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DUST—RECENT DEVELOPMENTS IN AUSTRALIA, U.S.A., CANADA, GREAT BRITAIN AND SOUTH AFRICA

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1. INTRODUCTION

The opportunity to tell you something of recent developments in dust research in the above countries originated in a much-appreciated invitation from the Australian authorities to attend their first Pneumoconiosis Conference in February of last year. They invited only three people from outside their country and it was a tribute to our knowledge of this subject in South Africa that two of us were from our country. Mr. P. H. Kitto, Director of the Physical Sciences Laboratory of the Chamber of Mines of South Africa, was the other South African delegate. The third visitor was Mr. Ken Morse, an Industrial Hygienist from the United States Steel Corporation, who was expert in the field of dust problems in coal mines. After the Australian Conference I visited, still as a guest, most of the major mining areas in that country.

My employers agreed that after the visit to Australia I should return via the United States, Canada and Great Britain to learn something of progress in recent years in these countries in the dust and industrial hygiene field and also to tell them of current developments in South Africa. Thus I was privileged to learn at first hand of modern work, both in mining and industry, in all the major English-speaking countries where dust in mines has long been a serious problem and where dust and similar problems in industry as a whole is being increasingly recognized as a major hazard.

2. THE AUSTRALIAN PNEUMOCONIOSIS CONFERENCE

2.1 Organization

The Conference was attended by nearly 300 delegates. Its emphasis was far more on the engineering aspects of dust than on the medical, although all the local medical experts were there, including their doyen, Dr. Bill George, well known to us here in South Africa which he has visited three times. The Conference proper lasted three days and 24 papers were read. After the Conference there was a further day's discussion on the action that should be taken as a result of the Conference.

The participants came from every industry in Australia even remotely concerned with dust problems. The evidence presented made it clear that their mines have achieved a great deal in dust suppression and the incidence of lung diseases in them has, in most cases, dropped sharply since efforts at dust control started 20 or 30 years ago. The one marked exception has been at an asbestos mine, now closed down, at which more than half the employees contracted asbestosis with less than 10 years' exposure—many of them have since died of this disease. However, in some Australian mining areas the low incidence figures reported may be somewhat suspect since in them there is, surprisingly, no compulsory medical examination such as we have here.

One factor clearly brought out was that pneumoconiosis might well occur in non-mining operations in Australia. Thus Sydney today is a thriving city where many buildings of 50 storeys or more are being built. The excavations for these are necessarily deep and the rock in which they are made is sandstone, nearly pure silica. Dust suppression techniques are at a minimum in such excavations and one must expect that such work will produce silicosis in the workers engaged at it for any appreciable time. Similarly the cutting of underground water mains and sewers in this type of rock must also obviously present a hazard. Quarrying is another activity which may well produce dangerous dust. Representatives from these types of industry were present at the Conference, and I think that what was said must have given them plenty to ponder on. My impression was that one of the principal aims of the Conference was to draw the attention of industry, *other than mining,* to the hazards of dust and the need for precautions against inhaling it in excessive quantities. In this respect, I think that the Australian example might well be followed in this and other countries.

Another interesting aspect of the Conference was that the Trade Unions were well represented. The average mineworker in Australia is most dust-conscious and I was told that they often complain and even refuse to work when they consider dust conditions are unsatisfactory. When such complaints are received, a dust sampler from the mine staff is usually sent to investigate conditions immediately and to try to produce on-the-spot improvements.

I will not deal in detail with the deliberations of the Conference, as the whole proceedings, including the discussion on all papers, will be published early this year and the book should be well worth studying.

2.2 Summary of Papers read by P. H. Kitto and D. G. Beadle to the Conference

Both Mr. Kitto and I presented information and thoughts on dust sampling and dust control based on recent work in South Africa, and since much of this is unpublished here, I feel that a summary of what we said may be of interest.

Mr. Kitto was asked to talk on subjects such as legislation in this country, maximum allowable limits, organization of dust sampling, and many other related matters. This he did most competently. He gave an excellent review of the procedures to which we work and was authorized by our Government Mining Engineers' Department to make several important statements on their views on what dust standards should be aimed at in various circumstances. I think it is a wise policy that we do not have rigid standards laid down in our legislation, but it would be very interesting, I feel sure, if the statements made by Mr. Kitto could be published in South Africa. Perhaps he, or a member of the Government Mining Engineers' Department, could report these statements either as a contribution to this paper, or in a separate paper in the near future.

My own paper was divided into the following sections:—

(i) The strategy of dust sampling.
(ii) The parameter to measure.
(iii) Instruments for dust sampling and assessment.

(iv) Acceptable dust limits.
(v) Dust surveys.
(vi) Storage and retrieval of information.
(vii) Dust control.
(viii) Communication and propaganda.
(ix) Conclusion.

In the present paper I would like to repeat and amplify what I said on the first of these subjects and to expand considerably what I said on the subject of dust control. I will also mention some recent developments in dust sampling. This I will do in later sections of this paper.

I have available copies of my full paper to the Australian Conference and can supply a copy to any interested persons or organizations.

3. GENERAL IMPRESSIONS IN EACH COUNTRY VISITED

3.1 Australia

During my stay in Australia I visited the following mining areas:—

Kalgoorlie (gold mines).
Kambalda (new nickel mining area).
Rosebery, Tasmania (zinc mine).
Broken Hill (four lead and zinc mines).
Mount Isa (copper mine).

At four of these I gave lectures to the local branches of the Australian Mining and Metallurgical Society. These talks summarized my paper given to the Conference. I also went underground wherever possible and had many interesting talks with their senior Management, Ventilation staff and Inspectors of Mines. Their keenness to know more about dust problems and dust control and a genuine desire to take positive action always impressed me.

Mining development in Australia is most exciting. It seemed to me that wherever anyone digs into the earth, he comes up with a new source of minerals—iron, nickel, copper, zinc, lead, oil and natural gas, asbestos, titanium and many other valuable materials are all being found on an increasing scale. Much of this boom in mineral exploration is due to enlightened State and Federal aid, but the exploitation and mining is normally handed over to private enterprise. One of the well-recognized sequels of such expanded mining is the need to watch health conditions in the new mines.

I have already remarked on the great improvement produced in the pneumoconiosis incidence in their mines. Despite this, there is a realization that they must still further improve their ventilation and dust control. The fact that there have been relatively few cases of pneumoconiosis in recent years has not lulled them into a false sense of security. Thus one of their major mines has undoubtedly had very little trouble from dust; but this mine is now moving into areas of nearly 80 per cent. free silica in the rock, whereas previously the rock mined contained only about 20 per cent. free silica. Simultaneously mechanization in this mine has been greatly increased in recent years. Indeed it was quite a frightening sight to see 10-ton mechanical loaders biting into the rock pile and conveying this huge load along the drives at high speeds to the tips. Thus the mine might well produce a much higher incidence of pneumoconiosis in the future. As a result, this mine is most dust-conscious.

The same mine also has a potential dust problem which is unique in my experience. In parts of the mine " hot spots " occur due to spontaneous combustion of oxidizable constituents in the rock—these are so hot that they often glow quite brightly. There is a real fear that as the loaders bite into such rock a minor " explosion " of hot dust might occur and be breathed by the loader operator and possibly destroy his lungs. Therefore the operators working in such ground wear huge ventilated helmets and look somewhat like the " moon-men " of science fiction! I do not blame them for taking such strict precautions.

The konimeter is fairly widely used in Australian mines, but the techniques of using it vary widely from one area to another and generally differ from our South African standard practice. Thus in one area, no adhesive is used on the slide; in another, the samples are examined under light field illumination; except at one mine (from which the Chief Ventilation Officer recently visited South Africa) acid treatment of the slides before counting is not generally practised, thus they include in their counts many soluble particles. Even ignition of the samples before counting is not uniform practice. In the case of konimeter counts, there are no legally recognized maximum dust levels.

In New South Wales coal mines, the Owens Jet Dust Counter is legally specified as the instrument to be used and maximum levels of permissible dustiness as measured by it are entrenched in their laws. The inadequacies of this instrument are recognized and today they cannot buy further models of this archaic instrument, so are placed in a most difficult position!

The Australians appeared to be most interested in what Mr. Kitto and I had to tell them about developments in dust sampling in this country and may well be inclined to follow our lead if present developments in South Africa (see section 5.5 below) prove to be successful.

Industrial hygiene services in factories are far more advanced in Australia than in South Africa. Federal and State assistance is readily available free to any industry in difficulties, and regular inspections are made to check on their dust and fume conditions. Valuable research on industrial hygiene is being carried out in the School of Public Health at the University of Sydney.

3.2 United States of America

One of my overriding impressions of dust research in America was the apparent lack of any co-ordination of research. Individually some very good work is being carried out, but it did not seem to me to form part of an overall plan. Perhaps one reason for this is that many of the leading fine particle workers have been attracted into the air pollution field, where apparently unlimited funds are available because of the great public interest and concern in this subject. For example, a National Air Pollution Research Institute is being built at present at a cost of $35,000,000. Nothing like that is being spent on dust control in their mines or inside their factories!

Another reason for lack of co-ordination is the American system of applying most control measures at State level, not at Federal (i.e. country-wide) level. Thus each of the 50 states has its own legislation (I presume even Hawaii has legislation on dust, although the only dust I saw there was from the swirl of the hula-hula skirts!) and this varies widely from state to state. Different dust levels are specified in different states; some have no legislation on mine or industrial dusts or medical examinations; others have excellent legislation. There are no uniform industrial hygiene laws. Action on Federal level is very difficult to implement. Thus, although the Bureau of Mines (a Federal body) is well aware of the need for more dust research in the mines, they must be circumspect as to the action they take to avoid infringing on State responsibilities.

At long last, the Americans appear to be realizing the limitations of dust sampling with the midget impinger and are seeking improved sampling methods. The American Conference of Governmental Industrial Hygienists (A.C.G.I.H.) is an excellent body which has for many years specified, for the benefit of its members, the Threshold Limit Values (T.L.V.) which it considers should be applied in judging levels of many toxic substances. Although the Conference itself does not believe that the levels should be entrenched in legislation, this is, in fact, done in some states. Many other countries, including our South African Government Mining Engineers' Department, accept these as useful limits by which to judge conditions. Certainly these A.C.G.I.H. levels are the most commonly applied in the world. I had the opportunity of meeting in Cincinnatti some of the leading members of this excellent organization. It was most interesting to learn that they had proposed to introduce last year new standards for dust containing quartz. This is being done because they recognize that the existing T.L.V., based on number concentration, is open to considerable doubt.

Two standards based on mass concentration have therefore been proposed. They will remain on a trial basis for two years (the "Intended Change List") and will then be reviewed in the light of comments received.

The new T.L.V.'s are:—

For "RESPIRABLE DUST"

$$\frac{10}{\%\ \text{Respirable } SiO_2 + 2}\ \text{mgm/cu m}$$

For " TOTAL DUST "

$$\frac{30}{\%\ SiO_2 + 2}\ \text{mgm/cu m}$$

" RESPIRABLE DUST " refers to dust sampled in such a way as to include only those particles likely to be retained in the human lung. At this stage the A.C.G.I.H. do not specify any particular sampling instrument or lung retention curve. They will recognize any method.

" TOTAL DUST " refers to sampling methods which collect all the air-borne dust, with no attempt to exclude non-respirable particles.

Using the above formulae, the following values are obtained for different values of the quartz content:—

TABLE I

Proposed A.C.G.I.H. Threshold Limit Values

% Quartz	Respirable Mass T.L.V.	Total Mass T.L.V.
100	0·10 mgm/cu m	0·29 mgm/cu m
80	0·12 mgm/cu m	0·37 mgm/cu m
50	0·19 mgm/cu m	0·58 mgm/cu m
20	0·46 mgm/cu m	1·4 mgm/cu m
0	5·00 mgm/cu m	15·0 mgm/cu m

No new standards have, as yet, been set for amorphous forms of silica, but in reply to a question from me, Dr. Herb. Stokinger (the Chairman of the T.L.V. Committee) suggested using a value equivalent to 10 per cent. quartz.

The principle of changing to " mass concentration " instead of " number concentration " is due to increasing evidence that the latter is not a good measure of danger to health of quartz particles. This was shown by King's experiment in Great Britain and more recently by Goldstein and Webster in South Africa.

The concept of measuring the " respirable fraction " is based in part on the recommendations of the Johannesburg International Pneumoconiosis Conference in 1959.

The actual levels proposed in the new formulae are based on a few comparative measurements in the granite industry. It is recognized that there will be no direct or constant relationship between the two parameters (the old number concentration and the new mass concentration). It is hoped, however, that the new basis of measurement will give results which mean that most places which would have been graded in a particular way (i.e. above or below the old T.L.V.) will be graded in the same way on the new parameter.

