Fibrous Dust — Its Measurement and Control

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ABSTRACT

The strategy of fibrous dust sampling is discussed, various sampling methods are critically reviewed and their application to coal dust is demonstrated. Fibre counting is described in detail. An attempt is made to explain the basis of determining the threshold limit value of asbestos and other dusts.

The paper also discusses such dust control methods as enclosure of the process, effective local exhaust ventilation, segregation, substitution, wet processing and continuous monitoring of the return air for recirculation.

INTRODUCTION

THE ENORMOUS INCREASE in the production and industrial use of asbestos and fibrous glass during the past 50 years has resulted in markedly widened exposure to fibrous dust for a great number and variety of workers. In recent years, a great number of reports have been published which discuss the effects of fibrous glass dust in the lungs. The evidence derived from these investigations indicates that inhalation of fibrous glass particles causes only respiratory tract irritation and does not produce permanent lung damage. In contrast, asbestos fibres have been known, since the beginning of the century, to cause fibrosis of the lungs. The greater threat from asbestos, however, lies in its possible association with lung cancer. In the last decade, several authors[1,2,3,4] have called attention to the association between long-term (?) exposure to asbestos dust (especially crocidolite) and mesotheliomas of the pleura and peritoneum. Hence, we are far more concerned about asbestos dust than any other fibrous material.

The word asbestos refers to a variety of hydrated silicate minerals which can be split into relatively soft silky fibres. The known varieties of asbestos can be divided into two main groups on the basis of their crystalline structure: (1) pyroxenes (serpentine) — chrysotile; (2) amphiboles — crocidolite, amosite, tremolite, actinolite and anthophyllite. The types most commonly used are chrysotile (it accounts for 95 per cent of all the asbestos produced today), amosite and crocidolite. The fibrous form of chrysotile (chiefly produced in Canada and Russia) is retained even when broken into small particles; the fibres are long and needle-like, with a thickness of about 0.5μ and a length of 10-20μ. The diameter of the finest fibre is in the range of 150 to 400Å[5] (1Å - 10⁻⁸ cm). Crocidolite, the blue asbestos, is found in Cape Town and Transvaal, South Africa. It breaks down to give enormously strong, fine fibres which are used mostly as a thermal insulator. Amosite is similar to crocidolite in chemical composition, but is not as strong. It fuses at higher temperature[6] than crocidolite, and is often blended with other fibres. The world production of asbestos in 1968 was over 3 million tons per year, which is five times more than twenty years ago. Workers now are not only exposed in mining and textile industries, as in the past, but also in many other industries using asbestos-containing products. There are more than 3,000 recorded uses[7] of asbestos. The uses range from floor tile, which consumes hundreds of thousands of tons, to special filtration applications which may consume a relatively small tonnage annually. Thus, with the increasing use of asbestos minerals, there has come the realization of some very real hazards which must be clearly understood and controlled.

The object of this paper is to offer up-to-date knowledge on various methods of measuring asbestos dustiness in order to provide useful and reasonably accurate information for achieving adequate dust control. As the author is an engineer, the material in this paper is presented with an engineer's point of view. In the past, it has been difficult for engineers to understand the language and interpretations of medical and research scientists. The literature review has revealed to the author that there exists a big gap between the two groups. Engineers who are looking for answers to "why", "where" and "when" are, therefore, completely lost before they pay attention to "how" and "what". Answers to these questions have to be found.

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During his stay at the Elliot Lake Research Laboratory, Mr. Rajhans carried out studies on various dust sampling instruments, on surface area measurements and on the correlation of electronic scanner counts with the visual counts of konimeter slides. In 1967, he returned to Queen's University to resume his studies on critical velocities of mineral dusts and the development of a technique to measure radon daughters in uranium mines. In July 1968, he joined the Occupational Health Service of the Ontario Department of Health, where, at present, he is in charge of the dust control section.

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STRATEGY OF ASBESTOS DUST SAMPLING

The main objects of asbestos dust sampling are:

(i) To determine whether an atmosphere is potentially dangerous; and

(ii) to ascertain whether the dust control measures are working efficiently to maintain safe working conditions.

How does one define "potentially dangerous" and "safe working conditions"? Epidemiological studies are not only confusing but contradictory. Although there is now considerable acceptance of a causal relationship between asbestos dust and asbestosis, lung cancer and mesotheliomas, scientists still do not agree as to what levels of dust exposure are required for the production of the various diseases[6]. A dose too small to produce fibrosis may, nevertheless, lead to lung cancer. A dose large enough to produce asbestosis may cause malignancy if the worker does not die first from his pneumoconiosis[7]. Again, it is not known precisely how asbestos fibres cause disease or if all forms and sizes of asbestos fibres are equally hazardous. The reason that no definite answers to these questions have yet been found is due to the differences in experimental and human asbestosis. In spite of extensive research on experimental asbestosis, it has not been possible so far to reproduce the disease exactly[3]. The marked variations in respiratory tract response by various animal species and the difference in the number of fibres present in relation to the degree of fibrosis make it difficult to translate any conclusion from experimental asbestosis to human asbestosis[8]. However, the experimental asbestosis has given rise to two causation theories which throw some light on the relationship of particle size and pathogenicity in asbestosis. These are, respectively, the theory of mechanical damage and the theory of chemical action.

The theory of mechanical damage is supported by the observation[9] that the asbestos dust particles, smaller than 3 microns in length, had little or no reaction on pulmonary tissues. This was very much in contrast to silicosis, which is caused by silica dust of the same size. Thus, if asbestos particles no longer than 5 microns are inhaled, very little disease would develop and the process would advance more slowly than when the airborne particles contained a predominance of fibres of 10 to 50 microns[10].

The chemical theory, on the other hand, favours the view that fibrosis is the result of the chemical action of an unknown fibrogenic agent (could be silica) released by disintegration of asbestos bodies[1] (silicates). This theory takes into account the delayed development and progressive nature of asbestotic fibrosis. Nagelschmidt[11] observed in 1965 that in over half the asbestosis lungs from Great Britain and South Africa, practically no asbestos fibre was found, irrespective of the grade of fibrosis, and that asbestos dust was possibly dissolved in the lungs. Knox and Beattie[1] studied the particle-size distribution from the insoluble residues of the lungs of twenty-seven cases of asbestosis. The fibres in excess of 26 microns were found to have almost disappeared from the lung when the period between last exposure and death was more than eight years. Significant changes in the number of fibres of less than 5 microns and those of 5 to 15μ were not found. Demy and Alder[12] suggested that the tendency of the fibre to subdivide almost endlessly may account for the failure to find asbestos in presumptive cases unless the electron microscope is used or incineration is done. This may account for the claim that inhaled asbestos disappears from the lung, when in reality it is fragmented into submicroscopic particles.

