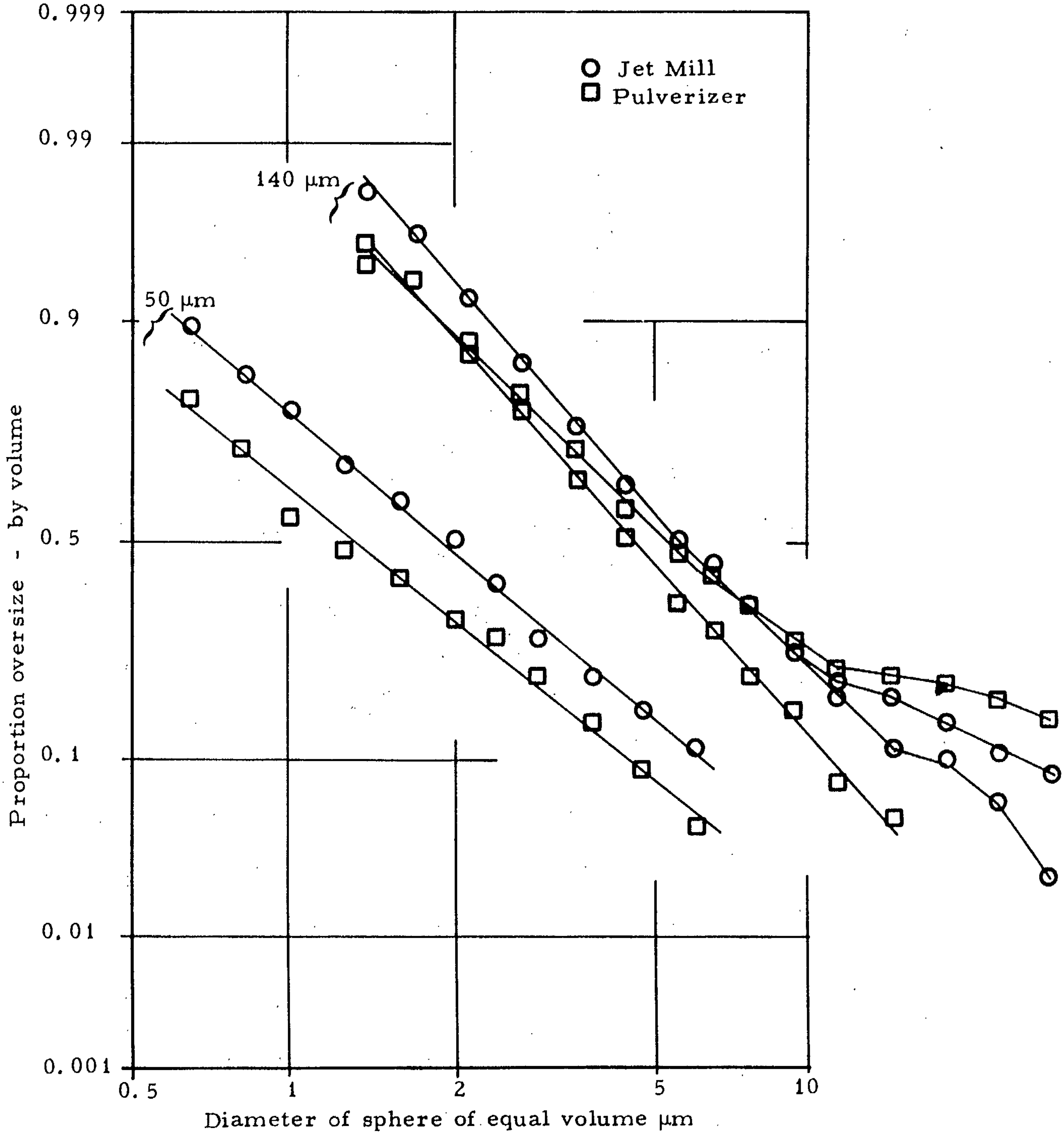


FIGURE A-13: Size distributions of the glass fibre dust clouds - Coulter Counter - 140- and 50-µm-diameter orifices.

TABLE A-5

Coulter Counter Log Normal Size Distributions
Constants for Best Fit

Dust Cloud	Geometric Mean Size μm		Standard Deviation
	By Volume	By Number	
Coal			
Jet Milled	1.8	1.0	1.6
Pulverised	2.6	0.52	2.1
Cyclone	4.5	1.15	1.95
No Cyclone	5.7	1.1	2.1
Silica			
Jet Milled	2.45	1.35	1.6
Pulverised	3.2	0.77	2.0
Cyclone	3.1	0.75	2.0
No Cyclone	3.7	0.89	2.0
Pyrite			
Jet Milled	1.9	0.29	2.2
Pulverised	2.6	0.48	2.15
Cyclone	2.8	0.82	1.9
No Cyclone	3.5	1.02	1.9
Mica			
Jet Milled	2.2	0.65	1.9
Pulverised	2.8	0.73	1.95
Cyclone	2.2	0.65	1.9
No Cyclone	2.6	0.55	2.05
Asbestos			
Jet Milled	1.1 - 4.6	—	2 - 5
Pulverised	2.7 - 4.8	—	2 - 5
Glass Fibre			
Jet Milled	2.1 - 5.9	—	2.6
Pulverised	1.3 - 5.5	—	1.9 - 2.65

TABLE A-6

Size Classification by Optical Microscope

Dust Cloud	Proportion of Dust in Size Range by Projected Area		
	< 0.5 μm* / 0.5 μm	> 1/> 0.5 μm	> 5/> 0.5 μm
Coal			
Jet Milled	1.3	0.32	0.00014
Pulverized	1.1	0.38	0.008
Cyclone	0.25	0.607	0.0274
No Cyclone	-	0.609	0.0288
Silica			
Jet Milled	2.6	0.334	0.0041
Pulverized	0.35	0.351	0.0144
Cyclone	0.5	0.501	0.0113
No Cyclone	0.24	0.482	0.012
Pyrite			
Jet Milled	1.6	0.13	0.000066
Pulverized	5.1	0.1575	0.00249
Cyclone	0.35	0.509	0.00915
No Cyclone	-	0.526	0.0265
Mica			
Jet Milled	4.2	0.387	0.00735
Pulverized	2.1	0.262	0.00252
Cyclone	0.65	0.354	0.0138
No Cyclone	-	0.357	0.0166
Asbestos	Non Fibrous Particles Only		
Jet Milled		0.0445	0.018
Pulverized		0.167	0.0041
Glass Fibre			
Jet Milled		0.268	0.018
Pulverized		0.213	0.0103

* < 0.5 μm includes all particles less than 0.5 μm that are visible on a high-resolution microscope (light field, oil immersion objective, approx. N.A. of 1.0).

results for 'all visible' particles are also shown.

The diameters and lengths of fibrous particles have been determined on one thermal precipitator slide taken in each of the four types of fibre dust clouds. The ratios in the various size ranges obtained are shown in Table A7.

TABLE A-7

The Size Distribution in the Fibrous Dust Clouds

Dust Cloud	Fibres in Each Size Range Expressed as a Fraction						
	Diameter			Length			
	< 0.25 µm	0.25 - 0.5 µm	> 0.5 µm	< 5 µm	5 - 16 2/3	16 2/3 - 50	> 50 µm
Asbestos							
Jet Milled	0.68	0.17	0.15	0.72	0.26	0.02	0.0
Pulverized	0.70	0.16	0.14	0.52	0.38	0.07	0.03
Glass Fibre							
Jet Milled	0.16	0.65	0.19	0.60	0.30	0.04	0.06
Pulverized	0.20	0.60	0.20	0.39	0.52	0.09	0.0

It can be seen that the asbestos fibres are fine, many having diameters less than the resolving power of the microscope. The glass fibres are coarser than asbestos and the diameter of each fibre is greater than the resolving power of the microscope.

SIZE CLASSIFICATION BY FALLING SPEED

A dust sampler fitted with a horizontal elutriator size selector consists, in its usual form, of a number of rectangular channels through which air flows horizontally, followed by a filter paper to collect the 'respirable' dust. The airborne dust particles settle towards the floor of each channel. Some of these particles reach the floor and adhere.

The theory of horizontal elutriators was given by Walton (4) who showed that in the size range below a critical maximum size x_E (the design top-cut of the elutriator), the proportion of particles of a given size that settle out in a rectangular channel is proportional to their settling velocity.

The top size cut is that size corresponding to a particle that will just fall the height of the channel during the period of time required for the air to flow from one end of the channel to the other. Because the settling velocity is proportional to the square of the aerodynamic size, x, the proportion of size x, settling out is given by,

$$p = \frac{x^2}{x^2_E} \text{ for } 0 < x \leq x_E .$$

This theory was developed by Knight (5) to fit a mathematical size distribution to the measurements made by a number of dust samplers fitted with size selectors with different top cuts. The parameters of an assumed logarithmic normal size distribution obtained by this technique are shown for some of the dust clouds in Table A8, together with the classification of falling speed obtained for all the dust clouds in the main series of experiments is the ratio of respirable dust to total dust (open filter) by mass. The respirable dust being defined by the Hexhlett as fitted with a size selector.

SURFACE AREA

It is stated that silicosis is dependent on the surface area of the silica deposited in the lungs and thus efforts should be made to determine the surface area of the particles in the dust clouds and differentiate between the respirable fraction and the total dust.

The surface areas of the laboratory test dust clouds have been obtained by two methods:

1. from permeametric measurements;
2. calculated from the size distributions given by the Coulter.

The permeametric measurements were made on samples collected directly onto filter papers in the dust chamber. The techniques for calculation were made following three authors (6, 7, 8) and are given in Table A9. The surface areas obtained from the size distributions by volume are based on the two assumptions: 1, the size distribution is logarithmic normal; and 2, the particles are spheres.

TABLE A-8

Experimental Determinations of Particle Size Distributions Using Size Selective (Horizontal Elutriator) Samplers

Dust Cloud	Mass-Median Aerodynamic Size x_g μm	Geometric Standard Deviation σ_g	Respirable Dust Fraction by Mass
Coal			
Jet Milled	2.5	1.7	0.84
Pulverised	- -	- -	0.64
Cyclone	- -	- -	0.61
No Cyclone	4.9	2.0	0.39
Silica			
Jet Milled			0.74
Pulverised			0.47
Cyclone			0.57
No Cyclone			0.37
Pyrite			
Jet Milled	2.3	2.15	0.80
Pulverised	- -	- -	0.60
Cyclone	- -	- -	0.44
No Cyclone	7.4	2.0	0.24
Mica			
Jet Milled			0.89
Pulverised			0.83
Cyclone			0.71
No Cyclone			0.71
Asbestos			
Jet Milled	0.9	18.	0.64
Pulverised			0.74
Glass Fibre			
Jet Milled			0.28
Pulverised			0.60

TABLE A-9

The Specific Surfaces of Cloud Dusts

Dust Cloud	Size Collected	Porosity Fraction	Specific Surface Area m^2/cm^3 Kozeny Carmen	Arnell	Benarie	Calculated Coulter Counter
Coal						
Jet Milled	Total	0.66	43	53	13.3	30.1
	Respirable	0.76	67	82	12.1	
No Cyclone	Total	0.63	25	29	6.65	13.9
	Respirable	0.75	40	46	10.5	
Silica						
Jet Milled	Total	0.58	18.8	21	6.3	27.2
	Respirable	0.89	148	180	8.8	
No Cyclone	Total	0.57	21.5	25	8.1	21
	Respirable	0.81	76.5	93	11	
Pyrite						
Jet Milled	Total	0.79	84	150	13.8	43.5
	Respirable	0.84	141	193	16.6	
No Cyclone	Total	0.68	340	40	8.2	21.1
	Respirable	0.95	218	247	12.7	
Mica						
Jet Milled	Total	0.77	89	118	14.1	33
	Respirable	0.75	88	121	18.8	
No Cyclone	Total	0.72	61.6	77	13.4	30.3
	Respirable	0.80	93.5	118	13.5	
Asbestos						
Jet Milled	Total	0.86	100	118	12.3	54.2
	Respirable	0.87	120	143	12.1	

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APPENDIX B
STATISTICAL ANALYSIS TECHNIQUE

INTRODUCTION

About 7000 measurements of dust concentration were made during the first part of the program on Comparison of Dust Sampling Instruments in non-aggregated dust clouds, and this chapter discusses the statistical technique and the computer program used in analyzing the results.

The statistical analysis and computer program are based on the REGRE Program given in the IBM scientific subroutines. This is a multiple linear regression analysis program derived from a treatment by B. Ostle (2).

EXPERIMENTAL DESIGN FOR THE COMPARISON OF INSTRUMENTS

The experiments were laid out as a factorial design as described in most statistical textbooks. The factors were:

1. material - six levels - coal, silica, pyrite, mica, asbestos, and glass fibre;
2. dust dispersion method - four levels - jet mill, pulverizer, air ejector with, and without cyclone;
3. dust feed rate - three levels - feed rates were chosen for each dust cloud such that the levels differed by factors of 2 to 2 1/2 and that the lowest concentration was near the approved limit for silicosis.

A dust cloud prepared from one material by one method of dispersion is termed a "type of dust cloud", regardless of the feed rate or the concentration.

Because two of the methods of dispersion were not suitable for two of the types of dust, a total of twenty types of dust cloud were examined each at three concentrations in duplicate, thus producing a total of 120 dust clouds in which 7000 measurements of concentration were made by seventeen dust sampling instruments. Some instruments gave more than one estimate of the dust concentration, and they are arranged in groups measuring the same property of the dust.

METHOD OF STATISTICAL ANALYSIS

The problem in the statistical analysis is solving the expected relationship:

$$y = A \cdot F(x) \qquad \text{(Eq. B-1)}$$

where y and x are the dust concentrations estimated by the two instruments being compared. A is a constant; its value being dependent on the type of dust cloud in which the measurement is taken and F(x) is a function of x.

The expectation is that the relationship between y and x will be linear in most cases; however, the analysis should be able to detect non-linearity.

$$\text{Linear case} \quad F(x) = x \qquad \text{(Eq. B-2)}$$

$$\text{Non-linear} \quad F(x) = x^S \qquad \text{(Eq. B-3)}$$

An example of the dependence on the dust concentration of the differences between the dust concentrations estimated by three similar instruments is shown in Figure B-1, together with the effect of a logarithmic transformation on these errors. It can be seen that the errors in the linear form are greater at high concentrations than at low and that the logarithmic transformation smooths them out. This suggests that an equation of the form:

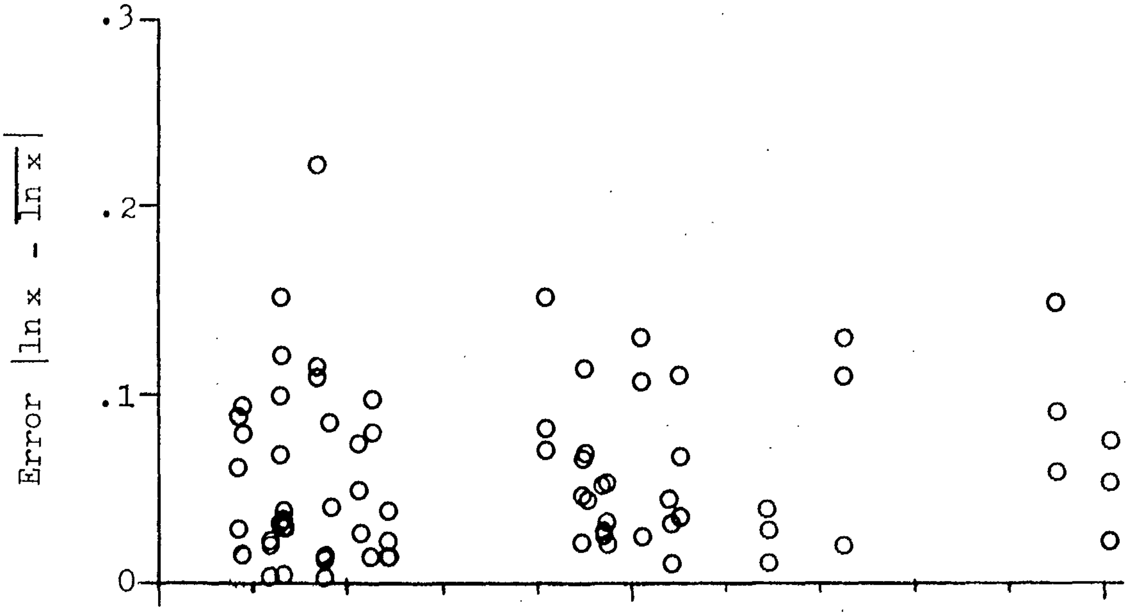
$$\ln y = B + C \ln x \qquad \text{(Eq. B-4)}$$

where ln y and ln x are considered as the variables while B and C are constants that might be applicable. The constant B in the above equation includes the differences between the various dust clouds and, if C is significantly different in value from 1, it would indicate non-linearity. Factor levels such as type of dust cloud, which have no numerical significance, can be handled by using dummy variables (3) which take the value 1 if the measurement is taken at the appropriate factor level and 0 if it is not.