A further, much more extensive, experiment to test this correlation is at present being undertaken by Dr. Murray Jacobson at the Bureau of Mines in Pittsburgh. Many thousands of parallel samples will be taken; the results will not be available, however, for several years.

Very little work appears to be in progress to develop improved dust control methods in American mines.

3.3 Canada

I was most impressed with the research work being carried out on dust in this country and with their interest in the subject. I was asked to address meetings in Ottowa and Toronto, and in both instances mining people and others travelled considerable distances to come to my talks and revealed, by their questions, a keen interest in this subject.

Although Canada has, to a certain extent, the same conflict between Federal and State laws and organizations that occurs in the United States of America, the two different levels of organization appear to collaborate well.

In the State of Ontario, which is the only one I could visit, the Government Department of Energy, Mines and Resources, the Canadian Public Health Service, and the Mines Accident Prevention Association of Ontario (which has some of the functions of our Chamber of Mines) are carrying out a number of interesting dust research projects.

If I have one criticism of the Canadian work it is that they have been too modest in publishing their research results.

The Government's main dust research is

undertaken in a special Dust Laboratory at Elliott Lake, which unfortunately I did not have time to visit. Here Mr. Geoffrey Knight has established an elegant laboratory dust chamber in which he is at present comparing the sampling characteristics of six or seven different instruments in an attempt to see if there is any relationship between them. These instruments include thermal precipitators, filter samplers, midget impingers, tyndalloscope and konimeters. These studies are being made on six different types of dust, including silica, coal and asbestos. The results of his studies should be of great interest.

In Canada the konimeter is the main dust sampling instrument used in the mines and is a special type made locally, called the " Gathercole." In general, Canada closely follows South African practice in taking and assessing dust samples.

I feel that studies of the composition of airborne dust are very important. For some time I had thought that our methods in South Africa for doing this were ahead of the rest of the world. Using X-ray diffraction we are able to measure about 0·05 mgm of quartz in a 1 mgm sample of dust. However, Dr. John le Roux of the Department of Health in Ottawa has developed techniques which are about 10 times as sensitive as our South African methods and mean that very much smaller samples can be used to determine composition. His work is impressive.

The Mines Accident Prevention Association of Ontario encourages dust sampling and dust control on the mines which are members of the Association. There is no dust sampling by Government Inspectors of Mines in this State and so the industry themselves must undertake this work, although the Public Health inspectors can be called upon in special cases. Mr. McIntosh of the Association is making a statistical study of trends in silicosis incidence in their mines and is attempting to correlate these trends with factors which may influence the disease.

Canada, of course, originated the use of aluminium powder as a therapeutical agent to prevent the development of silicosis. Use of this material is still carried out by daily injection of aluminium oxide powder into the change rooms after the shift. The theory is that the aluminium powder chemically counteracts the action of the silica dust in the miner's lung. Laboratory experiments have indicated that there is merit in this suggestion, but it is practically impossible to prove from the field use that improvements have been achieved in the miners. The reason for this is that more or less at the same time as aluminium treatment was introduced in Canadian mines, other major changes were made, such as far better dust control, improved ventilation and the introduction of medical examinations before commencing work underground to screen out unsuitable men. Thus although there has undoubtedly been a very significant improvement in the incidence of silicosis in the mines in Ontario, it is not possible to prove which of these various preventive measures is primarily responsible for this great improvement.

I was privileged to meet and spend a considerable time with Dr. Dudley Irwin who was one of the three workers who originated aluminium therapy and who is now the Director of the McIntyre Research Foundation.

I would have liked to have been able to visit Canadian metalliferous mines to study at first hand their methods of dust control, but this was not possible. I certainly gained the impresion that close attention is paid to this subject in many of their mines.

3.4 Great Britain

I have been privileged to visit this country a number of times over the past 20 years and am always impressed with the scientific attitude to dust research shown by the National Coal Board. Their work is continuing in many different fields; also the Safety-in-Mines Research Establishment at Sheffield is carrying out valuable work.

A special meeting of the Medical Research Council's Dust Panel was called so that I could tell them of recent developments in South Africa. This is an excellent body which brings together all the major research workers in the field of dust in Great Britain and forms an extremely sound forum for the free and critical exchange of information on work which is being carried out or should be carried out.

The largest dust research project ever undertaken in the world is now approaching completion. This is the " Pneumoconiosis Field Research " project or " 25 pit scheme " being undertaken by the National Coal Board. In it, the actual dust exposures of some 30,000 miners over a period of 10 to 15 years is being measured and recorded and compared with the development and progression of pneumoconiosis in these men. This study has required the services of over 100 persons for over 10 years and has already cost millions of pounds. However, it is felt that this sum has been worth spending as it is now leading to scientifically determined levels of dust which can be breathed by men without producing lung disease in them. Without such scientifically obtained information many of the allowable limits used in various countries are of doubtful value. Mr. Henry Walton and his team have done a wonderful job in bringing this long-term and highly complex project to a successful conclusion—their results, when available this year, will be of world-wide value.

In this connection I should like to quote a very sage statement made recently by Emeritus Professor T. E. Hatch, late head of the Graduate School of Public Health, Pittsburgh, U.S.A., and a world-famous authority on industrial hygiene engineering, whom I met again in the States. He wrote in an article:—

> " One important requirement for a successful programme of industrial control of a potentially hazardous physical or chemical agent is that there be available a systematic, quantitative statement of the relationship between magnitude of exposure to the stress agent and the kind and degree of response in a population exposed to that agent . . . A well developed dose-response relationship provides the essential information from which to start, and without it, no amount of wisdom or judgement will ensure a correct answer."

At present the thermal precipitator is the accepted instrument for dust sampling in British coal mines. However, the desirability of changing to respirable mass measurements for coal dusts, which cannot be done with the thermal precipitator, is well recognized and plans are being made for converting to this type of sampling instrument probably towards the end of 1969.

The British authorities firmly believe that dust sampling should always be carried out over the whole working shift and that samples taken over a short period, as we do in South Africa, have little value. We had an interesting discussion on this at the M.R.C. Dust Panel meeting, and I shall be expressing further views on this in Section 4 below.

Another way South African practice varies from the British lies in our present " Anti-Dust Campaign " in which our authorities are attempting to inculcate in the miner (European and Bantu) a greater awareness of the dangers of dust. Little along these lines is done in Britain. Their primary approach is to tackle the dust source, that is the machines which produce dust. A great deal of research is conducted at their Mining Research Establishment at Isleworth, London, by Mr. Bob Hamilton and his team. Basically their belief is that no mining machinery should be allowed underground until it has had built into it devices which limit its dust production to acceptable levels. How different to the approach in South Africa where practically any machine (except rock-drills, which must be approved by the Department of Mines—and only new drills are tested for this purpose) may be used underground. It is usually only some time later that anyone investigates to see if it is a dust producer. To take action then to decrease its dust-creating characteristics is usually much more difficult and expensive. We could do far more along the lines of prior approval of machinery (from the point of view of dust production) in South Africa than we are doing at present. At the same time, I do believe that the anti-dust campaign amongst the miners could be an effective way of reducing dust exposure underground and thereby reducing the incidence of silicosis. It is a pity that, on some mines, it is being conducted in a half-hearted manner.

A new Mining Medical Research Centre is presently being established in Edinburgh, where the National Coal Board's efforts to reduce dust and the incidence of coal miners' pneumoconiosis will continue on a scale and standard which is the envy of many other countries.

4. THE STRATEGY OF DUST SAMPLING

One aspect of dust sampling which is often given less consideration than it warrants is the STRATEGY to be used. I will therefore repeat and amplify what I said on this subject in Australia. I consider more attention should be paid than has been done in the past, to " WHY? "—and " WHERE? " — and " WHEN? " Many countries, including South Africa, appear to have given more attention to " HOW? " and " WHAT? " perhaps almost to the exclusion of the first three questions.

4.1 Objectives

In answer to my first question, namely " WHY? ", I suggest that the main overall objective of routine dust sampling in mines should be to provide useful and accurate information for achieving adequate dust control. Other reasons for undertaking dust sampling should be considered secondary objectives, such as compliance with regulations, obtaining data purely for the completion of records or returns, etc. I exclude dust sampling for research purposes, e.g. for correlation with medical findings, from the present discussion.

To assist in achieving adequate dust control, there are at least four possible different requirements for dust sampling techniques, namely:—

(a) What is the true average overall dust level in the mine, and in different main sections? How does it vary from time to time? Is it improving, static, or getting worse? How do different mines compare with each other?

(b) What dust levels are various categories of men exposed to? For example, developers, stopers, loco drivers, etc. Also, do these levels fluctuate during the shift? i.e. when do maximum dust levels occur for each category?

(c) What dust is produced by the various operations in a mine? e.g. scrapers, rock-drills, tips, etc. This will indicate if new dust control methods need to be developed for a particular operation.

(d) How do pinpoint individual causes of dust so local remedial action can be taken? That is, " trouble-shooting."

The various possible strategies of sampling to meet the above requirements are discussed in the various sections below.

4.2 Overall Dust Surveys

When he was Director of the South African Pneumoconiosis Research Unit, Dr. H. S. Gear considered that one of the most important needs in dust and pneumoconiosis research was to develop a technique by which independent dust survey teams could visit a mine, make a valid survey of dust conditions in that mine, and then suggest to the mine how dust conditions could be improved if they were found to be unsatisfactory. Rand Mines Limited undertook to do this.

This concept was similar to the medical " Survey and Demonstration Teams " in existence in the World Health Organization with which Dr. Gear had been connected.

It was agreed that the objects of this technique should be to provide information on two basic points. The technique should:—

(a) Be able to provide a " dust index " for the mine, i.e. to show whether the mine as a whole is dusty, borderline or relatively free of dust.

(b) Give some picture of how average dust concentrations increase or decrease in the air as it flows through the mine, and show the areas in which the dust has reached undesirable levels.

Before such a technique could be developed, it was essential to know how dust levels vary in a given working place. Obviously, if the dust level is always the same in a given place, a sampling technique which involves making only one measurement there will provide adequate information on the general average in that place. On the other hand, if the dust levels vary considerably either during each shift or from one shift to another, then a single sample will usually fail to provide a reliable estimate of the average or typical dust levels at that place. Such a single sample might,

TABLE II

Variations in Dust Levels

Value of coefficient of variation	" Overall " variation	" Within shift " variations only	" Between shift " variations only
0– 10	0	1	3
11– 20	0	6	13
21– 30	4	18	28
31– 40	27	34	18
41– 50	23	14	12
51– 60	11	9	7
61– 70	10	8	9
71– 80	8	3	3
81– 90	3	1	2
91–100	4	1	1
101–110	2	3	1
111–120	1	½	3
121–130	4	0	0
131–140	½	0	0
141–150	1	½	0
Over 150	1½	1	0
Mean Value	60	44	40

by chance, sometimes give the typical result, or a figure close to it, but it might also give a figure quite different from the average level. There is no way of telling from the single sample whether or not a typical result has been obtained. Therefore, if dust conditions do vary from time to time, more than one sample should be taken in order to obtain a valid picture of the typical dust levels in that place. Any decision on the optimum number of samples to take at any given place will depend on the variations in dust levels which do occur.

Thus an important preliminary study was to determine the typical variations which do occur in practice. Obviously a large number of working places had to be studied, covering a number of different mines, since the variation in one place or on one mine might not be typical of others.

This study was undertaken using " standard " thermal precipitators, each sample covering one to two hours. One hundred and forty-one different working places of all types, covering seven mines, were selected. A large number of samples was taken at each of these selected places, covering substantially the whole working shift. The maximum number of samples at any one place was 234, but a more typical figure was 30 to 40 at a given place. The samples were usually not taken on successive days, in order to give maximum spread over all possible variations in a place.

A preliminary inspection of the results showed that, in practically all working places, dust levels did vary appreciably from sample to sample. This refers to samples of the period of an hour or two; had the samples been taken over a short sampling period, e.g. with the konimeter, the variations would probably have been considerably greater.

Next, further statistical studies showed that these variations were usually randomly distributed—that is, the variations were not primarily due to steady increases or decreases in dust levels over a long period.

Finally, the observed results were analysed to determine the " within shift " variations, the " between shift " variations and the " overall variations " combining the first two sources. These variations were expressed as the " coefficient of variation," i.e. the " standard deviation " of the results at a given place divided by the mean dust concentration at that place, expressed as a percentage. In practice the calculations were based on the logarithms of the dust counts as we have evidence that such data usually follows a log-normal distribution.

Table II shows the percentage frequencies with which various coefficients of variations occurred.