Thus, if the chemical theory is accepted, then the smaller the fibre, the greater the solubility and hence a greater biological effect. On the basis of experiments, Holt *et al.*[13] concluded that chrysotile dust of small particle size (5μ), because it was easily engulfed by phagocytes, was capable of producing fibrosis. Thompson *et al.*[14], in 1966, showed that fibrosis may occur in the presence of few asbestos bodies and very small particles of asbestos dust, as well as with ultramicroscopic particles in the range of 200 - 250Å.

The increasing evidence of a relationship between asbestosis and carcinoma of the lung may postulate, in the future, a new dose-response relationship. We do not yet definitely know, however, whether asbestos has properties of primary carcinogenicity or whether its effect is entirely synergistic[7]. It has also been suggested by some authors[1] that the presence of polycyclic carbon compounds and trace metals in asbestos fibre may be carcinogenic. Gross *et al.*[15] observed that the presence of trace metals (nickel, chrome and cobalt) in the asbestos dust increases by 82, 145 and 34 per cent, respectively, when the dust is subjected to hammer milling.

In 1967, Collins[2] came up with another hypothesis. According to him, ingestion of fibres is probably as important as inhalation in the production of disease, and the 'asbestos corns' which occur in those who handle the material suggest that penetration of the skin occurs as well.

The question still remains as to what we should sample — total dust, long asbestos fibres (greater than 5μ in length), short asbestos fibres (less than 5μ in diameter) or metallic contents of the fibre. The obvious answer is that, in determining the dust hazard, both the total count of asbestos particles (including fibres) in the working environment and the prevalence of fibres of different lengths should be considered. The presence of trace metals and their carcinogenic qualities can, for the time being, be left to future confirmation.

THE BASIS FOR DETERMINING THE THRESHOLD LIMIT VALUE

The threshold limit value (TLV) is defined by the American Conference of Governmental Industrial Hygienists (A.C.G.I.H.) as the average of the time-weighted concentrations throughout the 8-hour daily operation under which it is believed that nearly all workers may be repeatedly exposed without adverse effect. Stockinger[16] in 1955 reviewed the TLV list of A.C.G.I.H. He showed that 42 per cent of the values were based on animal experiments and 11 per cent on human experiments, and that 4 per cent have the support of both, 33 per cent derive from industrial experience and 9 per cent were based on what was termed an "educated guess", with the origins of 1 per cent uncertain. In the case of asbestos dust, it is very difficult to apply the effective values established by animal experimenting to human exposure — due to the following reasons:

(1) The effect of asbestos dust causing asbestosis is recognizable only after a number of years. Hence, the animals have to be subjected to dust concentrations much higher than those which occur in industries to provide effective and rapidly assessable values.

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(2) There is a lack of general agreement about the theories on the formation of asbestosis.

In 1946, the A.S.G.I.H. proposed that the TLV for asbestos dust be set at 5 mppcf (million particles per cubic foot), as determined from impinger samples. This value was recommended by Dressen, Dallavalle, Edwards, Miller and Sayers[17] after a study of 541 employees in three asbestos textile plants using chrysotile asbestos. In 1967, Cooper[6] observed that the TLV of 5 mppcf for asbestos rests on shakier evidence than most TLVs. His chief argument was that the impinger counts include all dusts and that a large proportion of asbestos fibres have diameters below the resolving power of the light microscope and are not counted at all. He further reported that asbestosis appeared in insulating workers who were exposed to concentrations much below the time-weighted average of 5 mppcf. Leathart and Sanderson[18] also considered the TLV of 5 mppcf to be too high. In January of 1968, the A.C.G.I.H. issued the following statement:

"A limit to 5 mppcf, based on impinger samples counted by light-field techniques, is satisfactory to control exposures to most forms of asbestos. Crocidolite, however, has been shown to produce, in addition to the asbestotic inflammation, also mesothelioma. Since no safe limit can be established for this form of asbestos at this time, until more definitive data are obtained, it is recommended that workers exposed to crocidolite be equipped with air-supplied helmets." Since then, it has been suggested by various investigators that the TLVs for known or suspected carcinogens should be established as zero, as there can be no certainty of a concentration which is harmless to man. However, a zero concentration is meaningless from the point of view of an industrial hygienist trying to assess the efficiency of a dust control system. By using a sufficiently insensitive method and sufficiently impure reagents, an analyst can make almost any atmospheric concentration show no significant difference from the background concentration, which is the only meaningful definition of a zero concentration. On the other hand, if a definite concentration is aimed at, even though it is as low as the 5 fibres per ml currently being suggested by the A.C.G.I.H., in the case of asbestos dust it is possible for a scientist, by the selection of a sensitive method, to produce an answer with the agreed precision at this level.

In May, 1968, the A.C.G.I.H. proposed a TLV of 12 fibres per ml for asbestos fibres greater than 5 microns in length, as determined by the membrane filter technique[illegible]. Obviously, the committee accepted the theory of mechanical damage rather than the chemical action described earlier in this paper.

Our experience[illegible] showed that even in those places where visual impression sufficed to document the extremely dusty conditions and where impinger counts showed 10 to 15 times the TLV (proposed 2 mppcf — for total dust), the average fibre concentrations were much below the proposed TLV of 12 fibres ml. The British[illegible] have long been using a concentration of 4 fibres per millilitre (fibres longer than 5μ) as a goal in dust control.

The A.C.G.I.H., however, did not allow sufficient time for various investigators to critically analyse the TLV of 12 fibres ml. Now they are proposing to lower it to 5 fibres ml.

The author, however, is inclined to agree with German investigators[illegible], who decided to determine 'dust factors' rather than TLVs to evaluate working conditions. The 'dust factor' is determined by the following formula:

$$F = \frac{K_G \times K_A}{100} \quad \dots\dots\dots\dots\dots\dots \quad (1)$$

where F = dust factor

K_G = total concentration of all dust particles in ppcc of air (ppcc — particles per cubic centimeter)

K_A = asbestos fibre concentration in ppcc of air.