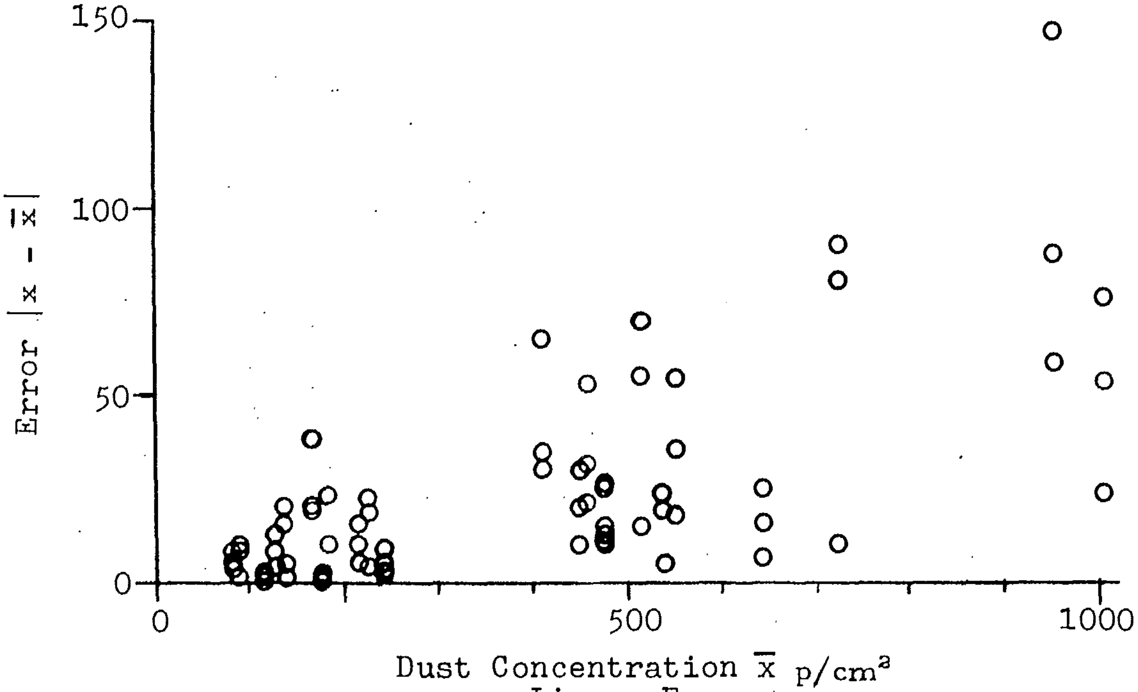
By using dummy variables, the constant B which depends on the type of dust cloud or characteristics of the individual sampling instrument in each group can be expanded to give an equation suitable for statistical and computer analysis:

$$\ln y = b_0 + b_1 \ln x + b_2 X_2 + \ldots + b_m X_m + b_{m+1} X_{m+1} + \ldots b_n X_n \qquad \text{(Eq. B-5)}$$

where, y = the concentration measured by the test instrument,
x = that measured by the reference instrument,
$\ln y$ = the dependent variable,
$\ln x$ = the independent variable,
b_0 = the intercept on the logarithmic plot,



Logarithmic Transformation



Linear Form

FIGURE B.1 THE DEPENDENCE OF THE ERRORS ON THE DUST CONCENTRATION (THE ERROR GIVEN IS THE DIFFERENCE BETWEEN EACH IMPINGER AND THE MEAN OF THREE IN EACH DUST CLOUD).

b_1 to b_n = the regression coefficients,
X_2 to X_n = the dummy independent variables.

This regression equation can be divided into various sections as shown below:

1. the dependent variable ln y;
2. the intercept b_0;
3. the feed rate or reference instrument part $b_1 \ln x$;
4. the part containing the dummy variables pertaining to the different dust clouds - $b_2 X_2$ to $b_m X_m$;
5. the part containing the dummy variables pertaining to the different test instruments in each analysis: $b_{m+1} X_{m+1}$ to $b_n X_n$.

These will, where necessary, be amplified in the following sections.

The Reference Instrument

The original intention in this analysis was to use the feed rate as an independent variable. However, a feed rate is not reproducible or measurable with sufficient accuracy, and a given feed rate results in a very wide range of concentrations depending on material and method of dispersion. Therefore each concentration (y) measured by the instrument under "test" has been compared with that (x) measured by a "reference" instrument in the same dust cloud. The program has been set up so that the log (concentration) measured by one instrument or the mean of the log measured by a group of instruments, i. e., the three thermal precipitators, can be used as the reference.

Independent Variables for Types of Dust Cloud

It seemed simpler to carry out the analysis with twenty types of dust cloud, and then determine the effects due to material and method of dispersion, rather than have five variables for interaction. In the analysis, as the measurement must have been made in one and only one of the twenty types of dust cloud, we have:

$$X_1 + X_2 + \ldots + X_{20} = 1 \qquad \text{(Eq. B-6)}$$

where X_1 to X_{20} = the dummy variables taking values of 0 or 1 and nineteen independent variables are sufficient to specify in which of the twenty types of dust cloud the measurement was taken. If a twentieth is used it produces an uncertainty and the equation for the regression coefficients would not be solvable. Inserting these nineteen dummy variables into the equation leads to the derivation of nineteen regression coefficients. The omission of the twentieth dummy variable is equivalent to setting the regression coefficient to 0. The regression coefficients (b) then measure the departure of the mean of each dust cloud from that of the dust cloud for which the dummy variable was omitted. The departure (B) of each dust cloud from the overall mean would be more valuable, and these can be derived as shown:

$$b_i = B_i - B_m \qquad i = 1, \ldots, m-1 \qquad \text{(Eq. B-7)}$$

$$b_m = 0 \qquad \text{(Eq. B-8)}$$

Hence,

$$\sum_{i=1}^{m-1} b_i = \sum_{i=1}^{m-1} B_i - (m-1)\, B_m \qquad \text{(Eq. B-9)}$$

$$= -B_m - (m-1)\, B_m \quad (\text{since } \sum_{i=1}^{m} B_i = 0) \qquad \text{(Eq. B-10)}$$

$$= -m\, B_m \qquad \text{(Eq. B-11)}$$

therefore,

$$B_m = \frac{1}{m} \sum_{i=1}^{m-1} b_i \qquad \text{(Eq. B-12)}$$

therefore,

$$B_i = b_i - \frac{1}{m} \sum_{i=1}^{m-1} b_i . \qquad \text{(Eq. B-13)}$$

The meaning of these coefficients can be clarified by considering the ith dust cloud.

The ith dummy variable takes the value 1 and the rest of the dust cloud dummy variables are 0, thus,

$$\log\ y = B_0 + b_1\ \log x + B_i \cdot 1.0 + B_j \cdot 0.0 \qquad \text{(Eq. B-14)}$$

where B_0 = the corrected intercept

or

$$y = x^{b_1} \cdot e^{B_0} \cdot e^{B_i} = x^{b_1} \cdot e^{B_0 + B_i} \qquad \text{(Eq. B-15)}$$

and exp (B_i) is the factor by which the overall mean is to be multiplied to obtain the mean for the ith dust cloud.

The mean effect for each material and each method of dispersion can be found similarly as shown below. Let t_1 be the mean value (over the four methods of dispersion) of the coefficients of departure obtained on the first material, and t_2 that on the second, etc. then

$$t_1 = \frac{1}{4}\sum_{i=1}^{4} B_i\ , \qquad t_2 = \frac{1}{4}\sum_{i=5}^{8} B_i\ , \qquad \text{etc.} \qquad \text{(Eq. B-16)}$$

The desired coefficient of departure T_i from the overall mean is obtained by setting

$$\sum_{i=1}^{6} T_i = 0 \qquad \text{(Eq. B-17)}$$

thus,

$$T_i = t_i - \frac{1}{6}\sum_{j=1}^{6} t_j \qquad \text{(Eq. B-18)}$$

similarly for the coefficients of departure for method of dispersion.

These results are printed by the program as:

1. the regression coefficients with an estimate of their standard errors;
2. a table of coefficients of departure from the overall mean for individual types of dust cloud, for mean material and for mean method of dispersion;
3. anti logarithms of the coefficients in 2 are also printed; these are multiplying factors for the ratios of dust concentrations.

Independent Variables for Instruments

Groups of instruments measuring dust concentration in the same way are analyzed together, i.e., one group is the staplex, electrostatic precipitator and the open filter all measuring the total mass of dust in the air, and the second group is the konimeters. Each instrument but one in a group is assigned a dummy independent variable, of value 1.0 or 0.0. The resultant regression coefficients indicate the mean differences between the corresponding instruments and the instrument for which the dummy variable was omitted. Each instrument provides a measurement of the dependent variable.

The Intercept

The intercept b_0 represents the value of the dependent variable when all the other variables are 0;

that is, $\ln y = b_0 + b_1 \log x + b_2 X_2 + \ldots + b_N X_N$ (Eq. B-19)

where $\ln x = 0$ and X_2 to $X_N = 0$,

or, $\ln y = b_0$ when $x = 1$. (Eq. B-20)

Therefore, the ratio of dust concentrations from test and reference instruments is given by,

$$\ln y - \ln x = b_0 \quad \text{or} \quad \frac{y}{x} = e^{b_0} \qquad \text{(Eq. B-21)}$$

This ratio pertains to the mean value of the particular dust cloud and instrument for which the dummy variables were omitted, and the corrected value for the mean over all the dust clouds and instruments is,

$$\ln\left(\frac{y}{x}\right) = B_0 = b_0 + k_D + k_I \qquad \text{(Eq. B-22)}$$

where the k's are the correction factors determined earlier.

If the relationship between the dust concentrations from the test and reference instruments is not linear (i.e., b_1 is not equal to 1), the ratio of concentrations varies with the concentration and the intercept B_0 is the estimated value at $x = 1$. As the mean value of x can be much greater than 1, a better estimate of the mean ratio $\frac{y}{x}$ can be found from the mean values of ln y and ln x by:

$$\sum_{i=1}^{N} \ln \frac{y_i}{x_i} = \sum_{i=1}^{N} \ln y_i - \sum_{i=1}^{N} \ln x_i \qquad \text{(Eq. B-23)}$$

where N = the total number of observations, and
i = the serial number of the individual observations.

The intercept, the corrected intercept, the mean ratio (from the corrected intercept) and the mean ratio (from the logarithmic means) are given by the program.

THE COMPUTER PROGRAM

The computer program is based on the IBM scientific subroutines REGRE, CORRE, ORDER, MINV and MULTR which analyze data and perform a multiple linear regression with up to forty variables. These subroutines are run under a main program called "DUSTMLR" which prepares the data for each problem into a form suitable for the other subroutines.

The functions of the various sections of the computer program are outlined below:

DUSTMLR

1. reads dust concentrations in batches of 120, each batch consisting of one measurement on each dust cloud by one instrument;
2. prints all dust concentrations for verification;
3. reads parameter card for each problem; this defines test and reference instruments;
4. reads dust cloud selection card ;
5. selects each measurement made by the "test" instruments over the required range and the corresponding measurements by the "reference" instruments and takes their logarithms;
6. calculates the values of the dummy variables pertaining to each test instrument measurement ; and
7. writes the values of the variables on tape in a form suitable for CORRE.

REGRE

8. reads the dependent and independent variable selection card;
9. calls the remaining subroutines in order;
10. calculates the variance attributed to the feed rate (or reference instrument), the dustclouds and the test instruments;
11. calculates the tables of dust type, method of dispersion, and dust cloud coefficients and multiplying factors;
12. prints all answers; and
13. prints the residual from both multiple regression and simple linear analysis for each observation (test and concentrations); optional.

CORRE

14. calculates means, standard deviations, and sums of cross products of deviations from means and product moment correlation coefficients from the data placed on tape by DUSTMLR.

ORDER

15. selects the variables to be analyzed;
16. prepares a matrix of intercorrelations among independent variables;
17. prepares a vector of intercorrelations of independent variables with the dependent variable.

MINV

18. inverts the matrix of intercorrelations among the independent variables.

MULTR

19. calculates regression coefficients;
20. determines the intercept b_o;
21. computes the multiple correlation coefficient;
22. performs analysis of variance; and
23. certain other statistics are computed - standard deviations of regression coefficients, computed t values of regression coefficients.

PRESENTATION OF DATA AND CONTROLS

The input data is punched on cards using four significant figures and an exponent (E 6.3 specification). This is arranged in sets of 120 measurements on twelve punch cards. Each set consists of one type of measurement made by one instrument for each dust cloud.

Three control cards are used:

1. DUSTMLR Control Card - specifies the test and reference instruments, the number of selections and the number of variables;
2. DUSTMLR Selection Card - controls the selection of measurements from specified types of dust clouds; and
3. REGRE Selection Card - is used to specify the dependent variable and the set of independent variables for the regression analysis.

PRESENTATION OF RESULTS

The program repeats the parameter cards and prints the problem number for each problem.

The printout for each problem consists of the following:

1. mean of each variable;
2. standard deviation of each variable;
3. correlation coefficient between each independent variable and the dependent variable;
4. regression coefficients;
5. standard errors of the regression coefficients;
6. computed t values;
7. intercept;
8. multiple correlation coefficient;
9. standard error of estimate - this term arises in the original IBM program, but the calculation would seem to produce the similar "standard error of observation";
10. corrected intercept;
11. mean ratio of test to reference dust concentrations and its geometric error;
12. an analysis of variance;
13. table of coefficients of departure from the overall mean for each dust type, size (method of dispersion) and dust cloud;
14. table of multiplying factors as for 13;
15. table of each observation of dependent variable and its residual after multiple and single regression analysis - optional.

The results of a typical analysis are given below.