As will be seen from the table, the average "overall" coefficient of variation was 60 per cent., with both the "within shift" and "between shift" variations being about 40 per cent. on average. The most common individual values of the overall coefficient of variation lay between 30 and 50 per cent., but in many working places this coefficient was higher, and in about 10 per cent. of all places observed it exceeded 100 per cent.

The variations found in a given working place are therefore seen to be large. It must be remembered that variations up to the given value of the coefficient of variation will occur in about two-thirds of all observations; between one and two times the coefficient of variation will occur in about three out of ten observations; and between two and three times the coefficient of variation will occur in about 5 per cent. of all observations.

Thus is can be seen that a single dust sample taken over an hour or two will often fail to indicate the true average dustiness in a given working place. To make sure that a typical figure is obtained, it is therefore obvious that the place must be sampled more than once; it must also be noted that variations occur both "within shifts" and "between shifts."

Therefore the first important principle that must be included in any technique of making overall dust surveys is that sampling must cover, for each selected working place, a number of different times of the shift, and must cover different shifts, so that the errors involved in a single sample can be reduced.

The next problem is to decide how many samples to take. If too few samples are taken, the average result is open to large errors. If too many samples are taken, the cost in time and effort becomes excessive. This problem has been solved by developing "sequential dust sampling charts" shown in Fig. 1.

This chart assumes a coefficient of variation of 40 per cent. in the dust levels. It assumes that the borderline between "satisfactory" and "unsatisfactory" dust conditions is 300—but this value is purely arbitrary.

The chart can be used in one of two ways. The first way is to use it to take the optimum number of samples needed to obtain a meaningful result.

After a small number of samples has been taken (say three) at a given sampling position, the average result to date is plotted on the chart, opposite the number of samples taken. If this point falls above the upper control line on the graph, then it is highly unlikely (95 per cent. confidence limits) that further sampling in the same place, under similar working conditions, will result in the average dropping below the "acceptable" level; similarly, if the plotted point falls below the lower control line, then it is also unlikely, at the same confidence level, that the average will rise above the acceptable level. Thus the sampling position can be accepted as "unsatisfactory" or "satisfactory" respectively, and further sampling, at that position in the current survey, is not needed. If, however, the plotted point falls between the two control lines, then no statement can be made as to the dustiness of the place relative to the acceptance level. The "true" average dust concentration in that place may, as further samples are taken, rise to above the upper control line, or it may, equally probably, fall to below the lower control line. Further samples must be taken and the new average of all samples plotted, until a clear indication is obtained by the average point eventually falling outside the control lines.

This first method, if applied, limits the number of samples which need to be taken to get a meaningful result. Only the minimum number of samples need to be taken, and sampling is continued only at those places which have dust conditions so close to the acceptance level that further sampling is needed.

The second use of the chart arises when it is impracticable to control the number of samples taken. It is not always feasible to plan subsequent sampling to take into account the results already obtained; for example, the assessment of the slides may lag behind by several days, and sampling must continue while facilities on the mine

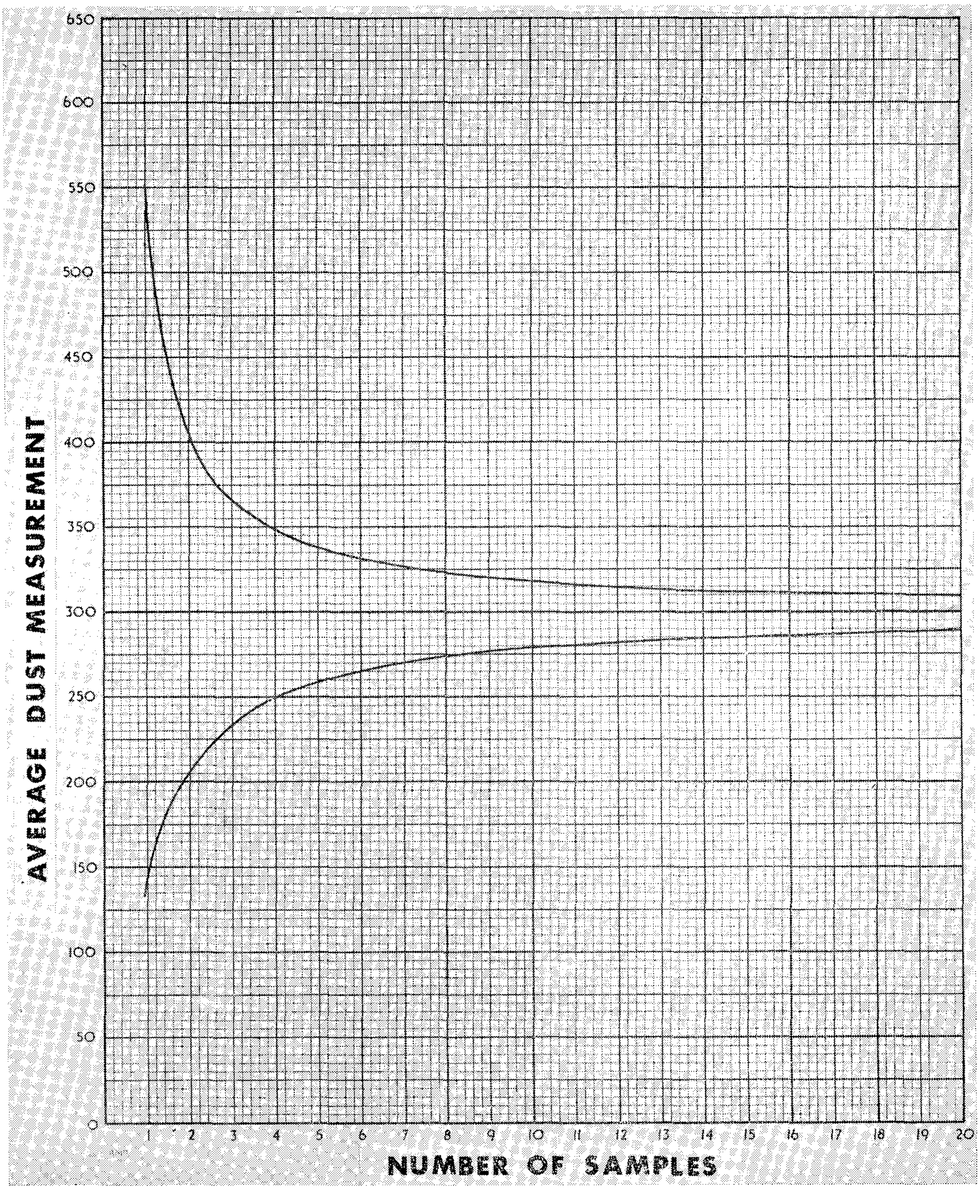

Fig. 1.

Sequential Dust Chart

Mine.. Position.. Dates..

are available. In such cases, the charts are applied to the results after they have all been obtained; the average of all the results at each place is plotted against the number of samples taken, and the statement is made that the dust conditions are "unsatisfactory," "borderline," or "satisfactory" respectively, depending on whether this point lies above, between or below the control lines respectively.

It will be noted, of course, that the width of the zone defining "borderline" conditions is very wide when few samples are taken, and becomes much narrower as greater numbers of samples are taken. Thus if a definite decision is required on whether a particular place is "satisfactory" or "unsatisfactory" and the available result is found to show "borderline" conditions, then additional samples will be required; on the other hand, there appears to be no serious objection to using the category "borderline" when necessary, as this is useful information, and using this category certainly reduces the number of samples required.

The use of these sequential sampling charts is the second important principle involved in this method of making a dust survey of a mine. It is a far more meaningful technique than simply determining if the average of a number of samples is above or below a fixed limit.

The third principle involved is not to attempt to sample every working place in the mine; although the policy of sampling every working place regularly is undoubtedly important in day-to-day dust control in mines, and the occasional visit by a dust inspector to each working place has very considerable propaganda effect on the workers, it does not appear to be necessary to do this to obtain the broader picture aimed at in overall surveys of the type considered here. For example, if a survey in a longwall stope shows that the dust level at the bottom is, say, 400, that half-way up it is 500 and at the top it is 600, there would appear to be little point in taking dust samples at intervening places; there is a good case for assuming that dust conditions throughout this particular longwall stope are "unsatisfactory."

By careful selection of sampling positions it is usually found that the broad picture can adequately be obtained from relatively few sampling positions.

This important task of selecting the sampling positions is always carried out by senior members of the Dust Sampling Team in close consultation with the Chief Ventilation Officer of the mine concerned.

It is essential to include sampling positions which will show clearly the "build-up" of dust in the air from where it leaves the downcast shafts, flows through the workings and up to the beginning of the return airway systems. Usually 40 to 50 sampling positions are enough to cover an average sized gold mine.

Typical sampling positions usually include the following:—

(a) Main stations on downcast shafts.
(b) Positions beyond main tips.
(c) Deliveries of intake airways.
(d) The bottom, centre and top of the main stoping sections.
(e) The faces of randomly selected development ends.
(f) Return air from randomly selected development ends.
(g) The intakes of main return airways.
(h) Randomly selected isolated workings.

The number of sampling positions of each type should take into account the proportion of workers in each type of place; i.e. many more sampling positions should be selected in stopes than in, say, haulages.

The samples are taken with the standard thermal precipitator, and each sample covers one to two hours. The slides are assessed, on return to the laboratory, using the Diffraction Size Analyser (see Section 5.5 below).

As the survey proceeds the results obtained to date are plotted on a plan of the mine (say, 1 in 5,000). In cases where the averages show sudden marked changes of dust levels between two successive sampling positions (for example, a change from 150 to 600), then additional sampling positions between these two points should be added to try to pinpoint more precisely where and why this sudden increase occurs. The persons in charge of the sampling strategy should not be satisfied if the final plot of results shows inexplicable changes in dust levels between successive sampling points.

TABLE III

Section of mine	Average dust level in this section	Number of workers in this section	Weighted dust level for section
1	240	110	26,400
2	360	272	97,920
3	220	148	32,560
4	490	221	108,290
5	370	137	50,690
6	150	94	14,100
7	410	255	104,550
	Total	1,237	434,510

$$\frac{434{,}510}{1{,}237} = 350$$

Calculation of Mine " Dust Index "

Frequent consultation with the ventilation staff of the mine is most desirable, and the application of intelligent thinking by all concerned in planning the sampling usually produces adequate coverage of the mine as a whole.

Each position is sampled on at least three different shifts, preferably some days apart, so that any variations in working conditions are likely to be covered.

The average result for each sampling position is plotted on the sequential sampling chart (described above). From this plot the statement can be made, for each position, whether average dust conditions there are above or below the " acceptance " level, or whether the results are " borderline."

In order to provide useful guidance to, say, the Mine Manager, on dust conditions in his mine, it is desirable that some definite " limit of acceptability " be set. It must be stressed that there is no legal limit, or even an agreed figure, for this level in South African gold mines. Nevertheless, it is considered pointless to present a set of dust measurements, after a detailed dust survey, if some target figure cannot be stated. In accordance with modern theory, we have always used, in the Rand Mines Group, the parameter of respirable surface area (R.S.A.) for determining dust levels in such overall surveys.

As an interim measure the figure of 300 R.S.A. (square microns per cubic centimetre) has been used as a " limit of acceptability," to give some indication in reports of dust surveys on whether working places are " satisfactory " or " unsatisfactory." It is emphasized that this figure is tentative.

As pointed out at the beginning of this report, there are two objects of these surveys: firstly, to provide a " dust index " for the whole mine and, secondly, to give a " picture " of dust conditions through the mine.

The overall " dust index " can be used to compare one mine with another, or to measure the degree of improvement or deterioration in the same mine between successive dust surveys. It is obtained as follows:—

The average dust count in a given section of the mine is multiplied by the approximate number of workers in that section. This is done for each section and the total weighted figure is then divided by the total number of workers. This calculation is shown in more detail in Table III.

The " dust index " is therefore 434,510 divided by 1,237, i.e. 350. This weighted figure can be compared with the average dust level of 320 which would have been obtained by straight averaging of the various dust levels.

To present the final overall picture of the dust in the mine, use is made of copies of the plan of the mine on a scale of, say, 1 in 10,000. On these are plotted all current working places, main directions of air flow, and the sampling positions used in the dust survey. Each sampling position is then coloured by hand according to the results found there—in RED if the dust conditions were found to be "unsatisfactory," YELLOW if "borderline" and GREEN if "satisfactory." Next, the working areas between actual sampling positions are shaded in, using the same colour scheme. Some intelligent deductions must be made at times to decide likely dust levels in intervening positions. Thus, if two successive sampling positions are green, it is likely that all working places between them are also "satisfactory." But if one sampling position is yellow and the next red, there is no clear proof exactly where conditions change from "borderline" to "unsatisfactory." However, a study of the plan and particularly discussion with staff on the mine will often enable an intelligent guess to be made where one colour should change to the other.