Kesting[24] suggested the following categories of describing safe limits:

F_1 = 0 – 20 .... no hazard
F_2 = 20 – 40 .... low hazard
F_3 = 40 – 60 .... medium hazard
F_4 = above 60 .... high hazard

According to him, an asbestos disease should not be expected with the range of $F = 0\text{-}20$. The proposed A.C.G.I.H. TLVs of 5 fibres per ml (membrane) or 2 mppcf (impinger), if and when substituted in equation (1), give: $F = 3.5$, which is within the range of F (0-20). Hence, the author strongly suggests that the TLV committee of the A.C.G.I.H. should follow the German concept of 'dust factor' and recommend both the total dust and fibre counts, in the case of asbestos dust, until we are reasonably sure about the relative hazards of fibres and other dust particles.

Furthermore, the 'dust factor' could be more applicable in the mining industry, where the total dust exposure may be higher than in the asbestos textile industry (mostly fine fibres), although 80-95 per cent of the dust may be parent rock dust which could be biologically relatively inert.

Before we finish discussing the subject of threshold limit values, I have one final comment to make:

The TLVs, or the safe limits established in various countries, are only meant to be used as a guide and should not be given a legal connotation. However, in my opinion, so long as these TLVs exist, there will be misinterpretations by those not fully informed of their nature. The TLV committee of the A.C.G.I.H. is aware of the fact that the TLVs have been used more absolutely than the recommendation justified.

It should further be understood that the values of TLVs have been, in some cases, decreased in the past and there is every possibility that they may be further reduced as fresh information becomes available, especially in the case of known or suspected carcinogens like asbestos.

SAMPLING INSTRUMENTS & TECHNIQUES

It has long been apparent that because the techniques of dust counting vary considerably, they need to be standardized. The writer has no intention to involve himself in the theories of commercially or otherwise available dust sampling instruments. Several comprehensive reviews on sampling instruments have been published in recent years[illegible]. An attempt is made here to describe an instrument which is not only very practical but also reasonably accurate in the case of fibre and total dust counting. Instruments measuring mass concentrations have very little application in the asbestos industries due to the following reasons:

(1) In most asbestos exposure, the asbestos is mixed with other dusts.

(2) When asbestos is shredded, the fibres tend to clump into balls which float around in the air; whether or not one of these balls are collected by the sampler would have a great influence on the mass concentration.

Furthermore, the threshold limit for asbestos dust, as mentioned earlier, is expressed in terms of fibre or total dust counts. The instruments capable of giving number counts are:

(a) Konimeter
(b) Impinger
(c) Thermal Precipitator
(d) Membrane Filter

The number counts are generally expressed in terms of either million particles per cubic foot (mppcf) or the number of particles per cubic centimeter (ppcc). In the case of fibres, the unit commonly used is fibres per cubic centimeter (fpcc). All of the instruments mentioned above have been described many times[26][27]. A common characteristic is the aspiration of a quantity of air for measurement and its subsequent examination and counting under the microscope. The aspiration volume could vary from 2.5 cc in the case of the konimeter to about 500,000 cc in the case of the impinger. Let us now examine the advantages and disadvantages of these instruments in fibrous dust counting. Fibres are almost universally defined as those particles with a length three or more times their width; that is, they have an aspect ratio of at least three.

Konimeter

In the case of the konimeter, the entire sampling process takes only a fraction of a second (snap sampling) and can lead to quite erroneous results in situations of varying concentrations. Various authors[26] have tried to correlate konimeter counts with other instruments. The results of several tests on coal dust show, on the average, twice the dust concentration as compared to that determined with the thermal precipitator. The higher counts were mainly due to the shattering effect of the impacting velocity. The instantaneous values of the konimeter results in the case of fibrous dust were observed by Kesting[24] in 1966. He concluded that: "The extraordinary divergence of individual results obtained from measurements near a spinning machine were repeatedly noted. A single break in a thread occurring at a spindle rotating at several thousand rpm shortly before measurement produced such high values that the total picture of dust concentration is negatively distorted. On the other hand, a period with few thread breaks can supply excessively favourable data. Furthermore, in two plants with almost identical machinery, it was by no means rare that results were favourable in one and alarming in the other. This was due to the different quality of the raw material processed, and also to the different degree to which different factories approach the spinning limit of the materials." Walter[23] found fibres up to 100μ in length in the suspended dust samples taken with the konimeter at plants processing asbestos textiles. The still longer fibres, which are usually present at higher concentrations, are not aspirated by the konimeter. He counted both the total dust and asbestos fibres (with an average length of 1-2μ) under the konimeter microscope. It was shown that optical evaluation was costly and time-consuming for the ever-expanding series measurements because of the considerable fluctuations of the dust situation. Two konimeter samples with an equal number of particles differed greatly in fibre count. Walter[23] then concluded that the use of the sectional counting method for such konimeter samples of asbestos fibres is highly problematical and leads to major errors. He also observed that the percentage of asbestos fibres in the total dust counts varied from 1 to 50 per cent, depending on the various stages of the working process (e.g. preparation, carding, spinning and wearing).

Counting and sizing under the optical microscope inherently leads to erroneous results, particularly with konimeter counts. Because the slides of this instrument are coated with a more or less thick layer of vaseline as an adhesive agent, the particles are less visible than in the samples of other number counting instruments. For example, the thermal precipitator samples, which do not have such a layer, permit the recognition and counting of particles smaller than can be recognized in konimeter samples[24] when studied under identical optical conditions.

The konimeter, however, could be a very practical instrument if the sampling is to be carried out in the respiratory zone of the worker. The instrument is especially valuable if a microscope is attached to the konimeter (e.g. Bausch and Lomb dust counter). An instant and rough estimate of dust concentration in the working place can then be obtained.

In any case, the konimeter slides should not be heat-treated before counting asbestos fibres. An experiment[29] in the past has shown that asbestos fibres, when heated to 700°C, lose their crystalline and fibrous form and become amorphous.