Printout from Computer Program showing a Comparison between Thermal Precipitators and Impingers

```
PROBLEM NUMBER TP13MI        NUMBER OF OBSERVATIONS    335
DUSTCLOUDS        1 TO    20 NUMBER OF VARIABLES 23
VARIABLE          MEAN      STANDARD          CORRELATION          REGRESSION
 NO.                        DEVIATION           X VS Y             COEFFICIENT
  2 REF I   5.84464         1.08347           -0.17616             -0.13403
  3           .04776         .21358             .20422               .11448 }
  4           .05075         .21981           -0.07481             -0.53698 } Coal
  5           .04776         .21358           -0.08679             -0.56661 }
  6           .05373         .22582             .08354             -0.13914 }
  7           .05373         .22582           -0.00553             -0.37051 } Silica
  8           .05373         .22582           -0.17237             -0.72992 }
  9           .05373         .22582           -0.14795             -0.67540 }
 10           .05373         .22582             .08192             -0.05108 }
 11           .05373         .22582             .26510               .23209 } Pyrite
 12           .05373         .22582             .04058             -0.34079 }
 13           .04776         .21358             .01146             -0.38501 }
 14           .05373         .22582           -0.06829             -0.39163 }
 15           .05373         .22582             .08826             -0.11293 } Mica
 16           .05373         .22582           -0.17556             -0.60413 }
 17           .05373         .22582           -0.15512             -0.57205 }
 18           .04478         .20712             .09237             -0.16579 } Asbestos
 19           .05373         .22582           -0.09227             -0.51454 }
 20           .04776         .21358           -0.15066             -1.03985 } Glass
 21.          .01493         .12144             .15983               .06427 }
 22 INSTR     .33731         .47350             .03404               .12195 LPDS head
 23 VARIA     .32239         .46809             .11164               .20030 LPDS
DEPENDENT
  1         1.07833          .52391
```

TYPES OF DUST CLOUD

```
                                     STD. ERROR        COMPUTED
                       Variable N    OF REG.COEF.      T VALUE
                            2          .03040         -4.40902
                            3          .14438           .79294
                            4          .14200         -3.78156
                            5          .14429         -3.92693
                            6          .14084         -0.98790
                            7          .14011         -2.64445
                            8          .14021         -5.20576
                            9          .14023         -4.81645
                           10          .14478         -0.35278
                           11          .14024          1.65496
                           12          .14006         -2.43321
                           13          .14418         -2.67026
                           14          .14417         -2.71651
                           15          .14131         -0.79916
                           16          .14552         -4.15152
                           17          .14474         -3.95216
                           18          .14684         -1.12902
                           19          .14114         -3.64555
                           20          .15884         -6.54654
                           21          .21891           .29357
                           22          .05573          2.18800
                           23          .05648          3.54643
```

REF I = Reference Instrument

INSTR
VARIA = Instrument Variables

Printout .... (2)

```
TOTAL OF DUST TYPE SIZE REGRESSION COEFFICIENTS      -6.78552

INTERCEPT                      2.10877

MULTIPLE CORRELATION            .63322

STD. ERROR OF ESTIMATE          .41955


CORRECTED INTERCEPT            1.87690

MEAN RATIO OF CONCENTRATIONS FROM TEST

                    AND REFERENCE INSTRUMENTS BASED ON

   CORRECTED INTERCEPT         6.5332469
   LOGARITHMIC MEANS            .0085118
GEOMETRIC ERROR OF RATIO       1.52127


                        ANALYSIS OF VARIANCE FOR THE REGRESSION

    SOURCE OF VARIATION         DEGREES    SUM OF   MEAN      F VALUE
                               OF FREEDOM SQUARES  SQUARES
ATTRIBUTABLE TO FEED RATE            1     2.84500  2.84500 16.16303
ATTRIBUTABLE TO INSTRUMENTS          2     2.26044  1.13022  6.42101
ATTRIBUTABLE TO DUST CLOUD TYPES    19    31.65495  1.66605  9.46519
ATTRIBUTABLE TO REGRESSION          22    30.76038  1.67093  9.49289
DEVIATION FROM REGRESSION          312    54.91784   .17602
      TOTAL                        334    91.67823
```

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```
                    TABLE OF DUST TYPE-SIZE FACTORS

                  DUST SIZE MEAN         COAL          SILICA

      DUST TYPE MEAN,                  .1044512      -0.1270166

      JET MILLED         .0767104      .3392759       .2001398
DUST
      PULVERISED         .2767659      .4537593      -0.0312376

      CYCLONE          -0.1783308    -0.1977010      -0.3906432
SIZE
      NO CYCLONE       -0.1751456    -0.2273317      -0.3361276

        PYRITE          MICA         ASBESTOS       GLASS FIBRE

      DU T M .2155295  -0.0684585     .0115602      -0.1360658

      JET    .2882000  -0.0523509     .1734872      -0.7005753

      PULV   .5713673   .2263463    -0.1752679       .4035424

      CYC  -0.0015158  -0.2648536            0               0

      NO CY-0.0457358  -0.2327778            0               0

 MULTIPLYING FACTORS FOR DEPARTURE OF CONCENTRATIONS

                                            FROM OVERALL MEAN

                                          COAL           SILICA
      DUST TYPE MEAN,                  1.1101012        .8807191

      JET MILLED        1.0797294      1.4039307       1.2215735
DUST
      PULVERISED        1.3188576      1.5742191        .9692453

      CYCLONE            .8366656       .8206152        .6766216
SIZE
      NO CYCLONE         .8393348       .7966565        .7145320
           PYRITE          MICA         ASBESTOS      GLASS FIBRE
      DU T M 1.2405186   .9338322      1.0116273        .8727852