In every case where the results have been presented in this way to senior staff on a mine they have expressed the opinion that this method of presentation gives them a clearer and more concise picture of the dust conditions on their mine than has been conveyed to them in any other way.

Finally, the report on conditions in the mine includes any useful advice that can be given on how to improve unsatisfactory dust conditions. Often in the course of the survey the field observers may have noticed practices that could be improved, and the report is a good opportunity to convey such recommendations.

After several years of developing and testing this technique on a number of mines, the following conclusions have been reached:—

(a) The technique gives valid results because:
   (i) It is based on sampling with an accurate instrument.
   (ii) The samples each cover an appreciable time.
   (iii) A number of samples are taken at each place.

(b) It is relatively simple to use the results obtained at the selected sampling positions (if they are well chosen) to obtain a good overall "picture" of dust conditions as a whole throughout most of a mine.

(c) The "dust index" is a good measure of the overall dust hazard in a mine because it takes into account the number of persons exposed to dust in different sections of the mine.

(d) The method of presentation of the results gives Mine Management and others a clearer and more accurate picture of the overall dust situation on the mine than they previously had.

(e) Although the method is not cheap, the results obtained can be so useful in improving dust conditions (where the survey has shown this to be desirable) that the ultimate savings should far outweigh the costs involved.

I have devoted a considerable portion of my paper to describing this technique because details have not been published before and because I sincerely feel this technique can be of major use in obtaining information essential to dust control.

4.3 Positional Dust Sampling

The technique described in the section above is one example of "positional dust sampling." That is, the strategy where dust samples are taken at fixed positions to determine how dust levels vary in space and time. Generally, this method involves a relatively small number of samples, each of long duration—ideally a full shift.

The National Coal Board in Great Britain relies heavily on positional dust sampling for their routine dust measurements. They position the dust sampling instrument on the return side of a working face and sample over the whole shift. At present they usually rely on a dust sampling technician to install and start the instrument and remove it at the end of the shift. However, they are considering using a mining official, who is working at the place to be sampled, to undertake this duty. This would considerably reduce the manpower involved. If the result of the shift-long sample is high, action is taken to improve dust control at that face. It must be stressed that the Coal Board do *not* take short-term individual samples at different positions along the working face, as we do in South Africa, both in the gold mines and collieries.

4.4 Personnel Dust Sampling

There is another way in which the overall dust picture in a mine can be obtained. This is by " personnel sampling," which involves the dust sampler travelling through the mine on a predetermined route and taking a short-period sample at every person he meets, or every second person, or every third person, etc. He takes the dust sample, irrespective of what the person is doing as he arrives. To obtain valid results, the sampling must extend evenly over the whole working shift.

" Personnel sampling " involves taking a large number of samples, each of relatively short duration. I consider that about two minutes is the optimum sampling time at each man, if most men are to be sampled. If a smaller proportion of the working men is to be sampled, this period should be increased.

" Personnel sampling " is used in South Africa by the Chamber of Mines to determine the overall dust levels in mines, members of the Chamber. The konimeter is used as the only sampling instrument. I consider the results obtained by the Chamber are not strictly valid for a number of reasons, which include:—

(a) The grave uncertainty attached to the accuracy of the konimeter, particularly for high dust levels.

(b) The extremely short period over which each person is sampled (each third person encountered is sampled)—namely $\frac{1}{4}$ second.

(c) The lack of statistical analysis of the data.

(d) The sampling is biased—the great majority of the samples in the working places are then within a two-hour period, whereas the working is six to seven hours.

(e) Men encountered travelling to and from their working places are over-sampled.

In addition, since all the konimeter samples must be counted under the microscope, this method is laborious and time-consuming.

4.5 Personal Dust Sampling

This method involves the workers themselves wearing a small sampling device attached to their clothing or helmet. It operates automatically throughout the working shift and measures the dust load each individual has been exposed to that day. If this is found to be high, steps can be taken to ascertain the reason and remedial action taken.

This method is analogous to the " film badge " device worn by workers exposed to ionizing radiations, with which many of you will be familiar. Unfortunately, the devices at present available for measuring dust exposure are not as small, cheap or easy to assess as the film badge. However, some progress is being made overseas in designing such equipment, and Fig. 2 shows a device now available. The dust samples taken on it can be weighed and the quartz content determined by X-ray diffraction or other means.

As far as I am aware, however, no use is being made of these instruments as a routine in any mining fields, but it would be interesting to see this done.

4.6 Occupational Dust Sampling

The dust risk associated with given occupations can be measured satisfactorily by " personnel sampling," but care must be taken that the samples cover all, or at least most of, the full shift. It might give quite misleading results to sample one type of worker mainly at the beginning of a shift and another type later in the shift. This technique of sampling is possibly the least useful of those I have listed for dust control purposes because the dust level at any

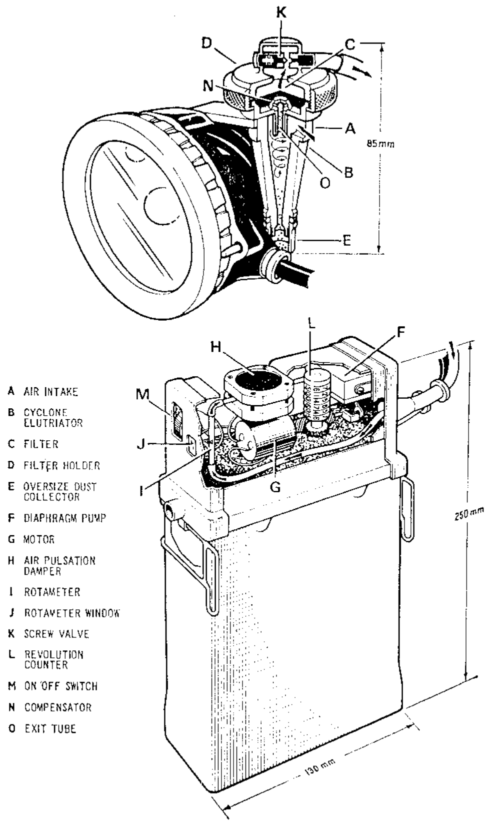

Fig. 2

Personal Dust Sampler Attached to Cap Lamp

given man may not be due primarily to the work he is doing. The dust at his working place may come from work carried out some distance away in the air stream reaching him.

However, occupational sampling is extremely useful for research purposes. I used it extensively for the epidemiological study I have made of the relationship between the amount of dust breathed and the development of silicosis. To measure the typical dust exposures of men in different occupations, the dust sampler followed the selected man throughout his full working shift, taking continuous samples on a portable form of thermal precipitator and a sample every ten minutes on a konimeter. The dust levels found in each occupation were then compared with the incidence of silicosis in the same occupations—this led to the derivation of curves showing the probability of contracting silicosis after working a specified number of shifts at stated dust levels.

4.7 Operational Dust Sampling

This method of dust sampling is designed to measure the dust produced by the various operations in a mine, e.g. scraping, drilling, tipping, etc. This is done by taking simultaneous samples of the intake air and the return air from the specific operation and excluding the dust from any other operation. It is quite likely that on one mine one particular operation is the major source of dust and, on another mine, quite a different operation may cause most dust. Even from one section or level to another of a given mine, the most significant dust-producing operations might vary. This method of sampling can locate the predominant source in each case.

We have carried out a limited amount of this type of sampling and obtained useful data. We hope to extend this type of sampling now that an ideal instrument for this purpose is available—the new modified thermal precipitator which I shall describe in Section 5.5 below.

4.8 Trouble-shooting Dust Sampling

This is the traditional way in which dust-sampling is carried out in South African gold mines. Samples are taken with the konimeter at various positions along the working face. If the results are high, remedial action is recommended. It should be recognized that this method does not give a valid overall picture of dust levels in the mine, nor does it provide reliable information on the specific operations causing the dust, nor does it determine how much dust men breathe throughout their shift. Each of these particular needs can, however, be met by one or other of the techniques described above.

Nevertheless, "trouble-shooting" dust sampling does play a very important part in dust control. It does reveal working places where dust levels are unsatisfactory, although it does not always show why this is so. However, an intelligent observer will often be able to identify the reasons and suggest what action is needed to improve the dust conditions.

4.9 The Choice of Methods

Having reviewed the various possible strategies of dust sampling and proposed names for them, the question remains as to which should be adopted. No single answer can be given. It all depends on the objective of the dust sampling. What I do plead for is that those in authority should carefully consider what they wish to achieve from dust sampling and, when this is clearly defined, then, and only then, should the best strategy be selected. There have been far too many examples in dust sampling of the phrase "Having lost sight of our objectives, we re-doubled our efforts!"

My personal view is that there should be an "overall survey" using "positional sampling" once per year on each mine—this should be carried out by a team from outside the mine. The mine staff should concentrate on "trouble-shooting" and "operational" dust sampling.

I did not include "WHO?" in my basic questions, but it is an important matter. In South African gold mines, most dust samples are taken by members of the "Ventilation Department," who are also primarily responsible for advising on efficient ventilation and dust control in the mine. If their dust sampling reveals unsatisfactory dust conditions, it may be a reflection on their work. The temptation to "suppress" dust by reporting biased dust sampling results undoubtedly exists. Also, it may mean that dust sampling is tied to the places where other ventilation observations (air velocity, temperature, etc.) must be made. These may not be the best places to determine dust levels or the causes of dust.

The coal mines in South Africa operate their dust sampling on a far more satisfactory basis. All dust samples are taken by members of an independent team, who travel to the mines from central headquarters and can, without prejudice to themselves, report the true dust levels revealed by their samples. Dust sampling is their main task, and any other observations they may make are subsidiary to this.

At least two of the major gold mining groups in South Africa have moved some way towards independent dust sampling teams, but staffing and other problems do exist. However, I personally would strongly commend consideration of the merits of divorcing dust sampling from the departments responsible for dust control. The National Coal Board in Great Britain is an excellent example of this type of organization.

4.10 The Time Factor in Dust Sampling

The above sections have dealt with "WHY?", "WHERE?" and "WHO?". Let us now consider "WHEN?". Ideally dust sampling should cover any periods when dust exists which may be breathed by persons in the mine; conversely, there is little point in taking samples when no one is exposed to the dust. Certainly, the whole of the main working shifts should be adequately covered.

In South Africa our dust sampling personnel are generally also responsible for a number of other important routine ventilation measurements or investigations, so dust sampling is necessarily only done intermittently by them. There is a tendency for their observations in the working places to be taken mainly over a period of two to three hours, starting a couple of hours after the mining shift commences work, and finishing several hours earlier. This is connected with the fact that they are "officials" who traditionally go down the mine later and return earlier than the "miners." That this limited time period covered by dust sampling is unatisfactory is recognized, and some enterprising efforts to overcome it have been, and are being, made. It is a practice which should be avoided.

Finally, I would like to touch on the frequency of dust sampling. Broad overall surveys of the type listed in Section 4.2 are probably sufficient if carried out annually on each mine. If a survey has revealed serious dust conditions then a follow-up survey should be made as soon as appropriate remedial measures have been taken. There is a strong case for this type of survey being undertaken by a team independent of the mine.

The mine staff should spend most of their time on "trouble-shooting" dust sampling, with perhaps a smaller amount of time on "operational" sampling. In South Africa, by law, dust samples must be taken at least once every three months in each working place. Some of our mines, in practice, attempt to do this more frequently, say once per month. One cannot be dogmatic on the optimum frequency—I can only say "The more frequently, the better."

The insistence on sampling each place once every three months may not be the wisest policy. On some mines the number of men available for dust sampling is so limited (for economic reasons and also through recruiting problems) that it may mean that every place can only be sampled once per quarter. There appears to be a good case for sampling places regularly found to be satisfactory, less frequently (say once per year) and to sample the unsatisfactory places more frequently. However, the Mining Regulations will have to be amended before this can be done.

5. RECENT DEVELOPMENTS IN DUST SAMPLING

5.1 The Need for Improved Methods

In each country I visited on my recent tour, the need for improved methods is clearly recognized and many—although not all—concerned with this subject in South Africa feel the same.

The main reasons for this position appear to be:—

(a) Recognition that measurement of particle number concentration is not the best way to determine the danger to health of a dust.

(b) The need to sample only the "respirable fraction" of a dust, that is, only the particles which reach and then react in the human lung.

(c) The need to eliminate the extremely time-consuming examination of dust samples under the microscope. The errors involved in this process are often large.