Impingers

There are two types of impingers currently being used in the industries — the Greenburg-Smith (rate of flow 1 cu.ft/min) and a smaller version, the midget impinger (rate of flow 0.1 cfm). *Figure 1* shows the Greenburg-Smith impinger, which is extensively used by the Environmental Health Branch of the Ontario Department of Health. The technique of sampling, which was originally developed for the evaluation of siliceous dust, has been well described by

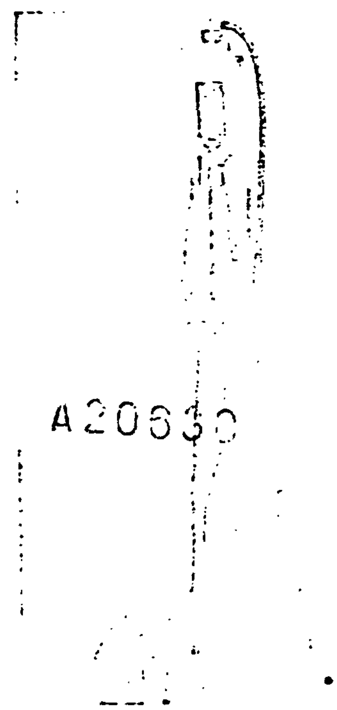

FIGURE 1 — Sampling with the Greenburg-Smith Impinger.

FIGURE 2 — Electronmicrograph of Asbestos Fibres.

Drinker and Hatch[?]. Davies *et al.*[?] observed that with coal dust the impinger was apt to give erroneously high dust concentrations due to the breaking up of coal dust aggregates originally present in the air. The counts were five to eight times higher than those determined by the thermal precipitator for the same environment. This compares favourably with our experience considering that Davies made high-power, dark-field counts on cells evaporated to dryness.

When the method was first applied to determine asbestos exposure, both total dust and fibres were counted. Because too few fibres were seen, due to the light-field counting method and a low magnification (16-mm objective), Ayer *et al.*[?] observed in 1965 that even when all particles with a length to width ratio of 3 or greater were counted as fibres, the fibre count was usually less than 10 per cent of the total impinger dust count. They further stated that "most airborne fibres are hundredths to tenths of a micron in diameter even when many microns long". (An electronmicrograph of a chrysotile asbestos dust sample is shown in *Figure 2*.) "Fibres of such small diameter may not be efficiently collected by the impinger. Of the collected, many of them would not settle to the bottom of the counting cell in the allotted settling time, and those that did settle would usually not be visible by the microscopic technique employed. Thus, it is not surprising that fibre counts with a 16-mm objective are low." Our experience[?] with the impinger technique in the past has shown that the fibres have a tendency to curl up in the water suspension and look like particles.

In 1965, Lynch and Ayer[?] analysed the results of environmental surveys of nine asbestos textile plants. Their conclusion was that the impinger is as convenient as any other instrument and, in view of the large variance found in the environment, no less accurate than other instruments. They, however, agreed that the impinger counts are dominated by grains and that determining a hygiene criteria based on these counts could be misleading, because the fibres are thought to be the causes of disease.

Thermal Precipitator

The thermal precipitator is regarded in many countries, including the U.K., as the standard instrument for atmospheric dust estimation. For some reason, however, it has not been very popular on this continent. The instrument was first developed by Bancroft[?] in 1920, and in 1936 a modified form was patented by Green, Watson, Whytlaw, Gray and Lomar[?]. Since then, several modifications to the standard design have been introduced[?]. The Long Running Thermal precipitator (L.R.T.P.), developed by Hamilton[?] in 1956, is supposed to be the most suitable for particles above 0.5 to 1μ. The instrument has long been used for coal dust sampling in the U.K. It is considered to be of uniformly high efficiency for coal dust particles below a 5-micron aerodynamic size. The results obtained are in close agreement with those obtained with the membrane filter (described later). For fibre counts, the instrument is very useful because it uses the principles of both settlement and thermal precipitation, in contrast to thermal precipitation only, as used by the standard thermal precipitator, which rarely collects fibres above 10 microns[?]. Holmes[?] observed fibres up to 300 microns in length in the samples collected by the L.R.T.P. Furthermore, the deposit covered an area ½ inch square and was therefore easier to count than the standard thermal precipitator deposit.

One great advantage of a thermal precipitator is that the samples are mounted dry and, therefore, very large magnification can be used to see the fibres. This is in contrast to impingers, where, because the mounting medium is a liquid, the limit is a 16-mm objective. Holmes[?] has used a 4-mm objective to count fibres between 5μ and 100μ in length. Roach[36] reported using a 2-mm oil immersion objective successfully. His conclusion was that the higher the resolving power of the microscope, the more fibres are seen. The mean of forty thermal precipitator results, in mppcf and ppcc, is shown in comparison with the results of other samplers in Table I (Roach[?]). The thermal precipitator counts are higher than other counts. However, the thermal precipitator is effective only at a slow rate (2 cc/min.) and therefore requires a long time (30 minutes or more) to take a sample considered reasonable for counting.

It has also been suggested that a horizontal elutriator be used on the intake side of a thermal precipitator. The purpose of this elutriator is to pass only the respirable fraction of dust to the collector side. The validity of this elutriator is, however, doubtful when sampling fibrous dust, as the shape factor becomes important.

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TABLE I—Number of Airborne Particles — Disintegrator Plant

Instrument	Microscope Objective	All Visible Particles	
		mppcf	ppcc
Midget Impinger	16 mm	1.1	38
Membrane Filter	16 mm	0.4	13
	4 mm	0.6	21
	2 mm	2.2	77
Thermal Precipitator	16 mm	2.8	98
	4 mm	5.5	195
	2 mm	10.8	382
Foyco Counter	—	20.9	740

N. B. mppcf = millions of particles per cubic foot
ppcc = particles per cubic centimeter

Membrane Filter Technique

A comprehensive review of the properties of various types of membrane filters has been published recently by the writer[37]. Fraser[38], in 1953, was probably the first to apply the membrane filter technique to the sampling and measurement of dust particles. In 1959, Kruse and Bianconi[39] applied the technique to coal dust. The coal particles were made visible under the microscope by treating a portion of the filter with immersion oil having a refractive index of 1.5. It was established that, by using a flow rate of 0.01 cfm and 950x magnification for counting, accurate counts of as high as 500 mppcf could be made. In fifty-three comparative tests, coal dust concentrations agreed closely with those obtained using the thermal precipitator but were, on the average, one-third of those determined by the midget impinger and one-half of those determined by the konimeter. The detailed technique for fibre counts was, however, first reported in 1965 by Ayer *et al.*[31] and Holmes[35] simultaneously. The main variations are shown in Table II.