      JET    1.3340240   .9489958      1.1894454        .4962997

      PULV   1.7706865  1.2540098       .8392321       1.4971188

      CYC     .9984853   .7673183              0               0

      NO CYC  .9552943   .7923296              0               0
```

DU T M = Dust Type Mean

DISCUSSION

The validity of the regression analysis depends on meeting the assumptions on which the method of least squares is based. The assumptions (4) are:

1. the average value of the errors is 0;
2. the errors have common variance;
3. the errors are independent;
4. the values of the independent variables are measured with negligible error.

For tests of significance the errors are also assumed to follow a normal distribution. Figure B-2 shows that the residuals in these analyses are close to a normal distribution.

Departure from the first assumption could be compared to a systematic difference between the counting of dust samples between laboratories, and thus, accepting the assumption is equivalent to saying that the results do not take into account the difference between this laboratory's estimate and a "true" mean of all laboratories.

The instruments are compared by subjecting them to the same dust cloud. They thus experience, except for variation from point to point in the chamber, the same fluctuations in concentration and the same mean concentration, which they are intended to measure. Provided that both samples are large enough, the deviation of each measurement from the "true" mean value should be approximately normally distributed at one concentration. These are the deviations that affect the analysis and the deviations of the "true" concentrations from the set or intended values are largely immaterial. Thus the errors are independent, and, after a logarithmic transformation as shown on Figure B-1, are of common variance.

The Errors of the Independent Variables

The independent variables can be divided into three groups:

1. the reference dust concentration;
2. the dummy variables pertaining to the materials;
3. the dummy variables pertaining to the instruments in the "test" group.

It is clear that the errors in the measurement of the reference dust concentration are of the same order as that of the test dust concentration

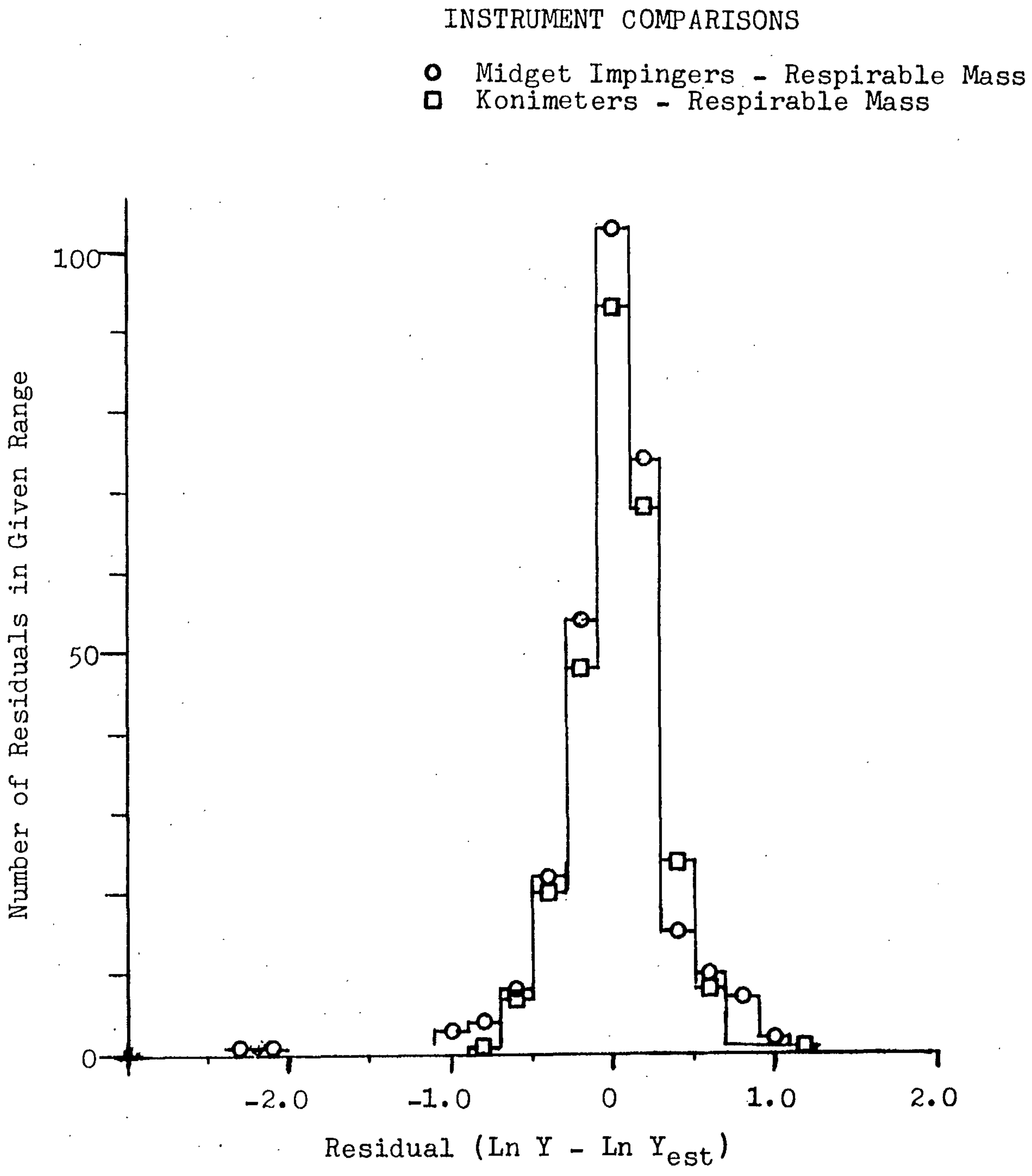

FIGURE B.2 DISTRIBUTION OF RESIDUALS FROM TWO REGRESSION ANALYSES (Eq. B.3).

(the dependent variable). However, the errors are small compared to the range of concentrations examined.

No errors are associated directly with the dummy variables. But variations in dust size distribution, etc. between the six dust clouds of one type could be considered equivalent to an error in the dummy variable; however, as these errors are small compared to the differences between types of dust cloud and to those of the dependent variable, they are assumed to have no effect on the analysis (5). There seem to be no errors associated with the dummy variables pertaining to the instruments.

The major departure from the assumption for the least squares method is the magnitude of the errors of the independent variable, reference dust concentration, in relation to that of the dependent variable. To examine this further, some comparisons have been examined in a number of ways.

Firstly, the values of the coefficients in the regression equation were determined.

$$\ln y = b_0 + b_1 \ln \bar{x} + b_2 X_2 + b_3 X_3 + \ldots b_n X_n \qquad \text{(Eq. B-24)}$$

Then those in the corresponding equation with the test and reference instrument transposed:

$$\ln x = b_0' + b_1' \ln \bar{y} + b_2' X_2 + \ldots + b_n' X_n \qquad \text{(Eq. B-25)}$$

This can be rearranged so that the terms match those in Equation B-24.

$$\ln y = -\frac{b_0'}{b_1'} + \frac{1}{b_1'} \ln x - \frac{b_2'}{b_1'} X_2 - \ldots \frac{b_n'}{b_n'} X_n \qquad \text{(Eq. B-26)}$$

These equations are the regressions of "observed" values on "observed" values, with the first used to predict ln y and the second or third to predict ln x. Because of the errors in both ln x and ln y, the regression of "true" values on "true" values will generally be steeper than given by the first two equations (5), and the "true" value of b_1 and $\frac{1}{b_1'}$. Under these conditions, Davies (5) suggests that it may be desirable to assume a "functional" relationship between y and x and he gives a technique for calculating it.

The slope S of the "functional" relationship is given by:

$$S = m + (m^2 + k^2)^{\frac{1}{2}} \qquad \text{(Eq. B-27)}$$

where

$$k^2 = \sigma^2_{\ln y} / \sigma^2_{\ln x}$$

and

$$m = \frac{1}{2b_1'} - \frac{k^2}{2b_1} \qquad \text{(Eq. B-28)}$$

$\sigma^2_{\ln y}$ and $\sigma^2_{\ln x}$ are respectively the variances of the dependent and independent variables. They can be derived from regression analyses using individual instrument readings in one type as the dependent variable and the mean of the type as the independent variable. b_1 and b_1' are given by equations B-24 and B-25.

The value of the slope S (5) should lie between those of b_1 and $\frac{1}{b_1'}$. Having obtained the slope of the "functional" relationship one can use the equation:

$$\ln\left(\frac{y}{\bar{x}^S}\right) = b_0'' + b_2''X_2 + \ldots + b_n''X_n \qquad \text{(Eq. B-29)}$$

where

$\ln\left(\frac{y}{\bar{x}^S}\right) = \ln y - S \ln \bar{x}$ is the dependent variable,

and

$\bar{x}$ is the mean of the concentrations estimated by the reference instruments in the one dust cloud.

In applying this technique it was found difficult to obtain sufficiently accurate values for k^2 and it seems justified to assume a linear relationship between the two instruments being compared when b_1 and $\frac{1}{b_1'}$ bracket the value 1 as occurred in all the comparisons except those with the konimeters. Thus, in most cases the equation above was solved with the slope S set equal to 1.

Another examination of the konimeter concentrations plotted against those given by other instruments suggests that the four konimeters differ appreciably in behaviour and that there is no simple way of expressing the functional relationship. In view of this, the comparisons between the konimeters and the other instruments were estimated, not rigorously, by using the equation:

$$\ln(K^{s}/\bar{x}) = b_{0}''' + b_{2}'''X_{2} + \ldots + b_{n}'''X_{n} \qquad \text{(Eq. B-30)}$$

where K is the dust concentration estimated by the konimeter, $\bar{x}$ is that estimated by the other instruments, and s is given by:

$$s = \frac{1}{S} = \frac{\frac{1}{b_1} + b_1'}{2} \qquad \text{(Eq. B-31)}$$

where b_1 and b_1' are determined by the Equations B24 and B25 with ln K as the dependent variable and independent variable respectively.

CONCLUSIONS

The independent variables of Equation B-29 meet the assumptions about errors and the regression analysis can be assumed to be applicable. This equation assumes a "functional" relationship between the estimates of dust concentration by the test and reference instruments in a given dust cloud of the form:

$$y = Ax^{S}$$

where A and S are constants.

The values of A will be different in each type of dust cloud and are obtained by the multiple linear regression analysis using Equation B 29. The value of S is assumed to be the same in each type of dust cloud and can be obtained from Equations B-24, B-25, and B-31. In many comparisons, S is near unity and a linear relationship was assumed.

ACKNOWLEDGEMENTS

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APPENDIX C
COMPARISON OF DUST SAMPLING INSTRUMENTS: TABLES OF RESULTS

The Tables C-1 to C-26 give full results of all the tests made in each type of dust cloud. Tables C-1 to C-20 are the main experiment. C-21 and C-22 are in dust clouds of aggregated particles. Tables C-23 to C-25 give the results at low concentrations obtained after fitting a high efficiency filter to the air intake on the chamber. C-26 gives the results of comparison of microscope techniques.

FOOTNOTES TO TABLES C-1 TO C-26

The flow rates for the various instruments are given below:

Midget Impinger	2.8 litres/minute (0.1 CFM)
Gathercole	5 cm^3 Snap Sample
Haslam	" "
Sartorius I	" "
Sartorius II	2.5 cm^3 Snap Sample
STP	7 cm^3/minute
LPDS Head	6 cm^3/minute
LPDS	2 cm^3/minute
Hexhlett	50 litres/minute
Electrostatic	85 litres/minute
High Volume	102 litres/minute
Medium Volume	20 litres/minute

Footnotes:

1. The counts given are for the konimeter samples prior to heat treatment and acid wash.
2. Standard Thermal Precipitator (STP).
3. Long-period dust sampler head without respirable dust size selector (LPDS).
4. Too high to count (THTC).
5. Too low to measure (TLTM).
6. Total count single particles and aggregates.
7. Aggregates per cubic centimetre (a/cm^3).

TABLE C-1
Concentration Measurements
Material: Coal: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	1.025	1.025	2.88	2.88	6.6	6.6
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	0	0	2.5	1.27	7.66	0
Midget Imp.	0.6	0.65	2.5	0	0	0
Konimeters [1]						
Gathercole	13.00	21.2	7.7	16.24	20	
Haslam	14.1	12.1	31.2	33.8	104	6.98
Sartorius	7.9	6.4	16.1	12.2	22.6	16.1
Sartorius	11.0	11.6	12.9	9.3	14	10.4
STP [2]	0	0	0	0	0	0
LPDS [3] Head	0	0	0	3.3	2	2
Midget Imp.	0	0	0	0	0	0
LPDS	1.6	1.6	0	0	0	1
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	139	142	226	244	495	560
Midget Imp.	122	132	221	246	567	546
Konimeters						
Gathercole	1157	1263	2438	2174	6042	THTC [4]
Haslam	882	858	1304	1326	2492	2392
Sartorius	1132	1268	2364	2160	4664	4092
Sartorius	1291	1471	3064	3064	6028	5436
Midget Imp.	117.5	136	200	232	585	518
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	195	247	407	360	712	666
LPDS Head	192	187	475	465	1103	991
LPDS	273	250	477	425	1649	936
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	730	752	1517	1247	2327	2476
LPDS Head	485	519	1525	1430	3635	3911
LPDS	724	638	1537	1415	5307	3608
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	5.45	5.75	6.60	6.95	11.7	11.85
	Dust Concentration by Mass; mg/m^3					
Hexhlett	0.74	0.85	1.38	1.64	3.48	3.78
NCB Grav.	0.55	0.65	1.2	1.8	2.6	2.8
Electrostatic	0.92	1.16	1.53	1.78	4.76	3.65
High Volume	0.86	0.94	1.70	1.47	4.05	4.2
Medium Volume	0.79	1.03	1.56	1.27	4.02	3.84

Footnotes on page -2

TABLE C-2
Concentration Measurements
Material: Coal: Dispersion Method: Pulverized

Sampler	Dust Feed Rate cm³/hour					
	6.6	20	20.5	57	57.5	114
	Dust Concentration by Number; p/cm³ (> 5 µm)					
Midget Imp.	10	10	13	14	47	16
Midget Imp.	5.8	14.5	25	14	39	32
Konimeters [1]						
Gathercole	6.4	.45	17		15.4	
Haslam	7.7	1.2	52.8	1.0	74.8	
Sartorius	3.2	2.5	11.6		11.8	
Sartorius	4.3	5.0	16.7	1.8	16	2.3
STP [2]	3.4	9		17	10	32
LPDS [3] Head	3.2	19	3	24	20	200
Midget Imp.	2.5	1.2	6.5	4	2.6	21
LPDS	0	3	9		18	81
	Dust Concentration by Number; p/cm³ (< 5 µm)					
Midget Imp.	121	118	490	427	635	660
Midget Imp.	118	155	485	477	735	618
Konimeters						
Gathercole	1400	1041	3308	THTC [4]	4182	THTC
Haslam	800	448	2258		2959	THTC
Sartorius	1556	1138	4106		5231	THTC
Sartorius	1734	1374	4878	2242	7012	3650
Midget Imp.	116	129	450	437	805	650
	Dust Concentration by Number; p/cm³ (1-5 µm)					
STP	244	270		1045	1245	2000
LPDS Head	230	384	782	980	1730	3160
LPDS	173	530	984		1530	2260
	Dust Concentration by Number; p/cm³ (1/2-5 µm)					
STP	797	1010		2417	3665	3900
LPDS Head	943	1184	2422	2190	3365	5030
LPDS	593	1380	3522		4160	3460
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	4.37	5.7	8.9	6.8	10.6	10.0
	Dust Concentration by Mass; mg/m³					
Hexhlett	0.88	1.43	4.05	3.9	4.90	6.87
NCB Grav.	0.8	1.85	4.8	6.0	3.6	9.0
Electrostatic	1.39	2.17	5.86	6.62	7.95	10.1
High Volume	1.63	2.47	5.80	5.22	8.86	10.7
Medium Volume	1.48	3.0	5.74	7.32	7.85	11.4

Footnotes on page C-2

TABLE C-3
Concentration Measurements
Material: Coal: Dispersion Method: Ejector - Cyclone

Sampler	Dust Feed Rate cm^3/hour					
	6.6	20	20.5	57	57.5	114
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	7	14	17	63	55	196
Midget Imp.	8.5	15	14	64	65	150
Konimeters [1]						
Gathercole	5.6	1.6	13.8		59.4	
Haslam	94.6	2.1	46	5.0	79.1	
Sartorius	6.9	1.25	10.7	3.0	46.2	
Sartorius	9.2	4.7	13.2	5.0	80.3	
STP [2]	8.3	18	12	12	45.5	79
LPDS [3] Head	13.5	34	13	87	60	141
Midget Imp.	2.5	8	10	14	21	75
LPDS	3		3	47	25	56
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	91	178	192	500	485	1100
Midget Imp.	79.5	180	192	460	487	895
Konimeters						
Gathercole	422	859	876	THTC	2072	THTC
Haslam	1183	531	644	1149	1430	THTC
Sartorius	612	954	922	1738	2430	THTC
Sartorius	859	1218	1089	2113	2920	THTC
Midget Imp.	77	175	168	585	449	865
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	143	425	256	1499	695	1670
LPDS Head	116	556	222	1610	785	1900
LPDS	126		330	1430	925	2260
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	277	830	503	2386	1337	3420
LPDS Head	197	1112	415	2385	1273	3565
LPDS	224		532	2360	1565	4480