It has always appeared important to me that measurements of dust should relate reasonably closely to the health hazard of the dust, if dust sampling is being undertaken to reduce the danger to health. This is often not achieved. There are, of course, situations where other types of measurement may need to be made; thus, in determining the performance of filter plants it may be necessary to measure the removal of particles of each size range; in such a case the number of particles in each range must obviously be measured in the intake and return air. But for the purposes of dust control one overall integrated measurement of the dust should be obtained, and the closer this relates to the health hazard of the dust the more meaningful it will be.

The International Pneumoconiosis Conference in Johannesburg in 1959, after careful examination of all the relevant information then available, recommended that:—

(a) Measurements of dust in pneumoconiosis studies should relate to the "respirable fraction" of the dust cloud. The recommended sampling curve was defined as effectively 100 per cent. for particle sizes of one micron and below; 50 per cent. for size 5 microns; and 0 per cent. for size 7 microns and greater. All these sizes refer to the equivalent diameter of unit density particles, but because of shape factors and the tendency of particles to be deposited on slides with their maximum cross-sectional area parallel to the slide, we in South Africa apply the same curve to quartz particles without a density correction. This respirable curve is shown in Fig. 3.

(b) In the light of present knowledge, dust measurements to assess the health hazard should be expressed as the average level of dustiness over an appropriate period of sampling, such as a shift.

(c) In the light of present available evidence, the best single descriptive parameter to measure is considered to be:—

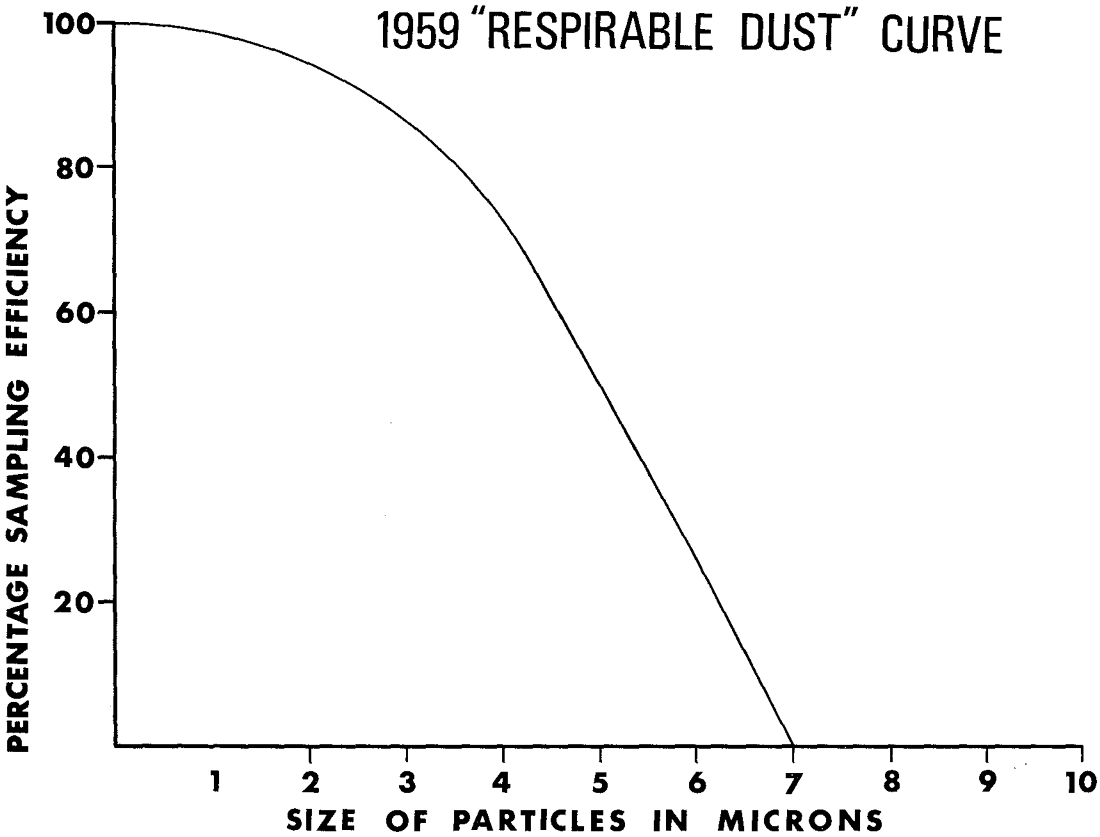

Fig. 3

(i) In the case of quartz dust, the surface area of the respirable dust.

(ii) In the case of coal dust, the mass of the respirable dust.

Since the above conference several countries have changed, or are about to change, to making respirable mass measurements, particularly in coal mines.

In 1966 Goldstein and Webster, of the South African Pneumoconiosis Research Unit, published their results on the intra-tracheal injection into rats of quartz particles of various size ranges.

Their results are summarized in Table IV.

The authors stated that the difference in reaction between the two latter groups was not pronounced. They also claimed that the degree of fibrosis was apparently related to the mass of quartz injected and not to the surface area. I have some reservations on this and consider it is highly desirable that they repeat their experiments using constant mass of the different size particles. But the important point is that the reaction produced is certainly *NOT* proportional to the number of particles injected. The correlation is a negative one—King in his classic experiments obtained the same result.

I submit, in view of the above, that to continue to measure dust on the basis of number concentration, and to ignore the effect of particle size within whatever size

TABLE IV

Size range-microns	Mass of dust injected — milligrams	Surface Area — square centimetres	Number of particles	Percentage of animals showing Group 3 or 4 fibrosis
Under 1	14	600	4000×10^8	6
1 to 3	46	600	100×10^8	77
2 to 5	93	600	5×10^8	85

range is included, (e.g. ½ to 5 microns) is manifestly unsound, if the health hazard of the dust is to be assessed.

In deciding what alternative parameter to use in future, if dust sampling is to be placed on a sounder scientific basis than it is at present, two important questions arise: —

(a) What *should* be measured?

(b) What *can* be measured?

It appears obvious that we should measure only the respirable dust, that is only the dust which reaches and remains in the lungs where it reacts to cause fibrosis. In the present state of knowledge the choice of respirable mass measurement for coal dust appears to be sound and is enjoying increasing support in many countries. The choice between respirable surface area (R.S.A.) and respirable mass for metalliferous mines is uncertain; I have been using respirable surface area measurements in my research dust sampling for more than five years. I must stress that the practical difficulties in measuring respirable mass in our gold mines are considerable, due to the very low mass concentrations we normally find—well under ½ mgm per cu m. Samplers driven by self-contained power supplies (e.g. batteries) have such a low sampling rate (2–10 litres per min) that sampling must continue for many hours to obtain a weighable sample. There are sampling instruments driven by compressed air with higher sampling rates, e.g. the Hexhlet or the BAT, but they have limited application in our mines as compressed air supplies are not always available where the dust samples should be taken. With the small mass of dust collected on the filter, weighing is time-consuming and may be of limited accuracy due to effects of humidity on the filter—to avoid this we use the "constant-weight" type of membrane filter for such work. Respirable mass measurements appear to me to be practicable when sampling extends over, say, a full shift, but at present I do not know of suitable methods of measuring this parameter in mines with sampling periods of the order of 5 to 10 minutes, which is what is needed for the types of dust sampling listed as requirements (b), (c) and (d) in Section 4.1. Certainly for short-period "trouble-shooting" dust sampling, which is so important, respirable mass is a very difficult parameter to measure.

On the other hand, apparatus (mentioned in Section 5.5. below) is currently available to take short-period samples (5 or 10 minutes) and to measure the respirable surface area of the samples automatically, rapidly and reliably.

If mines convert from sampling on a number concentration basis to respirable surface area or respirable mass it must be appreciated that there will be no direct relationship between the old parameter and the new. Thus places or processes which have high concentrations of very fine dust (we often obtain samples underground where over 90 per cent. of the particles visible under the high power optical microscope are less than ½ micron diameter) will, on the number concentration basis, be regarded as "dusty," while on the R.S.A. basis they will probably give a "low" measurement. Conversely, samples with a significant number of particles in the range of 2 to 5 microns may give a low result on the number concentration parameter but be regarded as high when assessed by R.S.A. or respirable mass. After starting dust sampling based on a new parameter it may take a little while to become accustomed to judging dust conditions in terms of the new basis.

Another important factor, ignored in most dust sampling, is the composition of the airborne dust. Firstly, it must be stressed that the composition of the airborne dust frequently differs quite significantly from the parent rock from which it is produced. Only a small fraction of the total airborne dust in our South African gold mines is quartz—commonly less than 30 per cent.—although quartz forms 60 to 80 per cent. of the original rock.

To determine the mass of quartz in airborne dust samples, we prefer the X-ray diffraction method. The samples for analysis are collected on a filter sampler. The membrane filters are placed directly into the X-ray apparatus and the result is obtained in about 5 minutes. Even if the concentration of quartz is as low as 0·05 mgm per cu m, a sample sufficient for analysis by this method can be collected in about an hour. Intercomparisons between two Laboratories using this method in South Africa have shown very satisfactory agreement. We are at present working on methods of spectrographic analysis of such samples for non-crystalline constituents.

To summarize my views on what should be measured in dust sampling in metalliferous mines, I suggest: —

For overall sampling (i.e. to determine the general level of dustiness in the mine as a whole)—Fixed position sampling over the whole shift, measuring either the respirable surface area or the respirable mass of the airborne dust, together with determination of the quartz in the sample.

For trouble-shooting sampling (i.e. to locate local sources of dust)—Measurement of respirable surface area, based on 5 or 10 minute samples, taken with a readily portable and easily operated instrument. The assessment of these samples should be rapid and automatic so that the results are available for use as soon after return to the surface as possible.

5.2 Developments in Great Britain

The need to convert to " respirable mass " measurements in their collieries is well recognized. A suitable instrument for this purpose has been developed by the Mining Research Establishment of the National Coal Board; it is known as the M.R.E. gravimetric sampler.

A small battery-operated pump aspirates 2 litres of air per minute through a horizontal plate elutriator, which only allows particles to pass through it according to the required sampling curve. The dust passing through the elutriator (that is, the respirable fraction of the dust) is collected on a glass fibre or other suitable filter in an easily removable support. The sampler operates automatically once it has been started. A built-in counter records the actual sampling time, and from this the volume sampled can be determined. The filter is weighed after use in order to determine the " respirable mass " of dust collected.

This instrument was thoroughly tested in a long series of field trials before commercial production was started. It is well designed and generally appears to operate satisfactorily. I have used it in some of our gold mines, but the sampling rate was too low to give a weighable sample in most cases, even after shift-long sampling. However, I understand it is being successfully used now in some of our collieries.

The National Coal Board and the Safety-in-Mines Research Establishment in Sheffield are both working on improved ways of determining the composition of the dust samples. Their preference seems to be for infra-red spectroscopy rather than X-ray detection, but this method is undoubtedly slower. Thus they estimate one operator could only handle about 10 samples per day on the spectroscope, whereas we find an operator can process nearly 100 samples per day on the X-ray diffraction instrument.

Efforts to develop automatic instruments for counting dust particles on slides, e.g. by scanning with a light beam, appear to have been abandoned in Great Britain.

5.3 Developments in United States of America

I mentioned earlier that the A.C.G.I.H. has now proposed standards based on respirable mass sampling of dusts containing quartz. This organization has not specified how such samples should be taken, but the

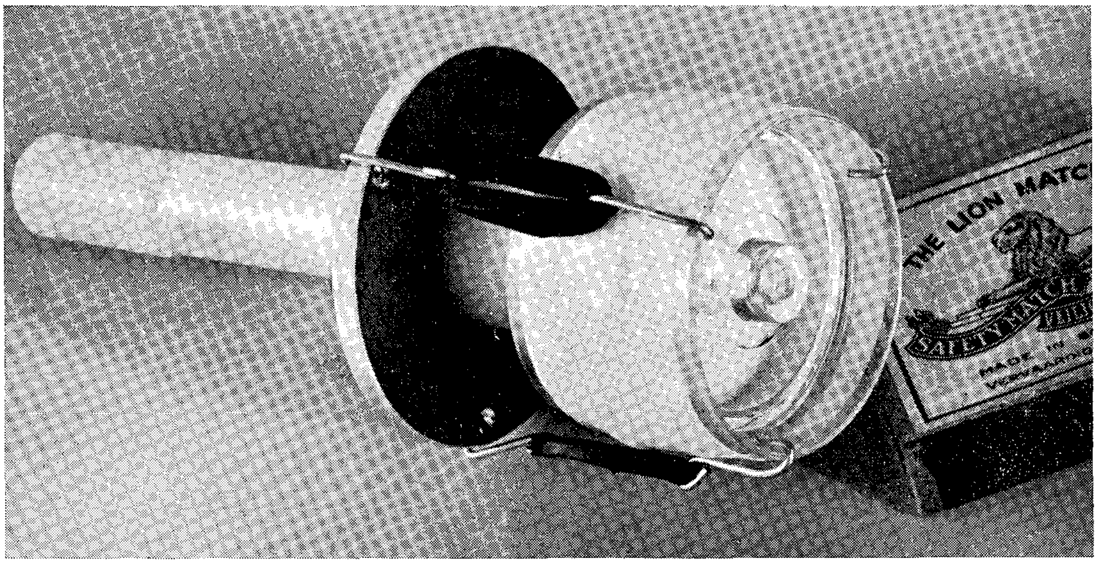

Fig. 4

American Respirable Mass Sampler

preference, amongst the workers I met, seems to be to use small cyclones to separate the non-respirable dust and to collect the respirable fraction on filter paper. Fig. 4 shows one instrument coming into common use. It is certainly light and easy to use.