Holmes[35] gave the following formula for the evaluation of the dust sample:

$$\text{Dust concentration} = \frac{D^2}{d^2} \times \frac{N}{n} \times \frac{1}{V} \qquad (2)$$

D = Diameter of the membrane sample area
d = Diameter of each field of view
V = volume of sample (cc)
N = number of fibres counted
n = number of fields observed

A slight modification over Ayer *et al.*'s technique was published by Edwards and Lynch[40] in 1968. The Occupational Health Laboratory of the Ontario Department of Health closely follows the technique described by Edward and Lynch. However, several modifications, based on experience and difficulties encountered in industry, have been introduced. The process is described here in detail.

Air Sampling

Air is drawn through a 37-mm-diameter cellulose acetate filter (Metricel, GA-6, pore size 0.45μ; Gelman Instrument Co.) at a flow rate of approximately 25 litres per minute. The face of the plastic filter holder is cut away, permitting air to strike the whole area of the membrane filter. In this way, an equal distribution of fibres is obtained on the filter. The holder, filter and pump are shown in *Figure 3*. *Figure 4* shows a close-up of the filter, with the collected sample on it.

Asbestos Fibre Count Method

A microscope (American Optical Co.) equipped with phase-contrast optics is used to count the fibres. The magnification is 400. *Figure 5* shows the microscope, with the photomicrograph equipment attached.

The filter containing the fibres is placed on a hard surface and a wedge-shaped section, representing about one-tenth of the total area, is cut out with a razor blade (see *Figure 4*). The section is placed on a glass microscope slide and a few drops of the solvent mixture is added to cover the entire wedge (*Figure 6*).

The solvent mixture is a 1:1 solution of diethyl oxylate: dimethyl phthalate containing about 0.1 gram of the membrane filter per ml of the above solution.

TABLE II—Comparison of Detailed Techniques for Fibre Counts

Ayer et al.[31]	Holmes[35]
(1) **Sampling Medium** — "Millipore", Type "AA", pore size 0.8 μ	(1) "Millipore", Type "HA", pore size 0.45 ± 0.02μ
(2) **Sampling Head** — Plastic holder containing a 37-mm-diameter filter with an open area approximately 850 mm².	(2) Aluminum holder with a 20-mm-diameter filter
(3) **Sampling Rate** — 2000 cc/min.	(3) 200 cc/min.
(4) **Liquid** used for making the filter transparent — a mixture of 50 per cent dimethyl phthalate and 50 per cent diethyl oxylate	(4) A few drops of glycerol triacetate
(5) **Mounting Technique:** A segment was cut from the filter, placed face up on a microscope slide, rendered transparent and a coverslip placed on top.	(5) The dust deposited on the MF surface was fixed by applying a drop of Perspex solution (0.05 per cent in chloroform) to the membrane and evaporating it quickly by pulling clean air through. A few drops of clearing agent (as mentioned in (4)) placed on a clean microscope slide, then place the filter on top of the clearing agent and cover with a clean 1-in.-diameter coverslip.
(6) **Counting Technique:** A 4-mm (43-x) phase-contrast objective, supposed to have the resolution limit of ½ micron. A Porton eyepiece (10x) graticule was used to define the counting field and to assist in making length judgment of fibres. Phase-contrast illumination was used for all counts. Three modes of counting were used: (a) counting all fibres with length to width ratios of 3 or greater; (b) counting only those fibres longer than 5 microns; (c) counting only those fibres longer than 10 microns.	(6) The cleaned samples were observed at a magnification of 500x. The sizing was carried out by incorporating a "Patterson Globe and Circle" graticule in one of the eyepieces. The graticule was calibrated against a suitable stage micrometer. The size ranges counted were: (a) 5 – 10μ (b) 10 – 20μ (c) 20 – 50μ (d) 50 – 100μ

The index of refraction of this medium is about 1.3. The wedge of filter containing the sample dissolves in about 10 minutes. A faint shadow of the wedge is visible after dissolution. This shadow is used to line up the field on the microscope.

A cover glass is placed over the sample on the slide and placed on the microscope stage (see *Figure 7*). All fibres greater than 5 microns in the eyepiece graticule (5,000 μ² area) are counted. Five different fields, selected at random, are counted and the results averaged.

$$\text{Total fibres} > 5 \text{ microns per cc of air} = \frac{\text{Average graticule count} \times 1071 \text{ mm}^2}{\text{cc of air samples} \times 5000\ \mu^2 \text{ or } 0.005 \text{ mm}^2}$$

Figure 8 shows a microphotograph of a slide seen through the phase-contrast microscope at a magnification of 400.

To summarize, the MF technique has the following advantages over other dust counting methods:

(1) The membrane filter has a pore size of 0.45 micron, which is quite adequate for trapping fibres in the length range of 5-100 microns. It has also been reported[26] that membrane filters can collect particulates as small as 0.1μ in diameter with practically 100 per cent efficiency.

(2) The fibres are collected on the surface and the filter can be examined directly with incident light, rendered transparent and examined by high-resolution transmitted-light microscopy; or the particles may be transferred to an electron microscope grid and examined by electron microscopy[36]. The electron microscope gives about four times as high a fibre count as the 4-mm objective with phase contrast.

(3) Higher sampling rates than are possible with the other instruments can be used, enabling large volumes of air to be filtered in a reasonable time. Addingley[27] reported that a variation in air sampling rate between 10 cc and 500 cc. min. does not effect the results. This enables samples to be taken over short or long periods, and is quite convenient as compared to the rather long periods of at least 30 minutes required with a thermal precipitator.

(4) The sampling head is small enough for incorporation in a personal sampler to give a more representative assessment of the true health hazard to which an operator is subjected. A personal sampler with a pump and motor which can be carried in a pocket and a membrane filter which can be mounted in the lapel of a coat is described by Hunt and Ellisch[41].

(5) Hand pumps can be used where electric supply is inconvenient.

(6) According to Addingley[27], the MF technique is of particular value in the estimation of mixed dusts containing asbestos, such as those found in the manufacture of brake linings. The asbestos component can be distinguished from that of the resins and fillers and counted fairly accurately under the microscope.