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	4.05	4.5	3.70	8.0	6.30	10.7
	Dust Concentration by Mass; mg/m^3					
Hexhlett	1.44	2.56	1.79	6.45	5.45	14.70
NCB Grav.	1.1	3.50	1.5	8.0	5.6	15.60
Electrostatic	1.56	4.42	3.12	11.4	10.30	27.2
High Volume	1.26	5.05	3.46	11.3	12.10	28.0
Medium Volume	1.59	4.4	3.08	11.1	10.79	29.8

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TABLE C-4
Concentration Measurements
Material: Coal: Dispersion Method: Ejector - No Cyclone

Sampler	Dust Feed Rate cm^3/hour					
	6.6	20	20.5	57	57.5	114
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	10	46	22	80	78	109
Midget Imp.	8	46	28.4	62	73	164
Konimeters [1]						
Gathercole	7	0.8	31.3		60.4	
Haslam	14.6	1.6	38.3	8.5	10.4	
Sartorius	8.4	1.2	9.8		50.1	
Sartorius	15.4	1.6	14.6	7	70.8	
STP [2]	3.2	16	12	28	36	114
LPDS [3] Head	10.5	24	21	130	48	220
Midget Imp.	2	34	16	31	15	49
LPDS	2.3		25	4	37	131
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	98	203	246	380	510	980
Midget Imp.	92	145	206	475	425	1080
Konimeters						
Gathercole	508	794	1222	THTC [4]	1029	THTC
Haslam	292	461	532	1154	344	THTC
Sartorius	483	775	1010	THTC	2179	THTC
Sartorius	662	1014	1246	2324	2806	THTC
Midget Imp.	80	146	220	375	435	950
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	99.5	325	223	965	658	1780
LPDS Head	97.5	470	355	1530	800	2280
LPDS	107		342		780	2500
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	184.5	647	410	1445	1210	3710
LPDS Head	172.5	965	584	2435	1423	5020
LPDS	205		500		1357	4540
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	4.22	4.1	5.35	8.2	6.80	9.8
	Dust Concentration by Mass; mg/m^3					
Hexhlett	0.95	2.28	2.48	7.38	5.41	14.75
NCB Grav.	0.95	2.70	2.5	8.70	5.0	17.2
Electrostatic	2.77	5.59	5.29	18.5	15.1	40.0
High Volume	1.74	6.55	6.25	19.3	17.2	42.7
Medium Volume	2.36	6.42	5.95	20.8	14.3	45.0

Footnotes on page C-2

TABLE C-5
Concentration Measurements
Material: Silica: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	1.025	1.025	2.68	2.88	6.6	6.6
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	0.65	0.65	2.59	16.6	36	31
Midget Imp.	0.65	3.9	1.29	10.1	46.7	44
Konimeters [1]						
Gathercole	1.8	1.04	4.52		22.04	22.68
Haslam	7.4	3.2	17.8	16.3		
Sartorius	2.4	1.52	2.96	3.96	17.80	17.8
Sartorius	3.84	1.60	5.92	6.32	31.2	35.8
STP [2]	5	3.35	4	11.7	57	48
LPDS [3] Head	0	3.0	3	24	69	51
Midget Imp.	0	0	0	0	0	5.17
LPDS	4.6	0	0	9.3	0	0
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	206	167	482	324	1206	1287
Midget Imp.	191	155	426	396	1285	1164
Konimeters						
Gathercole	933	1030	1844	THTC [4]	3234	3036
Haslam	1012	908	2084	2366	THTC	THTC
Sartorius	1292	1508	2536	2134	3971	2703
Sartorius	1885	1782	3517	2842	5608	4075
Midget Imp.	196	160	384	342	1368	1020
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	264	252	572	452	1197	830
LPDS Head	378	332	829	585	1452	1324
LPDS	479	400	855	1078	1413	1302
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	919	960	1732	1512	3457	2520
LPDS Head	1375	1310	2948	2045	3592	3980
LPDS	1437	1302	2724	2928	4110	3701
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	9.70	8.90	11.20	11.8	16.00	15.70
	Dust Concentration by Mass; mg/m^3					
Hexhlett	1.94	1.67	3.72	3.78	11.65	9.86
NCB Grav.	1.64	1.20	4.6	4.7	13.0	10.60
Electrostatic	2.26	1.84	4.54	5.65	17.65	17.55
High Volume	2.22	2.30	5.40	5.98	21.50	19.40
Medium Volume	2.30	2.14	4.86	5.75	19.30	17.82

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TABLE C-6
Concentration Measurements
Material: Silica: Dispersion Method: Pulverised

Sampler	Dust Feed Rate cm^3/hour					
	6.6	6.6	16.1	16.1	59.4	59.4
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	6.5	8.4	20.7	9.1	57	67.2
Midget Imp.	7.8	3.9	18.1	11.7	75	36.2
Konimeters [1]						
Gathercole	4.1	4.1	8.5	7.3	16.9	14
Haslam	16.5	10	13.4		46.5	45.4
Sartorius	2.4	4.6	10		11.9	9.2
Sartorius	4.3	6.5	10.6		18.9	12.5
STP [2]	4.5	7	7.5	9	38	38
LPDS [3] Head	10.4	9	18.5	19	61	29
Midget Imp.	1.3	0.65	1.3	0	5.2	13
LPDS	3.3	0	3	0	25	12
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	153	168	318	244	619	866
Midget Imp.	165	188	268	312	835	880
Konimeters						
Gathercole	872	900	1304	1329	2204	1956
Haslam	1039	779	1165		2352	2362
Sartorius	921	844	1026		2664	2170
Sartorius	1160	1111	1475		3211	2802
Midget Imp.	165	209	252	264	754	825
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	176	196	296	296	912	951
LPDS Head	224	204	380	508	1200	945
LPDS	230	206	418	408	1045	1010
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	604	633	959	986	2602	2631
LPDS Head	768	690	1165	1693	2945	2915
LPDS	695	649	1283	1156	2905	3230
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	4.15	4.08	5.53	5.44	8.35	8.45
	Dust Concentration by Mass; mg/m^3					
Hexhlett	1.14	1.25	2.13	2.01	6.73	6.16
NCB Grav.	1.75	1.50	3.5	2.2	6.0	4.8
Electrostatic	2.22	2.41	4.21	6.03	13.0	12.9
High Volume	2.74	3.40	5.35	5.20	17.8	15.8
Medium Volume	2.67	2.89	4.65	4.50	15.5	13.9

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TABLE C-7
Concentration Measurements
Material: Silica: Dispersion Method: Ejector - Cyclone

Sampler	Dust Feed Rate cm^3/hour					
	6.6	11.3	20.5	34	57.5	102
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	3.9	2	27.2		28.5	24
Midget Imp.	1.9	3	11.7	19	20.8	55
Konimeters [1]						
Gathercole	1.45		8.2		19	
Haslam	5.85		10.5		37.4	
Sartorius	3.1		3.6		7.3	
Sartorius	3.6		7.0		10.6	
STP [2]	2.6	5	5	6	25.8	14
LPDS [3] Head	3.8	5	11.3	35	40	130
Midget Imp.	0.65	0	1.3	0	2.6	5
LPDS	5.8	4	6.3	15	12.7	21
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	100	180	333	540	610	1140
Midget Imp.	95.5	220	360	545	625	1120
Konimeters						
Gathercole	368	710	1124	1210	1928	THTC [4]
Haslam	376	520	1204		2556	THTC
Sartorius	277	855	1300		2292	3030
Sartorius	349	875	1856		3154	3309
Midget Imp.	71.9	228	250	465	540	1070
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	64.2	420	264	740	595	960
LPDS Head	88	340	332	845	825	2380
LPDS	110	405	255	975	600	1660
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	172.2	765	749	1390	1600	1560
LPDS Head	173	585	777	1725	1825	3960
LPDS	261	690	810	1875	1436	3220
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	3.88	6.5	5.28	9.0	7.65	13.5
	Dust Concentration by Mass; mg/m^3					
Hexhlett	0.56	1.4	2.47	4.0	5.23	9.2
NCB Grav.	0.7		1.6		5.0	
Electrostatic	0.93	2.2	4.75	6.6	10.85	16.4
High Volume	1.17	2.2	5.66	6.3	10.7	15.5
Medium Volume	1.05		4.57		9.86	

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TABLE C-8
Concentration Measurements
Material: Silica: Dispersion Method: Ejector - No Cyclone

Sampler	Dust Feed Rate cm^3/hour					
	6.6	11.3	20.5	34	57.5	102
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	5.2	11	16.8	21	46	
Midget Imp.	3.2	16	22	20	67.5	50
Konimeters[1]						
Gathercole	3.6		17.3		15.1	
Haslam	8.0		17.4		40.2	
Sartorius	2.9		5.5		17.7	
Sartorius	3.8		6.5		22.6	
STP[2]	3.2	1	8.1	21	17.2	4
LPDS[3] Head	6.7	21	30	50	22	42
Midget Imp.	1.3	0	2.6	0	5.2	0
LPDS	0	12	16	12	12.4	4
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	86.2	206	318	585	575	1760
Midget Imp.	93.5	240	332	550	615	1650
Konimeters						
Gathercole	528	1410	1308	1695	1726	THTC[4]
Haslam	470		1360	1180	2164	THTC
Sartorius	340	1425	1486	1955	1913	3215
Sartorius	520	1364	2015	1774	2353	2845
Midget Imp.	87	195	140	585	580	1000
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	49.5	190	258	1065	710	2650
LPDS Head	98	230	540	760	570	1770
LPDS	129	370	530	855	713	1220
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	148	690	668	1955	1795	3300
LPDS Head	221	445	1180	1330	1435	3030
LPDS	295	665	1085	1735	1698	3020
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	4.50	6.5	6.98	7.8	8.90	13.0
	Dust Concentration by Mass; mg/m^3					
Hexhlett	0.74	1.8	2.83	4.4	5.49	10.0
NCB Grav.	0.7		3.0		6.0	
Electrostatic	1.88	3.5	7.45	12.2	14.8	27.6
High Volume	2.40	3.4	9.9	10.6	18.6	23.6
Medium Volume	2.08		18.6		16.0	

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TABLE C-9
Concentration Measurements
Material: Pyrite: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	0.25	0.25	0.51	0.51	1.025	1.025
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	0	1	0	2	3	0
Midget Imp.	6	3	0	0	0	0
Konimeters [1]						
Gathercole	1.12	1.4			9.24	
Haslam	3.1	2.3	3.5	12.3		
Sartorius	0.96	1.6	2.2	1.8		
Sartorius	0.96	1.4	1.4	2.4	2.3	4.0
STP [2]	0	0	0	0	0	4.5
LPDS [3] Head	0	0	0	3	0	6.5
Midget Imp.	0	0	0	0	0	0
LPDS	0	0	0	0	0	0
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	435	407	869	1000	1902	1820
Midget Imp.	405	378	853	903	2001	1620
Konimeters						
Gathercole	2562	2322	THTC [4]	THTC	2137	THTC
Haslam	1894	1948	2736	3504	THTC	THTC
Sartorius	2274	2744	3590	2990		
Sartorius	3088	3722	4640	3884	6764	6136
Midget Imp.	430	381	870	762	1872	1910
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	207	244	505	483	1300	1640
LPDS Head	156	153	440	435	1720	1098
LPDS	242	358	344	735	1520	1730
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	1957	1834	3465	3605	7800	7840
LPDS Head	2047	1681	3820	4327	9460	8248
LPDS	2635	2845	4688	5171	9620	10080
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	5.45	5.45	8.58	8.40	11.72	11.4
	Dust Concentration by Mass; mg/m^3					
Hexhlett	1.50	1.50	3.005	2.85	6.51	5.45
NCB Grav.	2.35	1.55	5.0		6.2	4.0
Electrostatic	1.92	1.98	3.38	3.40	9.96	6.1
High Volume	1.85	2.06	4.05	4.08	8.33	7.14
Medium Volume	1.29	1.92	4.45	3.56	8.01	6.95

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TABLE C-10
Concentration Measurements
Material: Pyrite: Dispersion Method: Pulverised

Sampler	Dust Feed Rate cm^3/hour					
	6.6	6.6	20.5	20.5	57.5	57.5
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	2.5	6.1	14.4	14.3	31	23
Midget Imp.	1	1.9	13	19.5	36	28
Konimeters [1]						
Gathercole	1.3	1.3	2.5	3.6		
Haslam	6.5	8.5	7.2	16.5		
Sartorius	3.5	2.1	5.7	3.1		
Sartorius	10.0	4.0	14.5	4.7	7	13
STP [2]	2.7	4.7	5.1	5.2	25.2	16.6
LPDS [3] Head	2.8	5.7	22.4	24	25	30
Midget Imp.	1.6	0.65	2.6	1.3	10	5.2
LPDS	0	0	9.2	12.3	0	12.8
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	101	210	332	481	810	995
Midget Imp.	117	100	375	522	825	900
Konimeters						
Gathercole	627	536	1352	1342		
Haslam	1016	747	1606	2214		
Sartorius	705	584	1154	1073		
Sartorius	748	683	1758	1312	2215	2754
Midget Imp.	193	116	320	403	770	879
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	133	108	340	290	635	765
LPDS Head	145	138	525	482	1220	1240
LPDS	102	148	485	510	790	1290
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	1058	1108	2380	2100	4245	4460
LPDS Head	995	1258	3295	3342	7320	6040
LPDS	968	1108	2585	3220	5090	5590
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	6.32	6.64	7.60	7.96	10.40	10.42
	Dust Concentration by Mass; mg/m^3					
Hexhlett	1.08	1.13	2.83	2.91	5.69	5.8
NCB Grav.	1.5	1.4	3.7	3.6	6.4	6.4
Electrostatic	1.57	1.96	4.8	4.95	10.3	10.2
High Volume	2.18	2.39	5.15	5.35	11.1	11.3
Medium Volume	2.01	2.00	5.65	5.65	11.2	11.7

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TABLE C-11
Concentration Measurements
Material: Pyrite: Dispersion Method: Ejector - Cyclone

Sampler	Dust Feed Rate cm^3/hour 6.6	11.3	20.5	34	57.5	102
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	3.9	1	14.5	3.5	39	15
Midget Imp.	5.8	1	27.1	6.5	54.5	28
Konimeters [1]						
Gathercole	3.84		8.5			
Haslam	7.7		21.8			
Sartorius	1.6		6.6			
Sartorius	3.0		12.7		12.2	
STP [2]	1.5	2	13	18	17	19
LPDS [3] Head	3.9	4	6.3	8	36	29
Midget Imp.	0	0	5.2	0	10.8	0
LPDS	1.5	0	6.2	15	0	0
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	117	47	318	167	585	304
Midget Imp.	110	45	384	171	705	392
Konimeters						
Gathercole	400	869	1124	1232		THTC [4]
Haslam	533	619	1036	1192		THTC
Sartorius	280	852	1086	1480		THTC
Sartorius	337	1114	1132	1968	2667	2959
Midget Imp.	93.5	43	266	172	630	363
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	57	219	246	810	540	710
LPDS Head	59	500	313	915	706	1765
LPDS	73	315	196	1180	770	1480
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	161	437	628	1610	1378	1075
LPDS Head	148	846	738	1398	1396	2602
LPDS	210	579	616	1850	1680	2645
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	3.39	5.0	4.92	6.3	5.75	8.0
	Dust Concentration by Mass; mg/m^3					
Hexhlett	0.75	1.8	2.43	3.9	6.31	9.7
NCB Grav.	0.65		2.9		7.0	
Electrostatic	1.87	3.2	6.10	8.7	18.1	20.3
High Volume	2.30	3.4	6.47	9.0	21.6	
Medium Volume	1.68		5.65		17.5	

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TABLE C-12
Concentration Measurements
Material: Pyrite: Dispersion Method: Ejector - No Cyclone

Sampler	Dust Feed Rate cm³/hour					
	6.6	11.3	20.5	34	57.5	102
	Dust Concentration by Number; p/cm³ (> 5 µm)					
Midget Imp.	4.5	2.7	10.8	8	67	15
Midget Imp.	4.5	4.6	26	12	78	24
Konimeters [1]						
Gathercole	3.9		8.5			
Haslam	8.3		33			
Sartorius	4.4		10.2			
Sartorius	9.8		13.7		26.6	
STP [2]	4.8	7	10.9	33		51
LPDS [3] Head	5.6	46	43		114	150
Midget Imp.	0	0.4	1.3	0	5.2	0
LPDS	0	5	6.1	0	0	0
	Dust Concentration by Number; p/cm³ (< 5 µm)					
Midget Imp.	110	85	337	173	976	320