Unfortunately the size-selecting characteristics of the cyclone are not the same as the desired curve laid down by the Johannesburg International Pneumoconiosis Conference. Also, the size-selecting characteristics of a cyclone separator depend very markedly on the flow rate through the cyclone; if this deviates even slightly from the specified rate, the effect on the particle size cut-off is quite large.

Although the adoption of respirable sampling by America is certainly a step in the right direction, it is a pity, in my opinion, that it may involve using a different "respirable curve" to that adopted at the Johannesburg Conference and which is utilized in the new instruments in Britain and South Africa. The need for International agreement on sampling methods is obvious.

The use of the midget impinger in America will obviously continue for some time, although the counting of the samples by microscope is laborious and open to many errors (as is all microscope counting). Also there is some lack of standardization of methods of using the impinger and assessing the samples. I was told of an experiment in which a number of expert industrial hygienists sampled a number of places side-by-side, each using their own midget impinger techniques. Their average results differed by a factor of 8 to 1, and individual samples covered a range of over 50 to 1.

In a commendable effort to overcome some of the disadvantages of microscope counting of impinger samples, Dr. Murray Jacobson of the Bureau of Mines has developed methods of using the Coulter counter. In this instrument the liquid containing the dust particles flows through a capillary tube. Two electrodes are located at either end of this tube. The resistance between the electrodes with particle-free electrolyte between them is first measured. When a particle is present in this electrolyte, the electrical resistance is changed; this change is measured and identifies the presence of the particle and its volume. The suspension must be extremely dilute so that only one particle at a time is in the capillary tube; however, this presents no problem.

Our Laboratories tried this instrument some years ago and found that in order to detect particles of about a micron size, a very small capillary tube had to be used. This was easily blocked if larger size particles were also present in the same sample, which is usually the case. Dr. Jacobson overcomes this difficulty by allowing the impinger samples to settle for some time before placing them in the Coulter counter; he then applies a correction for loss by settling of particles of different sizes.

Several firms in America have developed " aerosol photometers " which give continuous records of dust levels in the air passing through a light beam inside the instrument—the light from the particles is scattered in a forward direction and falls onto a photo-multiplier, whose reading actuates a recorder. I have one of these in my laboratory and find it extremely useful. However, it records all particles in the air (e.g. it is sensitive to cigarette smoke) and care is needed in interpreting the results. Two other makes are available which are even more sophisticated and determine the particle size as well as the total amount of dust.

5.4 Developments in Canada and Australia

I did not see any new developments in dust sampling equipment in either of these countries, but the authorities in each are well aware of the need for new methods and are watching developments in other countries, particularly South Africa, with much interest. I have already mentioned Dr. le Roux's fine achievements in determining the amount of quartz in very small quantities—to do this the sample is collected on a porous silver filter, which gives less background scattering than the membrane type filter we use. Also he uses a molybdenum target, instead of a copper target in the X-ray diffraction tube.

5.5 Developments in South Africa

The two major developments in South Africa in recent years have been the redesigning of the modified thermal precipitator and the invention of the Diffraction Size Analyser, known by its acronym D.I.S.A. I am confident that these two developments herald a new era in dust sampling and automated assessment of samples in our mines.

A joint Chamber of Mines/Corner House Laboratories committee designed the new form of modified thermal precipitator, but chief credit for many of its features must go to Mr. A. Nunlist of the Chamber of Mines. Fig. 5 illustrates this new instrument. Its principal design features are:—

(a) Fifteen samples of 5 minutes each are taken on a 3 in × 1 in slide.

(b) Moving the slide forward for the next sample, switching on the wire heating current, starting the motor for the diaphragm pump, switching on the indicator lamp and the timing device is all achieved by turning one control knob.

(c) The instrument switches itself off at the end of 5 minutes, after sampling 50 cu cm of air.

(d) The instrument can either sample all the dust in the air or only the respirable dust in accordance with the Johannesburg Conference specified curve.

(e) The sampling head is magnetically locked so that it cannot be opened underground.

(f) The nickel-cadmium battery locks automatically into position, making contact through two pins. It takes only a few seconds to insert or remove it.

(g) Including the carrying handle, the overall dimensions are $7\frac{1}{2}$ in × 7 in × $3\frac{1}{2}$ in and, including battery, it weighs under 5 lb.

Commercial production of a batch for field trials has now been completed. If these field trials are successful, the instrument will be considered as a replacement for the konimeter for routine dust sampling in South African gold mines.

D.I.S.A. (the Diffraction Size Analyser)

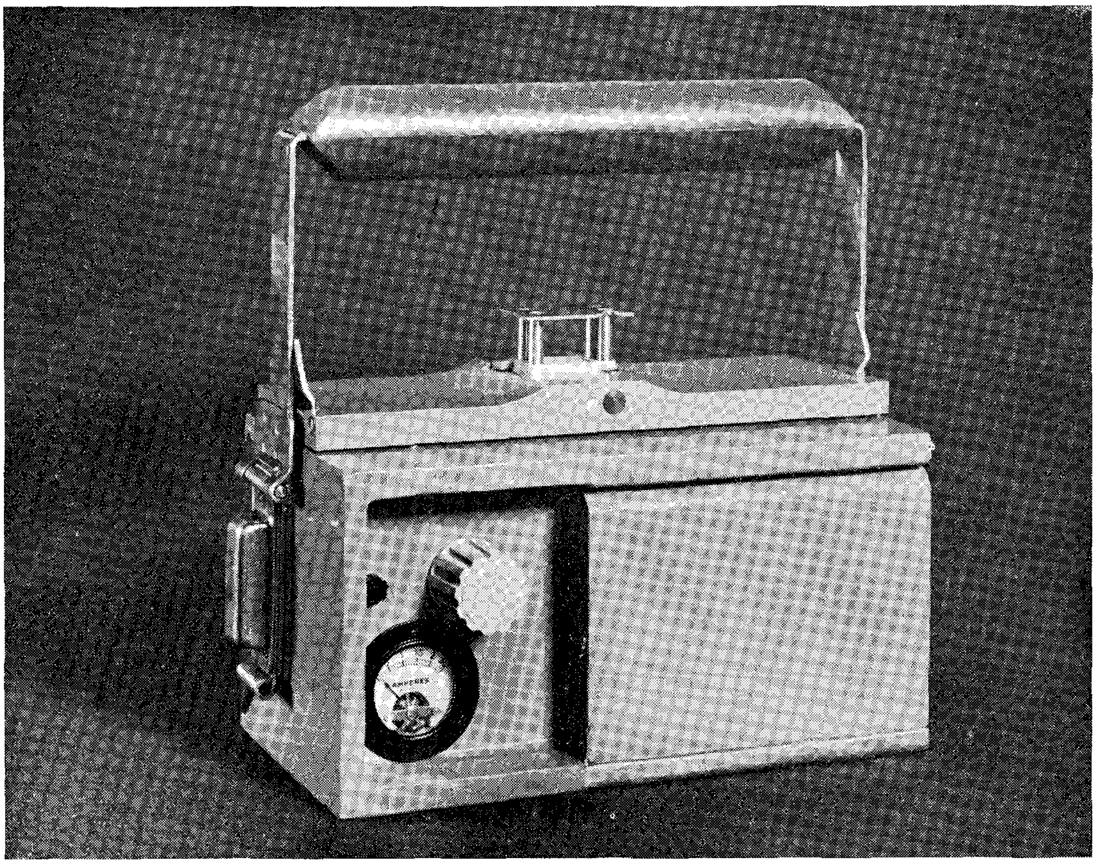

Fig. 5

Modified Thermal Precipitator

was invented by Mr. John Talbot of the Chamber of Mines of South Africa. This wonderful development, which has been described in our journal, is far ahead of any dust assessing instrument I know of. When Mr. Talbot's development of it had reached a certain stage a couple of years ago, we built our own version of it with Mr. Talbot's guidance and it has been in constant use in my laboratory ever since. We are now building a re-designed and improved version for the Mine Air Research Section of the Government Mining Engineers' Department. An even more advanced design is under development by Mr. Günter Dreibrodt, Head of our Instrument Development Workshop. Thus development of D.I.S.A. is still going on, but the basic principles remain unchanged.

To demonstrate D.I.S.A. to interested persons on my recent tour I made a ciné film illustrating its basic principles and showing it in operation. (This film was then screened at the meeting.)

I would like to say a few words on the time we have saved since introducing D.I.S.A. to assess our standard thermal precipitator samples, of which my dust research team takes many thousands per year. In all dust sampling work the major bottle-neck has always been the laborious and time-consuming assessment of the samples using the microscope. In much dust research work it has often been impossible or uneconomic to take as many samples as were desirable due to this limitation.

With conventional microscope counting and subsequent arithmetical calculation of the number concentration and the respirable surface area, it used to take us over an hour per sample (two slides). With D.I.S.A. the average time is about 7½ minutes per sample—this includes the time for aluminizing the slides, loading them into the holder, the measuring time in D.I.S.A. and the subsequent calculation of the results. These figures relate to handling a batch of 24 slides at a time. Instead of employing a team of five laboratory assistants on dust counting using microscopes, I now need only two assistants for dust assessment in my laboratory.

Apart from its spectacular time-saving, D.I.S.A. has other advantages over the microscope technique:—

(a) The whole sample is assessed, instead of only a small fraction of it as with the microscope. This fraction may or may not be representative.
(b) The "human" errors in counting and sizing particles are eliminated.
(c) There is no probability of fatigue or boredom affecting the results.
(d) Reproducibility of results is much greater—the same slide assessed a number of times in D.I.S.A. will give results agreeing within less than 1 per cent.
(e) Respirable surface area is determined directly without calculations.

With the old microscope technique, the time spent on the actual assessment of the slides formed nearly 90 per cent. of the total time of processing slides after receipt back at the laboratory. The balance of the time was spent on unloading the slides from the thermal precipitator heads, entering data, giving the slides the ignition and acid-treatment considered necessary before they are counted, and calculations. There was therefore no great incentive to reduce the time on these supplementary tasks.

But with D.I.S.A. assessment, these supplementary tasks now occupy more than half the total time required to process slides, and we have been seeking and introducing time-saving ideas. One such idea, for example, has been to insert a small locating pin in each thermal precipitator head, which fits into a small moon-shaped notch ground into each slide. The dust strip will thus lie in a pre-assigned position on the slide. This will eliminate the need to mark the strip with ink-dots to identify the position of the dust strip and will save the time needed to align the slides accurately in the D.I.S.A. holder.

The samples taken on the new modified thermal precipitators during the forthcoming field trials will all be assessed on the Chamber of Mines D.I.S.A. The samples will have to be transported to this central laboratory, which may mean that the results will not be available until about 24 hours or more after the sampler reaches surface. For a trial scheme, this is not serious. However, if these new sampling and assessing techniques eventually become the routine method on all gold mines, this delay may be undesirable.

If dust sampling by the mines is undertaken primarily as a trouble-shooting practice and with dust control as the main objective, it is essential, in my opinion, that the results be available without delay so that immediate control action can be started. If the results are available only say 24 or 48 hours later it is much more difficult to produce effective action. My view is that there should be one D.I.S.A. in each mining area—this would mean about six D.I.S.A.s to serve all our gold mines, one each located in Johannesburg, the East Rand (a mine near Springs), Far East Rand (Evander), West Rand (near Carletonville), Far West Rand (Klerksdorp area) and the Orange Free State. A despatch rider could collect all the samples in each area at lunch-hour (by which time the dust samplers have usually returned to surface), deliver them to the local D.I.S.A. centre, and have the results reported back, either telephonically or preferably by teleprinter, soon after 3 p.m. so that any necessary action can be taken that same afternoon. I feel that psychologically it will be far more effective to tell the production officials concerned that there was something wrong with their dust conditions that day (or of course, to tell them everything was satisfactory) than to delay such information by 24 hours or more—in the latter case it savours more of being a post-mortem!

However, there is no urgency at present for a decision on this matter, but it will certainly arise when the field trials have been completed.