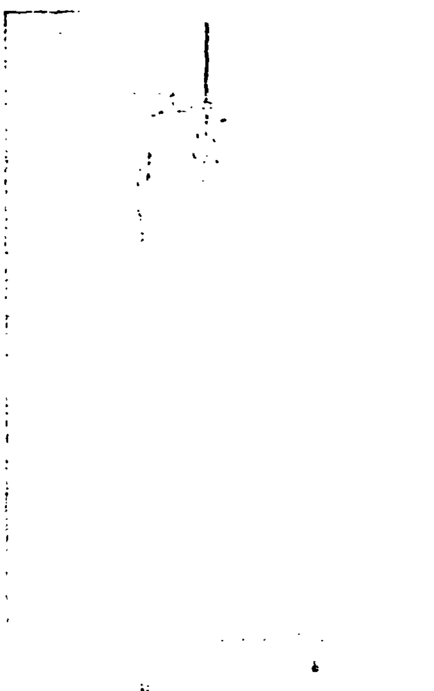

FIGURE 3 — Membrane Filter Sampling Technique Used by the Occupational Health Service of the Ontario Department of Health.

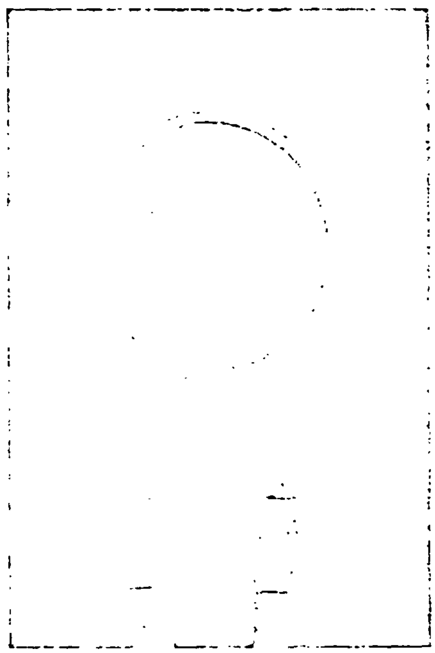

FIGURE 4 — A Close-Up of the Membrane Filter, with the Asbestos Sample on it. A piece is cut for viewing under the microscope (see text).

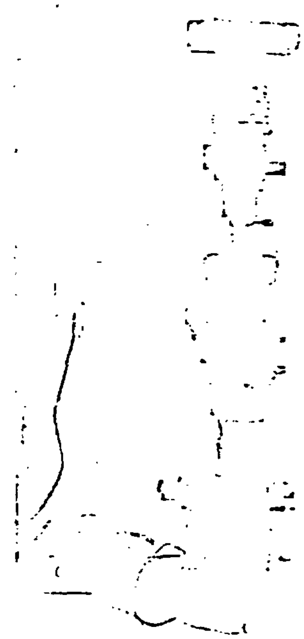

FIGURE 5 — Phase-Contrast Microscope, with Photomicrograph Equipment Attached.

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FIGURE 6 — A Wedge-Shaped Section (about 1/10th of the total MF area) Placed on a Microscope Slide.

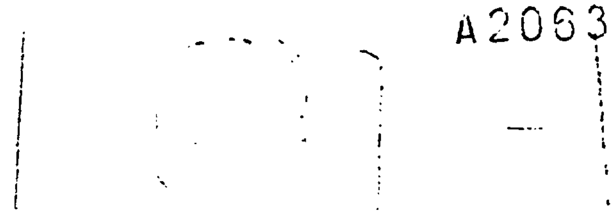

FIGURE 7 — A Cover Glass Placed on the Transparent MF Sample.

TABLE III—Number of Airborne 'Fibres'—Disintegrator Plant

Instrument	Microscope Objective	Length > 5μ Particle length > 3 x width	
		mfpcf	fpcc
Midget Impinger	16 mm	0.11	4
Membrane Filter	16 mm 4 mm 2 mm	0.06 0.37 0.48	2 13 17
Thermal Precipitator .	16 mm 4 mm 2 mm	0.31 0.54 0.57	11 19 20
Royco Counter.........	—	(0.12)	(4)

N.B. mfpcf = millions of fibres per cubic foot
fpcc = fibres per cubic centimeter

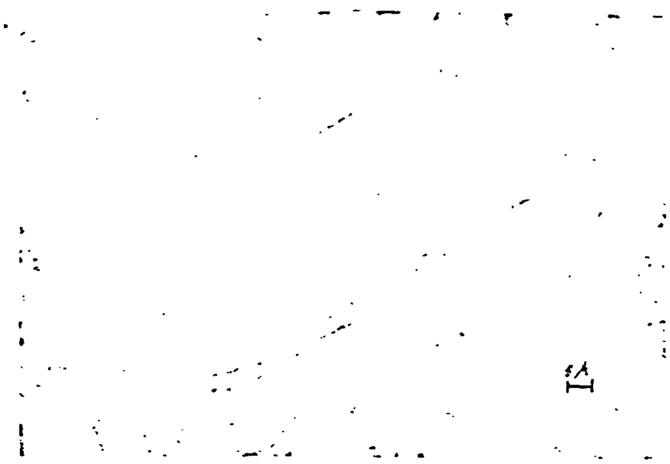

FIGURE 8 — Microphotograph of a Sample Seen Through the Phase-Contrast Microscope.

One common disadvantage of all these methods has always been the laborious and time-consuming assessment of the samples under the microscope. It is difficult to eliminate human errors in counting and sizing particles. Fatigue or boredom probably affects the results. Hence, there is liable to be a rapid turnover of operators. Lynch and Ayer[illegible] compared fibre counts by the impinger and membrane filter. The counts at 430x phase contrast were eight times those found on comparable impinger samples at 100x light field. In 1967, G. Knight *et al.*[illegible] observed that the total dust counts by the midget impinger were usually one quarter those of the thermal precipitator. The fibre counts of the impinger, on the other hand, were half those of the thermal precipitator. Roach[illegible], after comparing various instruments, concluded that, in the case of fibrous dust (Table III), the thermal precipitator had the greatest collecting efficiency. His reasoning was that the thin fibres were not collected efficiently by the impinger, and in the membrane filter the contrast between the filters and the mounting medium is poor, making them difficult to see. This difficulty was later eliminated by using a phase-contrast microscope in the membrane filter technique.

Thus, from the above discussion, one may conclude that the MF technique using the phase-contrast microscope is the most practical developed to date for fibre dust counting.

DUST CONTROL METHODS

Because asbestos exposures are of infinite types and intensities, each problem must be studied individually before dust control measures, requiring considerable engineering experience and ingenuity, can be designed or recommended. Their control presents a major problem.