Midget Imp.	156	66	431	222	1135	400
Konimeters						
Gathercole	500	1009	1364	THTC [4]		THTC
Haslam	367	575	909	1344		THTC
Sartorius	414		936	THTC		THTC
Sartorius	615		1682	3393	2829	THTC
Midget Imp.	114	85	338	189	1080	364
	Dust Concentration by Number; p/cm³ (1-5 µm)					
STP	74	360	196	945		2490
LPDS Head	81	475	315		706	2310
LPDS	78	415	272	1040	606	2300
	Dust Concentration by Number; p/cm³ (1/2-5 µm)					
STP	208	571	578	1535		3990
LPDS Head	201	724	728		1581	3750
LPDS	255	673	797	1450	1756	3600
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	3.46	5.2	4.13	6.0	8.55	9.2
	Dust Concentration by Mass; mg/m³					
Hexhlett	0.975	2.05	2.9	4.9	7.43	12.4
NCB Grav.	1.5		3.5		7.8	
Electrostatic	4.00	8.1	12.8	20	30.0	51
High Volume	4.88	8.1	14.9	21	40.6	54
Medium Volume	4.10		14.0		33.2	

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TABLE C-13
Concentration Measurement
Material: Mica: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	2.88	2.88	6.6	6.6	16.1	16.1
	Dust Concentration by Number; p/cm^3 (> 5 µm)					
Midget Imp.	8	7	39	42.7	112	82
Midget Imp.	11	13	21	31	82	93
Konimeters [1]						
Gathercole	23.9	23.7	58.6	39.2		50.2
Haslam	13.8	13.3	25.8	32.5		87.7
Sartorius	13.9	17.1	16.7	20.3		
Sartorius	23.2	16.4	26.4	22.5		
STP [2]	2	7	15	24.5	169	57
LPDS [3] Head	1.5	6	41	24	103	79
Midget Imp.	9	11	25	17	62	58
LPDS	6	9	55	0	56	0
	Dust Concentration by Number; p/cm^3 (< 5 µm)					
Midget Imp.	475	470	883	712	2550	1850
Midget Imp.	413	492	940	667	2030	2015
Konimeters						
Gathercole	1404	1830	2723	2899	THTC [4]	THTC
Haslam	1891	1871	3327	2838	THTC	THTC
Sartorius	2019	1866	2558	2091	THTC	3596
Sartorius	2742	2448	3477	2843	THTC	5145
Midget Imp.	444	458	746	775	2500	1830
	Dust Concentration by Number; p/cm^3 (1-5 µm)					
STP	512	245	1040	800	2860	1950
LPDS Head	436	355	1035	735	2230	2285
LPDS	535	567	1085	1015	3070	3345
	Dust Concentration by Number; p/cm^3 (1/2-5 µm)					
STP	1577	638	2910	2430	6600	5320
LPDS Head	1249	1139	2955	2175	6130	6155
LPDS	1555	2057	2925	2700	7610	8325
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	8.50	9.30	13.9	12.6	24.0	20.5
	Dust Concentration by Mass; mg/m^3					
Hexhlett	2.775	3.00	7.375	6.90	23.5	18.99
NCB Grav.	2.65	2.75	7.2	6.2	21.0	16.6
Electrostatic	2.98	3.20	7.75	7.80	26.5	24.2
High Volume	3.30	3.76	8.15	7.80	27.6	23.4
Medium Volume	3.16	3.50	8.50	8.25	28.3	24.1

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TABLE C-14
Concentration Measurements
Material: Mica: Dispersion Method: Pulverization

Sampler	Dust Feed Rate cm^3/hour 5	7	7.5	16.1	17	59
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	8	2	10	34	8	26
Midget Imp.	7	1	10	34	12	39
Konimeters [1]						
Gathercole	5.4		5.4	20		
Haslam	16		17.5	33.3		
Sartorius	7.9		8.8	11.6		
Sartorius	13.2		19.6	17		
STP [2]	7	1	14	11.5	0	44
LPDS [3] Head	13	0	15	32	7	64
Midget Imp.	4	3	5	10	1	15
LPDS	0	1	9	18	15	31
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	228	249	306	566	760	1790
Midget Imp.	228	226	366	638	699	1990
Konimeters						
Gathercole	1092	985	928	1487		
Haslam	1616		1571	2393		
Sartorius	1997	1586	1786	2428		
Sartorius	3068	2193	2684	3865	THTC [4]	THTC
Midget Imp.	224	230	330	537	749	1960
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	139	472	236	1025	1020	2580
LPDS Head	187	480	269	610	1325	2460
LPDS	95	705	305	625	1090	2450
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	648	1560	976	3165	3240	8100
LPDS Head	717	1500	1214	2060	4210	9750
LPDS	335	1960	1259	1950	4960	9530
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	7.47	7.9	8.82	9.97	13.8	24.3
	Dust Concentration by Mass; mg/m^3					
Hexhlett	1.88	2.26	2.46	3.09	6.42	20.22
NCB Grav.	1.45	3.05	1.9	3.6	7	20
Electrostatic	2.33	2.32	3.30	7.15	7	22.6
High Volume	2.80	3.13	3.87	7.75	8.02	25.05
Medium Volume	2.54	2.97	3.60	9.80	8.38	28.65

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TABLE C-15
Concentration Measurements
Material: Mica: Dispersion Method: Ejector - Cyclone

Sampler	Dust Feed Rate cm^3/hour					
	2.88	6.6	7	16.1	17	59
	Dust Concentration by Number; p/cm^3 (> 5 μm)					
Midget Imp.	10	11.5	19	34	58	40
Midget Imp.	14	18	14	26	42	38
Konimeters [1]						
Gathercole	10.44	20.8		33.3		
Haslam	36.8	46.8				
Sartorius	4.8	7.9				
Sartorius	8.6	13.7		48.6		
STP [2]	14.5	26	17	57	62	198
LPDS [3] Head	7.3	26	21	57	42	96
Midget Imp.	2.5	5	8	15.5	8	14
LPDS	1.5	6.2	14	12.5	9	55
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	330	617	494	1400	1285	3800
Midget Imp.	320	600	530	1600	1370	3780
Konimeters						
Gathercole	1016	1573	1723	3057	THTC [4]	
Haslam	1914	2225	1350	THTC	THTC	
Sartorius	1515	2336	THTC		THTC	
Sartorius	1413	2890	2553	6455	3907	THTC
Midget Imp.	314	584	500	1550	1380	3580
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	312	588	480	1225	1055	3580
LPDS Head	275	545	430	1290	715	3900
LPDS	309	620	590	1625	1290	3900
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	765	1318	1280	3095	3300	10800
LPDS Head	568	1285	1640	3080	2820	10700
LPDS	679	1343	1790	3640	4050	10710
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	6.97	9.4	11.8	15.7	15.8	27.3
	Dust Concentration by Mass; mg/m^3					
Hexhlett	2.56	4.25	2.67	10.4	12.3	35.95
NCB Grav.	2.6	4.3	2.75	10.4	13.50	41
Electrostatic	3.26	5.64	5	14.7	14.4	48.5
High Volume	3.78	6.95	6.72	16.0	15.47	45.75
Medium Volume	3.66	6.16	7.12	15.3	17.85	55.76

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TABLE C-16
Concentration Measurements
Material: Mica: Dispersion Method: Ejector - No Cyclone

Sampler	Dust Feed Rate cm^3/hour					
	2.88	6.6	7	16.1	17	59
	Dust Concentration by Number; p/cm^3 ($> 5\ \mu m$)					
Midget Imp.	14	13	22	75	30	41
Midget Imp.	12	15.5	18	57	33	49
Konimeters[1]						
Gathercole	8.1	14.7		43.2		
Haslam	36.3	52.4				
Sartorius	5.9	16.4				
Sartorius	9.4	28.2		35.1		
STP[2]	9	24	16	118	70	166
LPDS[3] Head	12.5	13	21	90	92	152
Midget Imp.	6	2.5	6	26	0	0
LPDS	8	6	5	0	9	183
	Dust Concentration by Number; p/cm^3 ($< 5\ \mu m$)					
Midget Imp.	260	506	538	1220	1220	3460
Midget Imp.	260	540	528	1440	1310	3480
Konimeters						
Gathercole	1428	1538	1842	3102	THTC[4]	
Haslam	1336	2206	1407	THTC	THTC	
Sartorius	1368	2000	1451		THTC	
Sartorius	1702	2932	2082	5278	4096	THTC
Midget Imp.	276	491	513	1420	1200	3475
	Dust Concentration by Number; p/cm^3 ($1-5\ \mu m$)					
STP	265	415	380	1240	1400	3460
LPDS Head	275	431	426	880	1170	4700
LPDS	329	440	558	945	1460	4350
	Dust Concentration by Number; p/cm^3 ($1/2-5\ \mu m$)					
STP	671	1201	1340	3150	3830	8850
LPDS Head	637	1096	1450.	2025	3880	8650
LPDS	721	1175	1640	2605	4050	10200
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	6.95	9.08	11.3	15.7	15.7	25.6
	Dust Concentration by Mass; mg/m^3					
Hexhlett	2.34	4.05	4.72	11.24	12.27	34.55
NCB Grav.	1.9	2.8	5.20	8.2	14.50	36.
Electrostatic	3.55	5.6	6.59	15.9	17.1	47.5
High Volume	3.74	7.0	7.33	19.4	18.50	47.56
Medium Volume	3.65	6.2	7.80	17.9	19.70	56.75

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TABLE C-17
Concentration Measurements
Material: Asbestos: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	1.025		2.88		6.6	
	Non Fibrous Dust Concentration by No. p/cm^3 ($> 5\ \mu m$)					
Midget Imp.	0	1.95	1.2	3.9	5.2	5.17
Midget Imp.	0	.65	0	1.3	5.2	7.8
Konimeters [1]						
Gathercole	6.52	2.08	29	12	12.0	8.24
Haslam		1.12	1.3	2.48		
Sartorius	1.84	1.2	2.28	1.7	2.15	2.4
Sartorius	8.16	5.9	4.0	4.5	5.3	2.8
STP [2]	.64	.64	0	3.79	7.5	2.6
LPDS [3] Head	3.26	3.1	7.0	3.2	106	12.9
Midget Imp.	0	0	0	0	0	0
LPDS		1.54		3.1		0
	Dust Concentration by Number; p/cm^3 ($< 5\ \mu m$)					
Midget Imp.	92.8	87.6	218	206	360	466
Midget Imp.	98.6	98.4	165	222	392	389
Konimeters						
Gathercole	2102	1200	2144	1774	3064	4708
Haslam	THTC	1018	1247	1648	THTC	THTC
Sartorius	1070	878	1771	1574	3604	3477
Sartorius	2799	2468	2968	2665	5924	4444
Midget Imp.	65	81.7	229	168	293	290
	Dust Concentration by Number; p/cm^3 ($1\text{-}5\ \mu m$)					
STP	3.5	4.46	11.6	6.3	2.51	20.5
LPDS Head	13.1	9.3	21.0	16.3	31.2	12.9
LPDS		1.54		15.1		4.95
	Dust Concentration by Number; p/cm^3 ($1/2\text{-}5\ \mu m$)					
STP	104.5	124.46	856.6	179.3	333.1	430.6
LPDS Head	211.1	93.8	903	175.3	429.2	412.9
LPDS		77.0		207.1		504.95
	Fibrous Dust Concentration by Number; p/cm^3					
Midget Imp.	22.8	30.3	62.1	53	143	111
Midget Imp.	20.8	23.4	49.2	50.4	111	83
Konimeters						
Gathercole	.68	.28	0	2.5	2	1.36
Haslam		.84	0	.76		
Sartorius	1.04	1.52	1	.7	12.05	13
Sartorius	13.96	8.3	2	2.0	12.0	4.8
STP	447	366	845	879	1820	1820
LPDS Head	700	620	882	770	1300	2040
Midget Imp.	2.47	18.2	51.8	38.8	67.5	67.5
LPDS		382		1120		2710
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	6.90		7.70		9.75	10.95
	Dust Concentration by Mass; mg/m^3					
Hexhlett	.88	.66	1.87	1.50	2.94	3.21
NCB Grav.	.95	.60	1.7	1.4	3.00	3.81
Electrostatic	1.19	.91	2.21	2.28	5.75	7.05
High Volume	1.31	1.27	2.75	3.05	6.45	6.96
Medium Volume	1.51	.81	3.06	2.68	5.66	6.44

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TABLE C-18
Concentration Measurements
Material: Asbestos: Dispersion Method: Pulverized

Sampler	Dust Feed Rate cm^3/hour					
	2.88		6.6	16.1		
	Non Fibrous Dust Concentration by No. p/cm^3 ($> 5\ \mu m$)					
Midget Imp.	4	10	13	11	8	16
Midget Imp.	8	8	13	17	10	16
Konimeters [1]						
Gathercole						
Haslam						
Sartorius		3.64	2.44	5.6		
Sartorius		6.64	4.2	25.8		17.4
STP [2]	2	11	9	4	6	12
LPDS [3] Head	0	7.5	9	22	6	12
Midget Imp.	3	4.5	13	6.5	10	8
LPDS	4	10	11	10	19	0
	Dust Concentration by Number; p/cm^3 ($< 5\ \mu m$)					
Midget Imp.	212	210	356	465	910	950
Midget Imp.	212	298	420	537	897	1050
Konimeters						
Gathercole						
Haslam						
Sartorius		2254	2312	1432		
Sartorius		3180	3884	3861		4921
Midget Imp.	166	262	406	505	655	1030
	Dust Concentration by Number; p/cm^3 ($1-5\ \mu m$)					
STP	59	146	164	270	412	320
LPDS Head	97	159	262	388	426	390
LPDS	108	91	264	225	277	166
	Dust Concentration by Number; p/cm^3 ($1/2-5\ \mu m$)					
STP	540	870	1025	1500	1690	1650
LPDS Head	650	1290	1400	1900	1945	2210
LPDS	580	1120	1280	1430	1790	1250
	Fibrous Dust Concentration by Number; p/cm^3					
Midget Imp.	13	13	18	20	31	34
Midget Imp.	14	12	27	28	41	41.5
Konimeters						
Gathercole						
Haslam						
Sartorius		1.32	5.16	0.8		
Sartorius		1.28	8.2	5.1		4.6
STP	128	172	292	294	390	446
LPDS Head	186	260	286	481	515	730
Midget Imp.	17	9.5	18	22	31	28
LPDS	112	226	354	405	446	440
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	6.35	6.47	8.55	8.4	9.85	10.6
	Dust Concentration by Mass; mg/m^3					
Hexhlett	1.39	1.87	2.78	2.65	4.25	5.25
NCB Grav.	1.0	2.0		1.5	5.0	7.0
Electrostatic	2.02	2.09	3.74	3.27	6.90	7.70
High Volume	2.35	2.52	4.27	3.91	6.25	7.61
Medium Volume	2.31	2.03	4.47	4.09	6.39	8.8

TABLE C-19
Concentration Measurements
Material: Glass Fibre: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	2.88		6.6		16.1	
	Non Fibrous Dust Concentration by No. p/cm^3 (> 5 μm)					
Midget Imp.	.53	.4	1.08	1.0	5.35	3.55
Midget Imp.	.75	.73	1.18	1.34	5.50	2.55
Konimeters[1]						
Gathercole					1	8.0
Haslam	.52	1	0.8	1.2	1.88	3.56
Sartorius	.80	1.56	2.08	.92	1.4	1.35
Sartorius	1.12	1.78	2.4	1.6	3	1.0
STP[2]	.5	.95	.69	9	.2	4.40
LPDS[3] Head		3.9			1.5	1.4
Midget Imp.	.05	.05		.1	6	1.33
LPDS	0	.62			2	5.6
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	7.95	8.85	15.2	12.9	74.9	40.5
Midget Imp.	7.50	8.6	16.3	14.4	79.4	42.6
Konimeters						
Gathercole	456	224	518	188	742	464
Haslam	174	274	515	381	1531	285
Sartorius	222	133	487	245	803	540
Sartorius	226	372	255	888	1124	780
Midget Imp.	5.30	5.43	10.1	8.63	45.0	27.0
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP	9.04	10.5	4.5	13.5	.8	18.48
LPDS Head		10			25	5.6
LPDS	19.5	4.5	10.1		9.8	36
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP			28.5		13	97.7
LPDS Head					134	55
LPDS					325	
	Fibrous Dust Concentration by Number; p/cm^3					
Midget Imp.	6.44	8.0	19.7	13.6	46	39.8
Midget Imp.	8.32	7.36	19.2	15.9	39.2	43.7
Konimeters						
Gathercole	15.0		13	1.3	1	7.6
Haslam	2.68	1.08	1.9	2.2	6.64	8.8
Sartorius	.52		1.64	1.08	3	9.05
Sartorius	1.84		1.7	13	1	5.2
STP	16	16.5	39	24	13	171.6
LPDS Head	24.84	30	78.5	49	139	148
Midget Imp.	5.19	5.43	10.1	10.6	30.8	26.4
LPDS	26.26	22			237	101
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	5.30	4.80	7.40	4.25	6.70	6.95
	Dust Concentration by Mass; mg/m^3					
Hexhlett	.27	.31	.39	.42	.81	1.10
NCB Grav.	.25	.25	.8	1.0	3.0	2.0
Electrostatic	.91	.786	1.59	1.8	2.02	5.72
High Volume	.924	1.03	1.71	1.5	2.64	5.05
Medium Volume	.710	.880	1.36	1.41	2.03	4.10

TABLE C-20
Concentration Measurements
Material: Glass Fibre: Dispersion Method: Pulverized

Sampler	Dust Feed Rate cm³/hour					
	6.6	16.1	16.1	57		
	Non Fibrous Dust Concentration by No.p/cm³ (> 5 µm)					
Midget Imp.			4.5	6.5		
Midget Imp.			2.2	12		
Konimeters [1]						
Gathercole						
Haslam						
Sartorius	4.68		5.76	2.24		
Sartorius	9.88		5.76	4.88		
STP [2]	1.6			4.1		
LPDS [3] Head	1					
Midget Imp.			.6	.5		