5.6 Storage and Retrieval of Information

Over half-a-million dust samples are taken annually in our South African gold mines. Each mine records its own data and also, by agreement, submits monthly summaries to the Chamber of Mines. The results must also be available, on request, to Inspectors of Mines.

Some mines, in presenting the dust sampling data to the mine management, also report the previous dust count at the same working place, usually taken three months earlier, but beyond this there is generally little effort to analyse the data more fully.

Our present methods of recording such data and compiling returns are laborious. It is not easy to determine from them trends in dust levels or to determine the major sources of dust.

I feel that all dust data, including the actual dust level and details such as the place and time of sampling, the work in progress, the mining conditions (e.g. rock wet or dry), ventilation parameters, the number of men at work in the place, and so on should be fed into a computer.

The computer could be programmed to prepare from this data much useful information such as:—

(i) Monthly summaries of dust conditions in different parts of the mine, e.g. in development ends, at tips, etc.

(ii) Monthly summaries of dust associated with each type of mining operation, e.g. drilling, scraping, etc.

(iii) Time trends in dust levels.

(iv) Weekly averages of dust in particular sections together with statistically determined trends in these levels for each section — i.e. are dust concentrations increasing, decreasing or fluctuating?

(v) Weekly data on common causes of high counts (e.g. scraping dry) in each section.

In the Rand Mines Group we have started to examine the possibilities of doing this.

Fig. 7 shows the form we have drawn up to record the necessary data; this is being done on a trial basis at one of our mines (Harmony Gold Mine). When adequate experience in using the form has been gained, and it has been modified where necessary, we propose to programme a computer to extract a variety of information from the data fed to it. We feel confident that this will result in much more information becoming available from the data than is the case at present.

6. RECENT PROGRESS IN DUST CONTROL

Although I have devoted the bulk of this paper to discussing the strategy of dust sampling and recent developments in dust sampling, I do not wish to create the impresion that these are the major problems in dust research. The ultimate aim of all dust research must be to reduce dust concentrations wherever they are excessive, to ensure that as few persons as possible are exposed to undesirable levels.

As long as the main dust sampling instrument in use in South Africa (the konimeter) was the only practicable one available, it was desirable, since the limitations of the konimeter are clearly established, to spend time seeking improved methods. Now that these appear to be available, the great proportion of research effort should clearly be spent on seeking improved methods of dust control.

The Corner House Laboratories have been actively engaged in recent years seeking such improved methods wherever they appeared to be required. Some of this work has been sponsored by the South African Pneumoconiosis Research Unit and latterly by the Chamber of Mines, but the greater percentage of the work has been undertaken directly on behalf of the Rand Mines Group itself. The co-operation of the various mines in the Group has played an important part in this work.

I do not propose to quote here the full results of all our recent investigations. These I hope to publish in later papers. All I will do is to mention some of our main findings in recent years.

INSTRUCTIONS FOR FILLING IN FORM A21

A. If any of the information asked for was not recorded, leave the space blank.

B. Use 24-hour time system, e.g. 2 p.m. – 1400 hours.

C. IF YES, fill in $\boxed{1}$ IF NO, fill in $\boxed{0}$

Use only these numbers.

D. Fill in: Below 25 $\boxed{0}$ 50–100 $\boxed{2}$

25–50 $\boxed{1}$ Over 100 $\boxed{3}$

E. Fill in: Upcast $\boxed{0}$ Downcast $\boxed{1}$

F. Fill in: Yes $\boxed{1}$ No $\boxed{0}$

G. Fill in the number allocated.

H. Under work in progress, fill in the code numbers according to the list below. Enger the main work under 1; other work under 2.

Code	Operation
00	No work in progress.
10	Barring.
11	Watering down.
20	Lashing.
21	Lashing behind scatterpile.
23	Loading cars.
24	Tipping cars.
40	Scraping face.
41	Tipping into scraper path.
42	Scraping gulley.
43	Scraping behind scatterpile.
50	Drilling.
61	Timbering.
62	Stone-walling.
63	Bratticing.
65	Sweeping.
70	Blowing out holes/charging Anfex.
80	Driving winch.

Fig. 6

Form for recording data for feeding to computer.

COMPUTER STOPE FORM

Form: A21

	Instruction
See back of form for instructions	A
Date:	
Time: From	
Time: To	B
Gang Number	
Was broken rock sufficiently wet	C
Were all rockdrills in good condition	
Were hoses, sprays, or dripfeeds used	
Was water from these atomizing	
Average velocity	
Average Temperature: Wet	
Average Temperature: Dry	
Average kata	
Average running water pressure	D
Airflow direction	E
Nightshift cleaning	F
Dust sampling instrument number	
Observer	G
Recorder	
	H

Sampling Position	CODE	Work in progress 1		Work in progress 2		Dust Counts		
Face	1							
Face Middle	2							
Face Bottom	3							
Behind Scatterpile Top	4							
Behind scatterpile middle	5							
Behind scatterpile bottom	6							
A.C.T./other stope dev.	7							
Drive/gulley above	8							
Drive/gulley below	9							
Centre gulley	10							
Spare (Fill in code)								
Spare (Fill in code)								

Deep cell count

6.1 Drilling Dust

We have shown that if the leakage of compressed air into the front head of the rock-drill can be eliminated, its dust production is practically nil. Compressed air entering the front head causes dust in two ways. Firstly, it can then enter the axial hole in the drill steel, thus causing intermittent dry drilling resulting in very high dust production. Secondly, it can leave via the front head release ports, together with some of the water feeding the drill. This water will be "atomized" into very fine particles due to the high compressed air pressure and the resultant particles (often visible as a fog at the release ports) evaporate rapidly, before they can fall to the footwall. If this water contains dust in suspension, as it frequently does, these dust particles will be left in the air stream.

A typical dust content of the water used in our rock-drills is 5 to 10 million particles per cu cm, and measurements we have made of the amount of water atomized at the release ports show that over 100 cu cm per minute is a common figure. Thus 1,000 million or more particles of dust can be added to the air passing over a typical rock-drill in each minute.

This source of dust can be greatly reduced by the use of what we call locally the "sealed spline" rock-drill, i.e. one in which the air which used to leak down the splines in the piston into the front head in the older "exposed spline" type of drill is reduced. "Sealed spline" rock-drills are now in use in practically all mines in South Africa as a result of the Rand Mines research on this subject.

6.2 Scraping Dust

The use of scrapers to move broken rock either at the face or in strike or dip gulleys is very common. This is one of the major sources of dust in the transport of broken rock from the stopes to the surface. The problem has been tackled in two ways.

A very fine series of experiments by Mr. Jack Drummond and his team from Union Corporation showed that considerable reductions in dust production could be achieved by scraping at slower speeds—if necessary using two or more scraper shovels in tandem to maintain production—and by using the most suitable design and weight of scraper blades.

Our team developed the so-called drip-feed, in which pipes or hoses with holes or slots in them are installed at intervals of, say, 100 or 200 ft above the gulley and permit water to drip steadily onto the top of the rock pile being scraped. This water penetrates into the broken rock and if the right quantity is added, dust production is greatly reduced. It is a far more effective way of applying water than allowing a hose to run on the footwall, which was the previous method of dust control in scraping. Water applied in this way will fail to wet the top of the rock pile being scraped and, if this is dry, much dust is created. The ventilating air tends to dry out the rock on the top of the pile, hence the importance of applying water at this point. Fig. 7 shows a drip feed in use.

6.3 Wetting Down Prior to Shovelling

South African mining regulations require that the broken rock be thoroughly wetted before it is moved or worked upon in any way. The traditional way of doing this has been for the miner to use a water hose on his re-entry to the stope after the blast. As soon as he is satisfied that the rock pile is sufficiently wet, he will set his gang onto the usual operations to move out the broken rock. In theory, if later on during the shift dry rock is exposed, further water must be applied. However, there is much evidence that subsequent "wetting down" is frequently not done.

We have been investigating ways of wetting down off-shift—that is in the interval between the blast and the re-entry of the miner. This interval may be anything from about six to sixteen hours, depending on whether night-shift cleaning is used, or if cleaning is done on the normal (single) day shift. Our first experiments used sprays, fed from a central water supply pipe, discharging at about 10 ft intervals along the length of the stope face and situated 10 to 15 ft from the face. We found that if the spray nozzle was mounted up against the hanging, by attaching it to a convenient pack, it could withstand many blasts. We

Fig. 7

Drip Feed in Operation in a Scraper Gulley

showed that wetting down by this means was at least as effective as the conventional method for dust control during the subsequent cleaning shift. The sprays were operated by a timing device which opened and closed the main valve to the water supply line. However, production officials who examined this system considered it would be impracticable to use in practice, due to the necessity and difficulty of moving the numerous sprays forward regularly as the face advanced.

More recently we have been using " fog nozzles " located in the drive below the stope. These fog nozzles produce a spray of very fine water droplets which " float " up the stope face in the air stream ventilating it. The coarser water particles settle out fairly soon, thus wetting the broken rock near the bottom of the face, while the finer particles are carried further and wet the higher parts of the stope. Tests have shown that the effective distance wetted by the fog nozzle is dependent on the water pressure applied to the nozzle, on the air velocity up the stope face and on the time for which the nozzle operates. It should be possible to wet effectively about 100 ft length of stope face by this technique, if the air velocity is reasonably high.

Here again, our tests (which are still continuing) indicate that wetting down by this method is at least as effective as the conventional method. This technique does not excuse the miner from doing some wetting down on re-entry as there may well be some patches of unwetted rock (e.g. in dead spots around corners where the air stream and therefore the fog does not penetrate); however, his time spent on wetting down, which is often done begrudgingly, is considerably reduced. Also, because the fog operates for many hours during the off-shift period, the water has time to penetrate well into the broken rock and subsequent exposure of dry patches during cleaning operations is less likely to occur. A final, and potentially very great advantage of this technique of off-shift wetting down is that the evaporation of some of the fog will produce subsequent cooling of the stope during the working shift. Dr. Austen Whillier, of the Chamber of Mines Mining Research Laboratory, has forecast that the reduction in wet bulb temperature during the subsequent working shift may be of the order of several degrees Fahrenheit.

For such watering down as is done by the miner, an open 1 inch water hose is often used. This is a bad practice. The water does not spread over any appreciable area and the strong emerging jet has been shown to stir up a great deal of dust, before the wetting takes effect. Several mines have introduced spray nozzles to be used on the wetting down hose, which spread the water over a much greater area and prevent dust being stirred up. Their use is to be recommended. Another disadvantage of watering down hoses is that they are often left running on the footwall after use. This misuse of water has many disadvantages, including:—

(a) Wastage of water.

(b) Deterioration in temperature conditions.

(c) Flooding of drains and/or ore-passes.

(d) Overloading of pumping systems and storage dams.

(e) Washing away "fines" which contain much gold.

It should be appreciated that any water seen running out of a stope has probably not done much useful work in dust control. It is the water which remains adhering to the broken rock which is doing a useful job.

To overcome this misuse of water, we have introduced, on a trial basis, a cut-off valve fitted to the delivery of the water hose which stops the water flow as soon as the operator drops the hose. It is not unlike the valve at the delivery end of a petrol pump hose. However, cutting off the water at this point often meant that the water hose burst, if it was in poor condition or contained many "menders," or the mains water pressure was high. To meet these conditions, Mr. L. Rennie, Head of our Mechanical Workshop, designed and built a cheap, robust and effective pressure control valve, which reduces the supply pressure to a safe predetermined level—say, 40 to 60 psi. This gives an adequate water flow through the hose and spray nozzle, but avoids burst hoses. Fig. 8 shows the three components now recommended for wetting down, namely a spray head, the cut-off valve and the pressure control valve.

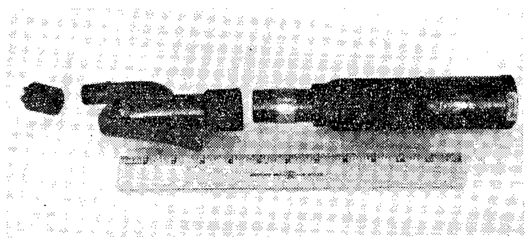

Fig. 8

Spray Head, Cut-off Valve and Pressure Reducing Valve for Use in Wetting Down

6.4 Tipping Dust

It has long been recognized that tips are a serious source of dust. Not only is their actual dust production often high, particularly if the tip naturally upcasts, but since they are commonly located in the haulages carrying the main intake air supply to the mine, they contaminate all the air feeding the stopes and other working places. On some mines the main tips are located in loops off the main haulages and thus do not contaminate the intake air—I do not know why this should not be standard practice.