Applications of various dust control methods to specific asbestos industries are discussed elsewhere in this paper. The following are general principles suggested by our service to minimize asbestos dust exposure:

(1) Substitution: The only sure way to prevent asbestos disease is not to use asbestos. Thus, in all cases, extensive efforts should be made to find substitutes. A large number of non-asbestos-containing materials, such as rock wool and glass wool, may be used. Cork and expanded polystyrene can be used for low-temperature insulation and, as one scientist has said, "This is the age of synthetic materials, and man surely can develop a substitute for asbestos which has all its useful properties without its harmful effects."

Harries[illegible] reported in 1967 that hot and cold water pipes and ventilation ducts in naval ships can very effectively be insulated with glass fibre cloth, felt canvas or polyurethane insulation rather than with asbestos cloth. Sound-insulating asbestos boards were replaced by those made of glass fibre and this material also had taken the place of sprayed asbestos as an environmental insulation for steel deckheads and bulkheads.

In those places where immediate substitutes cannot be found (e.g. machines subjected to long periods of intense heat, vibration and mechanical trauma), an attempt should be made to use asbestos cloth treated with a dust suppressant or coated with an impermeable plastic film.

(2) Segregation: It is possible, with suitable planning, to arrange that work producing high concentrations of asbestos dust be done in isolation. This reduces the exposure of 'neighbourhood workers' to a minimum. This is especially useful in the case of asbestos spraying operations, where the chances of contaminating adjacent areas are considered to be maximum. A study[illegible] has shown that the dust counts 15 to 30 feet from the spraying operation were found to range from 5 to 10 times the TLV.

"Asbestos worker" and "neighbourhood worker" should be clearly defined. "Asbestos worker" is a man directly employed using asbestos materials continuously or frequently. "Neighbourhood workers" are those who work in close proximity to the former without being directly involved with the use of asbestos.

One such case in which both substitution and segregation could have been effectively used was investigated by the writer last summer (1969). The case history is published in the March, 1970 issue of *Occupational Health in Ontario*. Humidifier plates for use in domestic boilers were being made from blue asbestos (crocidolite). The area where the crocidolite was being used was located in the east end of a cafeteria. The cafeteria, which had a coffee machine, a cigarette machine and a coke machine, was used daily by about 10 persons. The floor and the machines in the area were found to be covered with blue fibres.

When the company was asked to find a substitute, they said that, after 18 months of research, they had found crocidolite to be best suited for making humidifier plates. However, the company agreed to provide adequate dust control measures including segregation of the area.

(3) **Dust Suppression:** This includes such methods as enclosure of the process, as far as is possible, installation of adequate and effective local exhaust ventilation, automation of the process and wet processing. In some cases, materials containing or made from asbestos are impregnated with dust-binding agents. This helps reduce the dissemination of dust to a considerable degree.

As a rule, it is not enough to take only one of the above steps. It is necessary often to apply two or more in combination; for example, wet processing and dust extracting (local exhaust). Our experience is that the proper enclosure of the process and the provision of a dust extracting system at the enclosure makes a real contribution to the control of the airborne dust. However, two things we invariably notice in asbestos-using industries are:

(a) The dust control systems are seldom maintained in good operating condition. In most cases, they are never checked after installation. The design and maintenance of dust control systems is so complex that this review can do no better than refer to the many texts which adequately cover the subject[45][46][47].

(b) The operators are not instructed to use dust exhaust systems properly; e.g. turning on the fan before the start of a process or adjusting the damper to ensure adequate exhaust capacity.

One other problem we often are faced with in the industry is to convince management not to recirculate the air exhausted from any process using asbestos or other toxic material. The obvious disadvantage of recirculation is a continuous exposure of fine dust to the workers in the plant. The *Industrial Safety Act* of the Ontario Department of Labour (Section 20) requires that all the air exhausted from any process using silica, asbestos and other toxic material be exhausted to atmosphere. The main argument against this is the tremendous cost of providing heated make-up air in winter.

In 1965, Hills[illegible] reported that, for 1,000,000 cu.ft of air per minute, the running costs of the dust-extraction system, including electric power, labour, plant depreciation and other overhead charges and the extra heating cost because the filtered air cannot be recirculated, come to about $250,000 a year. This figure could go very high in the case of asbestos mines and mills, many of which are located in northern climates, where the winter is long and very cold.

We have, however, from time to time permitted the recirculation of air from the dust-collecting systems if the following requirements were complied with:

(A) An acceptable monitoring device should be placed in the return air stream to continuously measure the dust concentration. The device should be fitted with an alarm system to sound when the dust count exceeds 1 mppcf (half the proposed TLV). Here again there are many difficulties, which include the absence of standardization in various counting methods and an ignorance of what amount of asbestos dust, if any, is safe. It is, however, hoped that by maintaining the concentration at half the proposed TLV, a safe environment can be attained.

(B) The monitoring device should be calibrated at least once a month when operating against a standard dust-counting technique.

(C) The monitoring device should be checked at least once a day when operating.

(D) A dust-counting survey should be carried out by the company semi-annually, with a copy of the survey results submitted to this Branch.

(E) The collector system should be equipped with a damper so that air can be directed outside during warm weather or when the alarm sounds.

(F) The collector system, monitoring equipment, calibration equipment and calibration test results may be available for inspection by a member of this Branch or the Department of Labour at any time.

Dust suppression becomes a special problem for asbestos milling. It is a dry process and is therefore an extremely dusty operation. The condition is further aggravated by the leakage in conveyors and screens, spillage from the belts and improper enclosure of the machines. The successful control methods are: (1) complete enclosure of the dust-producing machine (*Figure 9* shows a Hazemag crusher with proper enclosure); or (2) adequate suction within the enclosure to prevent escape through openings.

Figure 10 shows the bagging machines in a mill. We have always found dust counts at these machines to be very high. In one case, compressed air was being used to clean the bagging platform. This stirred up a considerable amount of dust in the air. The dust counts during the blowing operation were too high to count. The obvious solutions to this problem were:

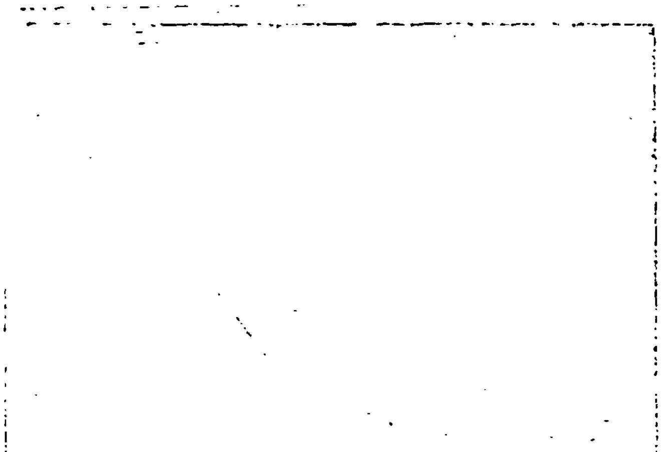

FIGURE 9 — Hazemag Crusher Used for the Fine Crushing of Asbestos Ore.