LPDS	1		5	6.5		
	Dust Concentration by Number; p/cm³ (< 5 µm)					
Midget Imp.			28	.25		
Midget Imp.			30	49		
Konimeters						
Gathercole						
Haslam						
Sartorius	605		787	925		
Sartorius	1423		1528	714		
Midget Imp.			20	32		
	Dust Concentration by Number; p/cm³ (1-5 µm)					
STP	16		10	50		
LPDS Head	27		43	37		
LPDS	20		20			
	Dust Concentration by Number; p/cm³ (1/2-5 µm)					
STP	92		79	153		
LPDS Head	141		233	147		
LPDS	70		234	147		
	Fibrous Dust Concentration by Number; p/cm³					
Midget Imp.			19	11		
Midget Imp.			15	19		
Konimeters						
Gathercole						
Haslam						
Sartorius	1.36		6.32	12.0		
Sartorius	1.16		17.64	13.36		
STP	48		92	105		
LPDS Head	59		183	200		
Midget Imp.	29		14	15		
LPDS			150	183		
	Dust Concentration by Light Scatter; degrees					
Tyndalloscope	5.65	7.9	10.25	10.15		
	Dust Concentration by Mass; mg/m³					
Hexhlett	.72	.6	1.24	1.9		
NCB Grav.	1.45	.8	1.0	3.2		
Electrostatic	.82	1.46	2	3.3		
High Volume	1.04	1.25	2	4.2		
Medium Volume	1.11	1.3	2	4.0		

TABLE C-21
Dust Concentration in Aggregated Dust Cloud
Material: Coal: Dispersion Method: Atomizer: Full Strength Suspension

Sampler	Volume of Suspension ml 10	6	3
	Dust Concentration by Number Total Count p/cm^3 (> 5 µm) [6]		
Midget Imp.	49	18	18.1
Midget Imp.	44	38.8	10.7
Konimeters [1]			
Gathercole		6	8
Haslam	6.5	6.5	6
Sartorius		10	9
Sartorius	7.5	10	6
STP [2]	96	50.4	19.3
LPDS [3] Head	156	55	17.5
Midget Imp.	7.8	5.2	2.6
LPDS	54.1	12.4	20.7
	(< 5 µm)		
Midget Imp.	1640	1060	538
Midget Imp.	1680	1120	510
Konimeters			
Gathercole	THTC [4]	1860	1050
Haslam	1550	1200	520
Sartorius	THTC	1850	800
Sartorius	3000	2050	950
Midget Imp.	1388	792	318
	(1-5 µm)		
STP	892	492	207
LPDS Head	1166	570	203
LPDS	989	495	261
	(1/2-5 µm)		
STP	1324	808	348
LPDS Head	2078	953	386
LPDS	1646	789	426

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TABLE C-21
Continued

Sampler	Volume of Suspension ml 10	6	3
	Dust Concentration by Number: Aggregates[7] 2 or 3 Particles a/cm^3 (> 5 μm)		
STP	28	16.7	3.8
LPDS Head	78	17.4	10.2
LPDS	21	4.1	0
			(1-5 μm)
STP	238	109	38
LPDS Head	250	122	26.2
LPDS	195	49.5	37.2
			(1/2-1 μm)
STP	8.6	0	0
LPDS Head	0	0	0
LPDS	0	0	0
	Dust Concentration by Number: Aggregates, 4+ Particles a/cm^3 (> 5 μm)		
STP	39	8.7	4.6
LPDS Head	0	0	0
LPDS	4.1	0	0
			(1-5 μm)
STP	8.6	1.1	0.4
LPDS Head	0	0	0
LPDS Head	0	0	0
			(1/2-1 μm)
STP	0	0	0
LPDS Head	0	0	0
LPDS	0	0	0
	Dust Con. by Light Scatter: Degrees		
Tyndalloscope	7.9	4.9	TLTM[5]
	Dust Concentration by Mass, mg/m^3		
Hexhlett	9.24	5.06	2.37
NCB Grav.	7.34	4.27	1.87
Medium Volume	15.6	8.74	4.0

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TABLE C-22
Dust Concentration in Aggregated Dust Clouds
Material: Coal: Dispersion Method: Atomizer - Dilute Suspension

Sampler	Volume of Dilute Suspension ml 80	40	20	10
	Dust Concentration by Number: Total Count p/cm^3 (> 5 μm) [6]			
Midget Imp.	49.2	49.2	13.0	13.8
Midget Imp.	41.4	39	10.7	10.8
Konimeters [1]				
Gathercole				
Haslam		2	7.5	8.2
Sartorius		11		5.0
Sartorius	10		6.2	4.8
STP [2]		39.2	26	16.7
LPDS [3] Head	107	62.5	21.1	18.6
Midget Imp.	7.8	2.6	0	1.7
LPDS	25.5	4.1	12.4	16.5
	(< 5 μm)			
Midget Imp.	2038	1420	717	363
Midget Imp.	1990	1420	775	344
Konimeters				
Gathercole				
Haslam	THTC [4]	2000	1150	620
Sartorius	THTC	THTC	2050	1100
Sartorius	5500	3400	2150	1350
Midget Imp.	1910	995	621	286
	(1-5 μm)			
STP	THTC	1100	596	283
LPDS Head	2390	1060	431	215
LPDS	2140	1040	665	328
	(1/2-5 μm)			
STP	THTC	2210	1181	639
LPDS Head	4715	2230	856	461
LPDS	4110	2300	1345	704

TABLE C-22
Continued

Sampler	Volume of Suspension ml 80	40	20	10
	Dust Concentration by Number Aggregates[7], 2 or 3 Particles a/cm^3 (> 5µm)			
STP		11.2	9.6	5.2
LPDS Head	3.9	3.9	6.6	4.3
LPDS	4.6	0	0	4.1
				(1-5 µm)
STP		287	123	25.0
LPDS Head	364	106	44.8	17.2
LPDS	288	124	62	8.2
				(1/2-1 µm)
STP		0	0	0
LPDS Head	0	0	0	0
LPDS	0	0	0	0
	Dust Concentration by Number Aggregates[7], 4+ Particles, a/cm^3 (> 5 µm)			
STP		10.1	1.4	0
LPDS Head	4.8	7.8	0	0
LPDS	4.6	0	0	0
				(1-5 µm)
STP	THTC[4]	2.2	0	0
LPDS Head	0	0	0	0
LPDS	0	0	0	0
				(1/2-1 µm)
STP	THTC	0	0	0
LPDS Head	0	0	0	0
LPDS	0	0	0	0
	Dust Con. by Light Scatter: degrees			
Tyndalloscope	10.6	9.6	7.2	6.0
	Dust Concentration by Mass, mg/m^3			
Hexhlett	13.95	8.11	4.32	2.12
NCB Grav.	12.0	6.4	4.26	3.0
Medium Volume	18.3	11.38	6.15	3.28

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TABLE C-23
Concentration Measurements: Extension to Low Concentrations
Material: Coal: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	0.125	0.36	0.51	0.72	1.025	2.88
	Dust Concentration by Number; p/cm^3 (< 5 μm)					
Midget Imp.	46	50	161	73	237	388
Midget Imp.	46	62	179	75.5	274	410
Konimeters [1]						
Gathercole	504	1065	1461	1600	2160	3204
Haslam	17	44	567	74	966	1591
Sartorius	410	888	1632	1200	2851	3602
Sartorius	522	900	1733	1296	3109	5133
Midget Imp.	37	52	167	69	174	351
	Dust Concentration by Number; p/cm^3 (1-5 μm)					
STP [2]	68	106	236	106	368	610
LPDS Head [3]	57	160				580
LPDS	73	112		160	372	710
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)					
STP	266	474	967	522	1508	2630
LPDS Head	270	800				1995
LPDS	312	418		680	1288	2945
	Dust Concentration by Mass; mg/m^3					
Hexhlett	0.17	0.36	1.0	0.444	1.70	2.30
Medium Volume	0.23	0.49	1.23	0.55	1.99	2.92

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TABLE C-24
Concentration Measurements: Extension to Low Concentrations
Material: Coal: Dispersion Method: Ejector - No Cyclone

Sampler	Dust Feed Rate cm^3/hour				
	0.26	0.51	1.025	2.88	6.6
	Dust Concentration by Number; p/cm^3 (< 5 μm)				
Midget Imp.	21	45	63		272
Midget Imp.	28	49	74		272
Konimeters [1]					
Gathercole	140	256	335	1001	1324
Haslam	6	9		50	75
Sartorius	250	358	600	1382	2200
Sartorius	322	472	624	2179	2461
Midget Imp.	19	40	59		204
	Dust Concentration by Number; p/cm^3 (1-5 μm)				
STP [2]	16.4	28	70	213	288
LPDS Head [3]		28	76	213	161
LPDS		33	91	161	201
	Dust Concentration by Number; p/cm^3 (1/2-5 μm)				
STP	36	64	141	366	567
LPDS Head		57	168	378	452
LPDS		78	142	270	505
	Dust Concentration by Mass: mg/m^3				
Hexhlett	0.152	0.294	0.706	1.65	2.73
Medium Volume	0.29	0.506	1.14	3.77	5.41

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TABLE C-25
Concentration Measurements: Extension to Low Concentrations
Material: Silica: Dispersion Method: Jet Mill

Sampler	Dust Feed Rate cm^3/hour					
	0.1	0.13	0.17	0.26	0.36	0.72
	Dust Concentration by Number; p/cm^3 ($< 5\ \mu m$)					
Midget Imp.						176
Midget Imp.						187
Konimeters[1]						
Gathercole	316	221	1005	1345	2180	2531
Haslam	124	2		611	1594	2218
Sartorius	325	781		1706	3041	3478
Sartorius	395	900		2223	4143	4578
Midget Imp.						168
	Dust Concentration by Number; p/cm^3 ($1-5\ \mu m$)					
STP[2]						505
LPDS Head[3]						635
LPDS						900
	Dust Concentration by Number; p/cm^3 ($1/2-5\ \mu m$)					
STP						1905
LPDS Head						2210
LPDS						2845
	Dust Concentration by Mass: mg/m^3					
Hexhlett	.092	.149	0.8	1.17	2.51	3.17
Medium Volume	.133	.242	1.01	1.57	3.46	4.23

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TABLE C-26
Comparison of Dust Sampling Instruments and Microscope Counting Techniques

Dust Type and Method of Dispersion	Run No.	Dust Concentration by Number (p/cm^3) $>5\mu m$					
		Instruments					
		LPDS (Head)				Imp.	Kon.
		Microscopic Techniques					
		tp < ½	tp<1	imp.	kon.	imp.	kon.
Coal							
Jet Milled	165	1430	465	977	1127	241	2181
Jet Milled	168	519	187	440	358	137	1218
Pulverised	62	1184	384	616	1055	134	1000
Pulverised	124	943	230	790	821	118	1372
Ejector Cyclone	58	1112	556	694		178	890
Ejector Cyclone	118	197	116	131	197	86	769
Ejector No Cyclone	121	584	355	507	611	224	1002
Ejector No Cyclone	66	965	470	725	476	165	761
Silica							
Jet Milled	153	1375	378	747	920	198	1281
Jet Milled	150	2448	829	1785	1880	431	2495
Pulverised	112	768	224	490	680	161	998
Pulverised	113	690	204	378	545	188	908
Ejector Cyclone	26	585	337	425	515	210	737
Ejector Cyclone	105	777	332	650	855	314	1371
Ejector No Cyclone	28	1330	760	1161		575	1610
Ejector No Cyclone	109	221	98	129	205	89	464
Pyrite							
Jet Milled	161	2047	156	2309	710	423	2454
Jet Milled	162	1681	153	2096	574	389	2687
Pulverised	97	995	145	639	637	137	774
Pulverised	98	1258	138	735	858	142	637
Ejector Cyclone	41	1398	915	1083	1355	170	1468
Ejector Cyclone	102	148	59	115	127	107	387
Ejector No Cyclone	101	201	81	184	212	127	475
Ejector No Cyclone	100	728	315	781	673	369	1220
Mica							
Jet Milled	170	1139	355	633	844	473	2004
Jet Milled	172	2175	735	1572	1450	718	2668
Pulverised	176	1214	269	930	1632	344	1742
Pulverised	71	1948	480	1295	1320	235	1588
Ejector Cyclone	183	568	275	372	678	321	1464
Ejector Cyclone	78	2070	430	595	1158	508	1875
Ejector No Cyclone	79	1876	426	870		526	1697
Ejector No Cyclone	178	1096	431	736	752	512	2169

TABLE C-26
Continued

		Dust Concentration by Number (p/cm^3)>5μm					
		Instruments					
		LPDS Head				Imp.	Kon.
		Microscopic Techniques					
		Particles and Fibres					
Asbestos							
Jet Milled	141	713		162	273	113	1391
Jet Milled	143	945		271	423	246	1915
Pulverised	85	1345		427	576	256	2717
Pulverised	86	1838		694	443	526	2646
Glass Fibre							
Jet Milled	144	273		234	183	105	1050
Jet Milled	148			44	61	14	269
Pulverised	90	347		268	295	52	820
Pulverised	91	373		249	224	42	1157
		Fibres Only					
Asbestos							
Jet Milled	141	620		65	51	23.9	2.74
Jet Milled	143	770		167	278	47.4	1.49
Pulverised	85	226		68	49	11.2	1.30
Pulverised	86	405		209	95	23.3	2.95
Glass Fibre							
Jet Milled	144	139		76	13	38.7	2.9
Jet Milled	148	25		18	19	6.6	5.0
Pulverised	90	200		62	31	15.0	12.0
Pulverised	91	183		64	26	16.0	11.98

APPENDIX D
COMPARISON OF SIZE SELECTORS
TABLES OF RESULTS

These tables list the detailed results obtained in comparisons between dust samplers fitted with respirable dust size selectors. Table D-1 gives the results of the first set of comparisons between horizontal elutriators and 10 mm nylon cyclone size selectors.

Tables D2 to D-11 give the results obtained in the main experiment in which various cyclones and size selectors and construction details of the horizontal elutriator samplers were examined.

FOOTNOTES TO TABLES

1. Hexhlett operated as supplied by Casella with critical-flow control orifice between elutriator plates and filter.

2. Hexhlett operated for shorter time than other instruments - results not comparable with them.

3. Hexhlett modified by removal of critical orifice from between elutriator plates and filter. Another flow control placed after filter.

4. Laboratory sampler 1 built to similar specifications as Casella type 113A but without turned-up lip on ends of elutriator plates.

5. As LS 1 but with a 0.2-inch-diameter orifice between elutriator plates and filter.

6. As LS2 but with a 0.1-inch-diameter orifice.

7. Casella personal sampler as supplied.

8. Casella personal sampler modified by removing one rubber finger cot and restrictive orifice from flow smoother.

9. Flow obtained from Casella personal sampler pump with smoother.

10. Laboratory sampler.

11. Laboratory sampler upside down.

12. Unico 0.5 inch cyclones, stainless steel sheet.

TABLE D-1
Dust Concentration Measurements Using Elutriator and Cyclone Size Selectors

Dust Cloud	Respirable Dust Concentration mg/m³							
	Horizontal Elutriators				Cyclones			
	5 µm	MRC Standard						
		Airflow ℓ/min						
	25	50[1]	2.83	2.5	2.64	1.95	1.65	1.3
Coal								
Jet Milled	15.5	16.8	17.8	17.9	10.9	17.1		18.0
	19.5	21.4	20.6	22.6	16.6	25.0		25.6
Cyclone	14.1	20.3	18.5	20.2	10.1	13.6		22.9
	15.3	21.1	21.2	24.0	13.2	16.4		24.9
Silica								
Jet Milled	14.35	16.1	18.8	17.5	12.2	15.4	15.3	18.1
	10.6	11.9	12.1	12.2	9.0	11.2	10.2	13.7
	9.90	10.75	13.0	11.7	10.3	13.4	13.5	14.2
	10.9	12.1	13.4	13.4	8.3	11.5	13.6	15.0
Pulverised	13.0	19.0	17.1	18.4	10.7	14.6	16.7	19.6
	12.9	18.5	17.7	18.2	9.95	13.8	15.8	20.2
Cyclone	11.1	18.9	16.3	17.0	7.8	12.3	13.6	16.2
	10.6	15.5	15.6	14.6	7.8	10.5	13.2	15.8
	5.3	6.7	7.0		4.9	6.4	6.8	7.1
	8.8	11.8	11.5	12.6	7.1	8.6	10.2	11.9
No Cyclone	10.9	16.3	16.0	17.1	9.1	11.9	13.6	18.8
	10.9	16.4	15.8	16.1	7.9	11.8	12.1	16.9
Pyrite								
Jet Milled	43.8	52.7	46.5	53.4		45.7	47.4	53.1
	18.7	21.0	21.7	21.6	16.0	18.8	20.0	24.4
Cyclone	3.3	5.3	5.5	5.6	2.75	3.9	4.4	6.35
	3.8	6.0	5.6	5.25	3.1	4.4	4.6	5.6
	3.5	5.7	5.16	5.8	2.4	3.3	3.6	4.7
Mica								
Jet Milled	16.1	19.8	19.0	20.3	15.2	16.2	19.6	20.3
	17.05	20.95	21.95	23.3			22.2	23.9
Glass Fibre								
Jet Milled	3.4	3.9	3.7	3.7	2.8	3.0	3.4	4.0
Pulverised	1.6	2.25	1.85	1.9	1.45	1.7	2.3	2.3
	.97	1.21	.91	1.1	.48	.8	.77	1.1
Asbestos								
Jet Milled	12.6	13.6	13.75	12.0	11.8	12.05	11.8	11.2
	12.5	13.3	12.7	13.0	9.5	11.5	12.2	12.7
Pulverised	4.2	5.4	4.9	5.4	2.8	4.2	4.2	4.8
	5.2	6.6	6.0	6.6	4.3	5.0	5.0	6.2

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TABLE D-2
Dust Concentration Measurements