The conventional, and very effective, method of dust control at tips is to exhaust a suitable quantity of air a few feet below the opening of the tip and feed this, via a fan and suitable ducting, to a filter plant. The conventional filtering material in our mines is closely woven flannel or similar material. It is often considered that the optimum downcast velocity at the mouth of the tip should be 100 fpm.

However, plants of this type consume considerable quantities of electricity, mostly at a time when the mine is at its peak load. The power cost is therefore high. As a result we have been investigating the optimum operating conditions. We have found that providing the downcast velocity at the mouth of the tip is 40 fpm, at all points, the dust control is as effective as at higher velocities. This lower velocity will mean a smaller pressure loss in the filter—if it is kept at the same size. Thus power consumption at tip filters could be less than a quarter of present values.

Our experiments also have shown that if the air velocity over the tip increases, the dust production from the tip decreases, as would be expected due to the extra dilution, but that this effect only applies up to a critical velocity, which appears to be about 500 fpm. If the air velocity increases above this figure, the dust counts *increase* again, despite the still higher amount of dilution. We have now observed this at a number of tips, but do not know exactly why this increased dust production occurs, although several hypotheses have been suggested. Any mine with such high velocities over tips should carefully examine the position.

Flannel is the traditional material for tip filtration, but it has several disadvantages. It is easily damaged, it is affected by fungi and by water, and cleaning the bags, unless expensive shaking mechanisms are built in, is laborious and often creates a lot of dust.

At the suggestion of Mr. John Terry, Chief Ventilation Officer of City Deep Limited, we have developed and tested on an experimental basis, open mesh polyurethane foam as a dust filtering material.

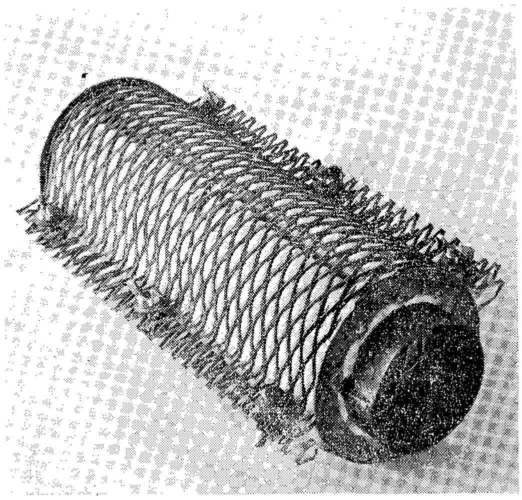

Fig. 9

*Cylindrical Version of Polyurethane Foam Filter**

It appears to be excellent in many ways. Our first installation utilized it in the form of a horizontal bed. The air velocity through it can be 100 fpm or more; it is not affected by fumes or water; it has a very long life; it is easily cleaned by simply hosing down *in situ* and it gives a satisfactory filtering efficiency—over 80 per cent. If a higher efficiency is required, two beds can be used in series. Our original installation has been in successful operation for over 18 months.

More recently, in collaboration with Harmony Gold Mining Company, polyurethane has been made up in the form of cylindrical filters. The material is wrapped around an inside former of "Expamet" and held in place by an external divided shell of the same material. A unit, 6 ft long and 30 in dia, filters 8,000 cfm. Fig. 9 shows a model of this type of filter. We have also successfully used polyurethane in a box-shaped filter (2 ft by 2 ft by 2 ft) at Blyvooruitzicht Gold Mining Company to deal with dust created at a stope tip. Conventional shaped

* We call these Polyurethane Foam Filters, "P.U.F.F."

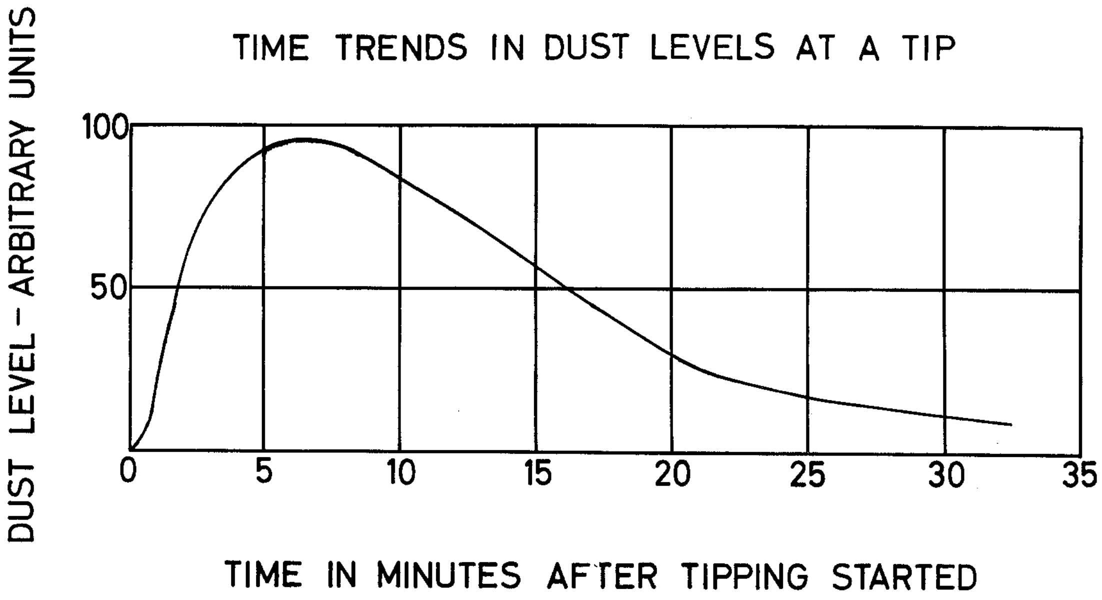

Fig. 10

and designed filters are not practicable at stope tips, but the box design worked well and was acceptable to the production personnel.

We also used the fog nozzles (described in Section 6.3) with success at stope tips at Blyvooruitzicht.

Using the aerosol photometer which I mentioned earlier, we have been studying time trends in dust production at a tip. The photometer enables us to record the dust levels instantaneously and continuously. At the one tip we have studied so far we were surprised to find that the dust did not reach a peak until six minutes after the 50-ton span had been tipped. Fig. 10 shows the time trends in dust levels at this tip—we do not know if this is typical of other tips. If it is typical, other methods of dust control, apart from filters, might be more economical, such as horizontal doors which are closed after tipping and before dust emerges from the mouth of the tip.

6.5 Mechanical Loaders

These can create a lot of dust if the rock pile is not sufficiently wetted. We fitted experimental sprays to a loader which operated automatically as the loader moved forward to make its next " bite " into the pile of broken rock—these sprays ensured that the pile of rock was always sufficiently wetted.

We also demonstrated that the conventional exhaust to mechanical loaders which discharges vertically downwards can stir up dust from the footwall if this is dry. It only requires a simple mechanical conversion to the exhaust to prevent this source of dust.

A third aspect of this study demonstrated that the cleanliness of the hoppers being filled by the mechanical loader played an important part in dust production. If they were dry and dirty, they caused dust; if they were clean and wet, there was little dust.

6.6 Dust Control in Longwall Stopes

Despite every effort at dust control, it often happens that dust levels increase steadily as air flows up a longwall system of stopes. In the case of increasing heat content, this situation is met today, in our deep mines, by installing heat exchangers at suitable points. These bring in chilled water from central cooling plants and cool the air flowing up the stope face, bringing it to acceptable temperature levels, so that it can effectively ventilate further faces.

Why don't we do the same thing with dust filtration?

We have recently carried out an experiment along these lines on one of our mines. We installed a cylindrical polyurethane foam filter at a suitable position in a stope, and connected it to a fan which forced about 10,000 cfm through the filter. This was about half the air flowing up this longwall system. The fan was switched off before blasting time and a cover plate put over the intake to the filter to prevent it being overloaded with blasting dust. The typical dust production per panel in this section was about 300 R.S.A., but in the panel fitted with the filter the dust content *decreased* by 250 R.S.A.. We feel that if such filters were installed at, say, every second level in a longwall system they would keep dust down to reasonable levels. This type of cylindrical filter stood up well to the daily blasts even though it was within 20 or 30 ft of the face, behind a pack. Moving it forward when necessary did not give any problems as it was light enough to be carried by two men. Where cooling coils are in use the polyurethane filter could operate from the same fan and, if placed on the intake side of the coils, would keep dust off them, thus improving the heat transfer characteristics.

6.7 The Future of Dust Control

I hope I have said enough in this section to show that there are ample opportunities to improve dust conditions in our mines and that when such problems are tackled logically a solution can usually be found.

A great deal of useful work can be done by the men on the mines themselves and I would like to urge members of this Society to play their full part in seeking and introducing new ideas in dust control.

Unfortunately, one of the greatest weaknesses in our system in South Africa is the failure to convey information obtained by research units to the men underground who can and should apply this information. In the Rand Mines Group, we appointed a " DUST LIAISON OFFICER " whose main function it is to visit the mines regularly, keeping them in the picture with regard to recent discoveries and at the same time to collect ideas and information from each mine which he can pass on to other mines. It is an idea which I think could well be introduced by other Groups.

ACKNOWLEDGEMENTS

I wish to acknowledge permission from the Managing Director of The Corner House Laboratories (1968) (Pty.) Limited to present this paper to the Society.

I would, however, like to go further than just this formal acknowledgement. I have been privileged to work for this Company for a number of years and I appreciate the facilities they have given me, including this recent study tour. I am indeed fortunate that from Mr. F. G. Hill, Dr. A. J. Orenstein, Mr. M. Barcza and the late Mr. Gordon Metcalfe, I have had wonderful support for the dust investigations carried out for the Group, some of which information has been used in this paper. Other work reported has been undertaken in terms of contracts with the Pneumoconiosis Research Unit and the Chamber of Mines of South Africa.

Finally, I wish to thank Dr. Gordon Smith, Chairman of the Organizing Committee of the Australian Pneumoconiosis Conference, members of his Committee and my various hosts in Australia for the much appreciated opportunity of attending the Conference and seeing some of the activities in this field in Australia.

VOTE OF THANKS

A VOTE OF THANKS TO MR. D. G. BEADLE WAS PROPOSED BY MR. P. H. KITTO AND SECONDED BY MR. R. S. J. du Toit

By P. H. Kitto

The latest issue of the *Mine Ventilation Society Journal* contains a reprint of an article giving suggestions on how to propose a vote of thanks to the author of a technical paper. It is clear from this that the vote of thanks should be short and complimentary to the author, and not constitute what amounts to a contribution to the paper. However, with your permission I should like to pass one or two comments on certain aspects of Mr. Beadle's excellent paper because I consider them to be particularly significant.

In the first place I agree with him wholeheartedly when he says that number count is a very poor measure of dust risk, and a very bad choice of what to measure for dust control purposes. I have had personal experience of dust counting and sizing for the past 31 years, and the more I see of it the less I like it. It is inaccurate, time-consuming and excessively boring. In the larger sizes it is not too bad a measure, because the large particles which do not constitute much of a hazard are few in number, but in the small sizes it is completely hopeless. The number counted depends on the microscope system used and the eyesight of the observer or on some lower size limit decided upon arbitrarily. No matter what method of cut-off is used, the result is inaccurate.

Weight is a good measure of dust risk, providing the larger particles can be removed in some approved and consistent manner, but it is not a sensitive measure, while surface area is easier to measure accurately, and is a more logical parameter to use both for dust control purposes, and as a measure of dust risk.

Referring to Mr. Beadle's description of Australian methods, I might add that it was a revelation to me to find out how dust conscious the average miner in Australia is, and how much has been achieved in dust control in spite of the inferior instruments and techniques used.

Mr. Beadle's paper contains too much material for me to make detailed comment in a vote of thanks, but I should like to end by endorsing his general recommendations for dust sampling in metalliferous mines. They are:

1. a long-term sampler for measuring either respirable surface area or respirable mass as a general control measure or monitor, and

2. a short-term sampler measuring respirable surface area to investigate local sources of dust.

In my opinion the second instrument would be used only, in routine work, when the first instrument had shown the general dust level to be too high. I am quite sure there would be no difficulty in getting the regulations amended to cater for this type of sampling.

I should like to congratulate Mr. Beadle on a first-class review of the present position regarding dust measurement and dust control, and have much pleasure in proposing a hearty vote of thanks to him for his presentation.

Mnr. R. S. J. du Toit

Mnr. die President, Dames en Here,

Dit is vir my 'n voorreg en 'n eer om mnr. Kitto se bedanking te beaam.

Mnr. Beadle is gewoonlik vóór met baie dinge en derhalwe verras hy ons dikwels met een of ander aspek van die stofprobleem.

Waar *hy* gewoonlik die verrasser is, het ek dit goed gedink om *hom* vandag te verras en wel deur hom in *Afrikaans* te bedank.