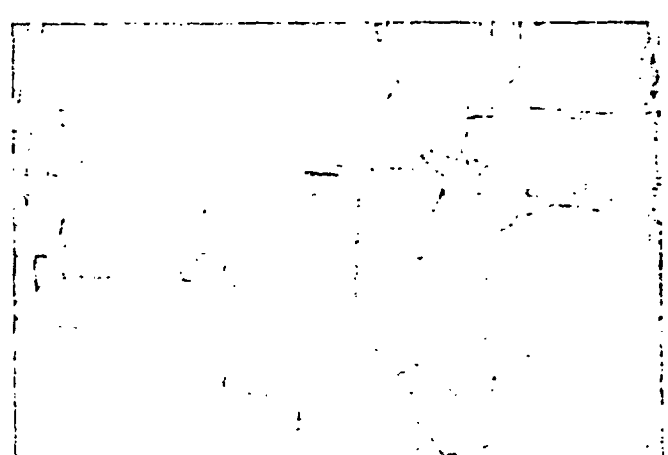

FIGURE 10 — Bagging Operation in an Asbestos Mill.

(1) air-tight attachment of the bags to the machine; (2) the use of suction rather than blowing for cleaning the platform; and (3) the installation of a dust-extracting system at the machine to remove any spill of fibre when the bag is detached from the machine.

(4) Personal Protection: In places where machines and processes cannot be provided with effective enclosures and adequate local mechanical exhausts, respiratory protection for each worker becomes an absolute necessity (e.g., dockyard workers engaged in the loading and unloading of asbestos bags). Adequate respiratory protection in the case of asbestos involves either the use of air-line breathing apparatus or approved respirators[8]. It should, however, be realized that the provision of approved respirators and their proper use by the operators are two different things. Unless an effective program of educating the workers in regard to the dangers of asbestos is carried out, the personal protection devices will not be effective. It is also necessary that, after each use, the respirators be cleaned, maintained and stored in a relatively dust-free place to avoid any contamination[30].

(5) Good Housekeeping: This includes cleaning of the floor and machines regularly and thoroughly. To avoid stirring up dust during cleaning, the dust must either be dampened with water or removed by means of a central vacuum cleaner. On our suggestion, a few companies have successfully used their central dust-extracting system for vacuum cleaning. The maintenance of good general ventilation also improves housekeeping.

(6) Medical Supervision: For a number of years, it has been a policy of the Environmental Health Branch of the Ontario Department of Health to regularly X-ray all employees exposed to asbestos dust. It has also advised the industries that all employees engaged in 'asbestos work' should be given pre-employment physical examinations. In 1969, the Occupational Chest X-ray Section of our Branch provided X-ray examination and lung function tests to a total of 2,644 asbestos workers, of which 818 were exposed to both silica and asbestos. An attempt is being made to maintain detailed medical records capable of yielding valuable and necessary information on statistical analysis. This information is valuable in the early detection of bronchial carcinoma, and it is of value in preventing the progression of cases of asbestosis.

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Earth Science Symposium on Offshore Eastern Canada

Ottawa, Ontario, Canada, February 22-24, 1971

AN EARTH SCIENCE SYMPOSIUM ON OFFSHORE EASTERN CANADA will be held in Camsell Hall, 588 Booth Street, Department of Energy, Mines and Resources, Ottawa on February 22-24, 1971. The Chairman of the Program Committee is DR. PETER HOOD, Room 573, Geological Survey of Canada, Ottawa 4, Ontario, Canada.

The main objective of the Symposium is to summarize the present knowledge of the continental shelves and slopes of eastern Canada so that emphasis will be on results rather than on techniques, although descriptions of new techniques will be encouraged. Areas to be discussed are the Bay of Fundy, Scotian Shelf, Gulf of St. Lawrence, Grand Banks, Flemish Cap, Labrador Sea, Ungava Bay, Foxe Basin, Baffin Bay and Greenland Shelf. The topics will include Surficial Geology, Geochemistry, Repetitive-Source Seismic, Bedrock Geology and Tectonics, Seismic Reflection and Refraction, Gravity, Magnetics, Magnetotellurics, Crustal Seismic, Heat Flow, Continental Drift, and Offshore Drilling.

Papers are invited for this symposium. Abstracts should be submitted before *November 1, 1970*. A number of papers have already been offered, mainly by government agencies and the universities, and there has been some response from industry. It is recognized that the symposium will be a greater success by widespread industry participation. It is therefore urged that individuals and representatives of exploration companies indicate to Dr. Hood their degree of interest.

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Symposium on Stability in Open-Pit Mining

Vancouver, British Columbia, November 23-25, 1970

A PRACTICAL SYMPOSIUM ON STABILITY IN OPEN-PIT MINING will be held at the Bayshore Inn in Vancouver, B.C. November 23-25, 1970. This symposium, part of the continuing education program for engineers given at The University of British Columbia, has been arranged by an *ad hoc* committee representing not only the University but also the Vancouver Branch of The Canadian Institute of Mining and Metallurgy and the Vancouver Branch of the Engineering Institute of Canada.

The Symposium lectures will be directed toward mining executives, managers, operating engineers, and planning and design personnel. As the majority of these people have been out of university for many years and have largely lost contact with theory and college mathematics, the emphasis of the Symposium will be on the practical aspects of stability and surface mining.

Speakers at the Symposium will include Drs. D. Deere, E. Hoek, N. Morgenstern, A. Bauer, R. Whitman, D. Pentz, H. Q. Golder, D. Coates and L. Casagrande, Mr. R. Stewart and Mr. C. O. Brawner.

The cost of Symposium registration will be approximately $100. For more information, please contact Engineering Programs, Extension Dept., The University of British Columbia, Vancouver 8, B.C.