Material: Coal: Dispersion Method: Jet Mill

Size Selectors	Air Flow ℓ/min	Run Number 7	8	9	10	11	12	13	14
		Respirable Dust Concentration mg/m³							
Elutriators									
Hexhlett [2]									
Standard	50	38.1	39.4	36.3	42.7	54.8	55.8	46.7	56.4
Modified [3]	50	39.5	42.2	38.4	46.3	58.7	58.7	50.5	59.4
Casella									
Type 112A	2.5		38.0		43.6			47.0	
Upside down	2.5	43.6		41.2			51.2		52.4
Lab. Built									
I [4]	2.83	45.2	40.6	39.3	46.6	50.0	55.4	47.5	54.8
II [5]	2.83		36.0		40.9	41.6		44.0	
III [6]	2.83	37.5		40.9			49.5		48.3
Cyclones									
10 mm Nylon									
A	1.28	30.9				41.0			
	1.68				30.4				43.4
	1.92			22.4				35.2	
	1.77 [9]		28.9				41.3		
B	1.28		35.9				38.9		
	1.68	32.4				36.4			
	1.92				33.0				40.4
	1.77 [9]			28.6				37.6	
C	1.28			35.5				45.6	
	1.68		32.4				46.7		
	1.92	34.4				41.2			
	1.77 [9]				37.0				45.8
D	1.28				41.9				54.0
	1.68			31.8				39.6	
	1.92		30.0				42.2		
	1.77 [9]	32.8				34.1			
Casella									
Complete [7]	1.83 [9]		40.0		46.2	53.3	61.5		
Modified [8]	1.90 [9]	42.7						49.2	61.3
		Total Dust Concentration mg/m³							
Open Filters									
	2.63	46.4	45.0	45.0	51.7	54.5	68.2	53.6	67.2
	3.41	46.6	45.5	44.0	51.5	55.5	65.8	53.9	66.3

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TABLE D-3
Dust Concentration Measurements
Material: Coal: Dispersion Method: Ejector - No Cyclone

Size Selectors	Air Flow ℓ/min	Run Number				
		15	16	17	18	19
		Respirable Dust Concentration mg/m³				
Elutriators						
Hexhlett [2]						
Standard	50	47.9		36.9	30.3	34.1
Modified [3]	50	49.6		41.6	34.3	32.3
Casella						
Type 112A	2.55				40.0	
Upside down	2.55		39.4	40.4		30.8
Lab. Built						
I [4]	2.83	46.0	43.6	45.7	37.8	34.4
II [5]	2.83		32.7	42.8		32.5
III [6]	2.83	40.4			32.4	
Cyclones						
10 mm Nylon						
A	1.28	36.8		41.5		
	1.68					26.0
	1.92				30.6	
	1.77 [9]		34.7			
B	1.28		40.6			
	1.68	30.8		31.0		
	1.92					22.3
	1.77 [9]				27.5	
C	1.28				33.1	
	1.68		34.8			
	1.92	29.7		28.4		
	1.77 [9]					27.1
D	1.28					31.1
	1.68				26.5	
	1.92		27.3			
	1.77 [9]					
Casella						
Complete [7]	1.83 [9]			56.3		44.8
Modified [8]	1.90 [9]	51.0	51.0		48.3	
		Total Dust Concentration mg/m³				
Open Filters	2.63	92.5	75.4	111.0	116.9	90.2
	3.41	96.8	91.2	111.0	98.8	90.5

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TABLE D-3
continued

Size Selectors	Air Flow ℓ/min	Run Number 20	21	22	23
		Respirable Dust Concentration mg/m³			
Elutriators					
Hexhlett [2]					
Standard	50	29.8	39.2	36.9	33.4
Modified [3]	50	33.6	39.8	39.2	41.4
Casella					
Type 112A	2.55		45.4		47.2
Upside down	2.55	44.0		50.0	
Lab. Built					
I [4]	2.83	38.4	40.8	43.1	43.9
II [5]	2.83	33.0		38.6	
III [6]	2.83		36.4		
Cyclones					
10 mm Nylon					
A	1.28	35.5			
	1.68				35.2
	1.92			32.7	
	1.77 [9]		32.4		
B	1.28		34.2		
	1.68	27.2			
	1.92				29.2
	1.77 [9]			37.4	
C	1.28			37.4	
	1.68		30.9		
	1.92	28.1			
	1.77 [9]				35.0
D	1.28				37.5
	1.68			41.2	
	1.92		32.7		
Casella					
Complete [7]	1.83 [9]	45.6		54.6	
Modified [8]	1.90 [9]		51.9		54.2
		Total Dust Concentration mg/m³			
Open Filters					
	2.63	70.7	83.1	80.3	
	3.41	73.9	83.2	84.2	92.5

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TABLE D-4
Dust Concentration Measurements
Material: Coal

Size Selector	Air Flow ℓ/min	Dispersion Method							
		Ejector - No Cyclone				Jet Mill			
		Run Number							
		24	25	26	27	28	29	30	31
		Respirable Dust Concentration mg/m^3							
Elutriators									
Hexhlett [2]									
Standard	50	6.58	9.62	7.57	6.59	15.8	15.1	17.0	18.7
Modified [3]	50	6.83	10.33	7.29	7.05	16.4	17.9	18.1	19.2
Casella									
Type 112A	2.55		10.61	7.34	6.96	15.9	18.0	17.9	18.8
Lab. Built									
I [4]	2.83	7.1	9.95	7.15	7.1	16.1	18.2	17.8	19.3
II [5]	2.83		9.0		6.52		15.8		17.1
III [6]	2.83	5.61		6.22		14.1		15.4	
		Total Dust Concentration mg/m^3							
Open Filters									
	2.63	19.5	28.1	20.2	19.5	22.7	25.8	25.8	28.4

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TABLE D-5
Dust Concentration Measurements
Material: Coal: Dispersion Method: Jet Mill

Size Selectors	Air Flow ℓ/min	Run Number 43	44	45	46	47	48	58
		Respirable Dust Concentration mg/m³						
Elutriators								
Hexhlett Modified[3]	50	69.0	62.0	64.5	59.2	54.9	52.5	29.4
Casella Type 112A	22.5		56.0	62.4	54.4		46.0	31.7
Lab. Built I[4]	2.83		60.5	65.8	58.4	55.5	52.5	29.2
II[5]	2.83	69.7		67.0		54.3		
III[6]	2.83		57.8		54.3		50.5	29.7
Cyclones								
10 mm Nylon								
A	1.28							27.9
B	1.28			67.6			46.0	
	1.68	59.5			61.0			23.8
	1.92		49.0			42.2		
C	1.28		62.5			51.5		
	1.68			56.7			48.8	
	1.92	57.5			54.0			26.1
D	1.28	60.4			55.0			
	1.68		50.3			45.8		
	1.92			57.4			43.0	25.5
Casella Complete[7]	1.83[9]	80.5		74.3		61.0		
Modified[8]	1.90[9]		64.5		66.3		58.7	
		Total Dust Concentration mg/m³						
Open Filters	3.41	82.6	72.6	79.8	71.4	66.2	63.6	

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TABLE D-6
Dust Concentration Measurements
Material: Coal: Dispersion Method: Ejector - No Cyclone

Size Selector	Air Flow ℓ/min	49	50	51	52	53
		Respirable Dust Concentration mg/m³				
Elutriators						
Hexhlett						
Modified [3]	50	46.3	47.1	45.8	46.8	43.3
Casella						
Type 112A	2.5	51.2	48.1	45.8	49.1	46.7
Lab. Built						
I	2.83	45.6				
IV	2.83	47.7		43.5		41.3
V upside down	2.83		44.5		44.4	
Cyclones						
10 mm Nylon						
A	1.28	48.1				38.3
	1.68				36.9	
	11.92			33.6		
	1.95		28.6			
B	1.28		39.9			
	1.68	33.1				29.4
	1.92				32.6	
	1.95			27.7		
C	1.28			41.5		
	1.68		35.5			
	1.92	32.8				30.5
	1.95				37.2	
D	1.28				45.8	
	1.68			35.4		
	1.92		31.3			
	1.95	30.3				27.2
Casella						
Complete [7]	1.85 [9]	59.4		55.1		54.7
Modified [8]	2.07 [9]		51.8		52.8	
		Total Dust Concentration mg/m³				
Open Filters	3.41	95.7	95.8	92.0	103.5	90.6

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TABLE D-6
continued

Size Selector	Air Flow ℓ/min	Run Number 54	56	57	60	61
		Respirable Dust Concentration mg/m³				
Elutriators						
Hexhlett Modified [3]	50	57.2	57.7	49.5	58.6	47.9
Casella Type 112A	2.5	60.8	54.0	49.5	61.5	48.8
Lab. Built						
I	2.83	54.2		46.9	56.2	48.2
IV	2.83	55.0		48.7		
V upside down	2.83		50.4		54.5	42.8
Cyclones						
10 mm Nylon						
A	1.28				58.6	42.2
	1.68			36.1		
	1.92		36.5			
	1.95	40.6				
B	1.28	50.0				
	1.68				41.2	32.0
	1.92			33.1		
	1.95		33.4			
C	1.28		46.5			
	1.68	42.3				
	1.92				36.6	32.3
	1.95			37.1		
D	1.28			49.0		
	1.68		39.8			
	1.92	42.5				
	1.95				35.2	31.8
Casella						
Complete [7]	1.85 [9]		63.4			
Modified [8]	2.09 [9]	62.4		53.9	65.6	55.4
		Total Dust Concentration mg/m³				
Open Filters	3.41	119.8	105.3	103.0	117.2	110.0

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TABLE D-7
Dust Concentration Measurements
Material: Coal: Dispersion Method: Ejector - No Cyclone

Size Selectors	Air Flow ℓ/min	Run Number 65	66	67	68	69	70	71	72
		Respirable Dust Concentration mg/m^3							
Elutriators									
Hexhlett									
Modified [3]	50	46.2	45.2	46.4	49.1	48.7	49.3	49.3	49.0
Casella									
Type 112A	25	47.5	47.8	49.5	49.8	48.4	52.4	51.8	51.8
Lab. Built									
I	2.83	47.6	48.4	50.4	49.7	47.5	49.7	49.3	49.4
IV	2.83		42.2		46.6		49.3		48.6
V	2.83	44.3		46.5		46.0		46.4	
Cyclones									
10-mm Nylon									
C	1.28	40.6				43.4			
	1.68				34.2				33.9
	1.92			34.0				29.6	
	1.95		31.0				33.1		
D	1.28		39.4				46.1		
	1.68	34.8				37.2			
	1.92				36.2				32.6
	1.95			32.1				32.1	
E	1.28			39.1				42.1	
	1.68		27.4				34.4		
	1.92	28.4				31.7			
	1.95				38.8				29.6
F	1.28				46.5				43.0
	1.68			38.7				36.7	
	1.62		22.4				36.5		
	1.95	30.5				32.6			
Casella									
Complete [7]	1.85	57.5		60.3			61.2		62.2
Modified [8]	2.1		50.7		54.1	57.9		58.1	
0.5-in. S.S.									
A	8.21	50.0		62.5			68.0		63.8
	9.95		59.7		56.7	58.9		55.2	
B	8.21		56.7		62.8	64.2		61.6	
	9.95	52.1		62.0			61.7		60.6
		Total Dust Concentration mg/m^3							
Open Filters	3.41	97.2	96.5	99.0	103.7	102.0	107.1	103.4	102.1

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TABLE D-8
Dust Concentration Measurements
Material: Coal: Dispersion Method: Jet Mill

Size Selectors	Air Flow ℓ/min	Run Number							
		73	74	75	76	77	78	79	80
		Respirable Dust Concentration mg/m³							
Elutriators									
Hexhlett									
Modified [3]	50	24.5	29.2	36.7	38.25	39.5	37.8	36.6	38.7
Casella									
Type 112A	2.55	26.6	30.1	38.9		40.4			
Lab. Built									
I	2.83	23.9	29.5	36.5	37.4	40.4	37.4	35.8	38.7
IV	2.83	24.9		34.6		39.5		37.0	
V	2.83		26.9		36.5		35.0		38.0
Cyclones									
10-mm Nylon									
C	1.28	21.5				36.8			
	1.68				31.5				32.1
	1.92			29.5				27.7	
	1.95		23.4				30.8		
D	1.28		27.0				37.8		
	1.68	1.99				33.4			
	1.92				31.3				31.6
	1.95			28.1				27.4	
E	1.28			35.4				35.7	
	1.68		23.0				33.1		
	1.92	21.6				30.5			
	1.95				28.8				29.5
F	1.28				35.7				35.2
	1.68			31.8				28.9	
	1.92		22.7				30.1		
	1.95	20.5				29.0			
Casella									
Complete [7]	1.85	28.1		40.8			42.8		45.3
Modified [8]	2.1		30.9		39.4			42.1	
0.5-in. S.S.									
A	8.21	23.6					36.4		33.8
	9.95		25.5		33.8	35.1		31.6	
B	8.21		27.4		36.7	35.8		35.0	
	9.95	22.1					33.0		36.7
		Total Dust Concentration mg/m³							
Open Filters	3.41	29.2	34.9		46.2	47.8	45.8		46.1

TABLE D-9
Dust Measurements at Low Concentrations
Material: Coal

Size Selectors	Air Flow ℓ/min	Dispersion Method Jet Mill					
				Ejector - No Cyclone			
		Run Number					
		81	83	84	85	86	87
		Respirable Dust Concentration mg/m^3					
Elutriators							
Hexhlett Modified [3]	50	11.3	5.65	40.2	6.81	11.4	11.7
Casella Type 112A	2.55	12.1	6.01	43.4	7.25		
Lab. Built I	2.83	10.8	5.52	41.5	7.03	11.3	12.0
IV	2.83	10.8		42.1	6.97	11.1	11.9
Cyclones							
10-mm Nylon C	1.28	10.5		36.2	5.73	8.83	10.1
	1.93		4.12				
D	1.28		5.60				
	1.68	9.01		26.0	4.48	7.08	8.21
E	1.68		4.20				
	1.75	8.7		21.2	4.16	6.74	7.16
F	1.75		4.35				
	1.93	7.81		23.5	3.83	6.78	7.72
Casella Complete [7]	1.85	15.1	7.2	50.6	8.76		15.3
0.5-in. S.S. A	8.21		5.4		7.98		
	9.95	11.4				13.7	13.9
B	8.21	11.4					
	9.95		4.94		7.93		
		Total Dust Concentration mg/m^3					
Open Filters	3.41	16.8	7.71	81.5	13.9	23.7	25.1

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TABLE D-10
Dust Concentration Measurements
Material: Coal: Dispersion Method: Jet Mill

Size Selector	Air Flow ℓ/min	Run Number 105	106	107	108	109	110	111	112
		Respirable Dust Concentration mg/m³							
Elutriators									
Hexhlett Modified [3]	50	19.6	21.0	25.4	21.1	18.8	20.3	18.1	20.9
Casella Type 112A	2.55	19.3	22.0	25.5	21.9	18.3	22.3		
Cyclones									
10-mm Nylon									
C	0.99	17.2	21.8			17.2			
	1.52				19.7			14.9	
	1.71			22.9			17.9		18.5
D	0.99			24.9			21.1		22.6
	1.52	17.7	19.1			17.6			
	1.71				17.5			15.6	
E	0.99				22.0			16.6	
	1.52			21.1			17.1		18.6
	1.71	15.2	17.3			14.9			
Casella									
0	1.91							19.0	23.0
	2.39			2.44			21.0		
	2.82	16.4	16.8			15.8			
1	1.91	19.1	21.6			19.0			
	2.39				19.4			15.5	18.0
	2.82			18.8			16.4		
2	1.91			28.9			23.4		
	2.39	17.7	20.6			17.7			
	2.82				18.1			13.6	16.9
3	2.1	20.3	22.4	23.0	22.0	20.5	22.2	17.5	20.3
4	2.1	18.4	20.5	25.4	22.6	21.3	22.1	18.3	19.8
0.5-in. S.S.									
A	8.15	18.2	19.7		19.6	17.7	20.0		
	16.15			20.2				14.3	16.2
B	8.15			26.8				16.6	17.0
	16.15		15.45		15.75	13.3	16.3		

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TABLE D-11
Dust Concentration Measurements
Material: Coal: Dispersion Method: Ejector - No Cyclone

Size Selectors	Air Flow ℓ/min	Run Number				
		113	114	115	116	117
		Respirable Dust Concentration mg/m^3				
Elutriators						
Hexhlett Modified[3]	50	31.0	31.7	24.6	31.8	27.2
Casella Type 112A	2.55					
Cyclones						
10-mm Nylon						
C	0.99	33.8			34.0	
	1.52			21.0		
	1.71		22.1			19.1
D	0.99		37.6			30.3
	1.52	34.6			27.4	
	1.71			20.4		
E	0.99			22.7		
	1.52		22.8			19.5
	1.71	17.1			21.2	
Casella						
0	1.91			30.2		
	2.39		28.0			24.5
	2.82	22.9			23.6	
1	1.91	29.6			33.4	
	2.39			18.4		
	2.82		18.0			16.1
2	1.91		35.0			34.4
	2.39	20.2			26.8	
	2.82			17.1		
3	2.1	27.4			29.6	27.4
4	2.1	27.5		23.6	30.5	28.4
0.5-in. S.S.						
A	8.15	33.0		30.3	40.2	
	16.15		26.9			26.0
B	8.15		28.6			37.0
	16.15	27.0			31.4	

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TABLE D-11
continued

Size Selectors	Air Flow ℓ/min	Run Number 118	119	120	121
		Respirable Dust Concentration mg/m³			
Elutriators					
Hexhlett Modified [3]	50	30.6	26.0	29.8	26.4
Casella Type 112A	2.55	34.0	29.2	32.7	25.9
Cyclones					
10-mm Nylon					
C	0.99		30.3		
	1.52	25.9			21.5
	1.71			22.8	
D	0.99			34.5	
	1.52		22.4		
	1.71	24.8			20.3
E	0.99	33.4			27.3
	1.52			21.9	
	1.71		18.3		
Casella					
0	1.91	38.4			31.6
	2.39			27.2	
	2.82		18.6		
1	1.91		26.2		
	2.39	24.4			19.7
	2.82			17.6	
2	1.91			32.0	
	2.39		18.8		
	2.82	22.4			17.0
3	2.1	31.4	23.1	27.4	25.0
4	2.1	33.8	24.6	31.0	27.4
0.5-in. S.S.					
A	8.15		31.9		30.4
	16.15	25.9		26.3	
B	8.15	41.7		36.6	
	16.15		27.1		25.3

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