CIS 878 1059 NBH 2.12-28-1
Fse Gtz Mpz Qem (627)

PLAINTIFF'S EXHIBIT
DOW-1967

HYGIENE STANDARDS FOR CHRYSOTILE ASBESTOS DUST

from the
Committee on Hygiene Standards
of the
BRITISH OCCUPATIONAL HYGIENE SOCIETY

COMMITTEE ON HYGIENE STANDARDS

R. E. LANE (Chairman), J. M. BARNES, D. E. HICKISH, J. G. JONES, S. A. ROACH and E. KING (Secretary)

SUB-COMMITTEE ON ASBESTOS

R. E. LANE (Chairman), J. C. GILSON, S. A. ROACH, S. SMITH, C. G. ADDINGLEY,* S. HOLMES,* R. HUNT*, J. F. KNOX* and E. KING (Secretary)

By invitation

G. BERRY, Pneumoconiosis Research Unit, Medical Research Council
B. HARVEY, Ministry of Labour
S. G. LUXON, Ministry of Labour
W. J. SMITHER, Asbestosis Research Council
V. TIMBRELL, Pneumoconiosis Research Unit, Medical Research Council
J. C. WAGNER, Pneumoconiosis Research Unit, Medical Research Council

ST0001829

Summary and recommendations—1. As long as there is any airborne chrysotile dust in the work environment there may be some small risk to health. Nevertheless, it should be realised that exposure up to certain limits can be tolerated for a lifetime without incurring undue risks.

2. The committee believes that a proper and reasonable objective would be to reduce the risk of contracting asbestosis to 1 per cent of those who have a lifetime's exposure to the dust. By "asbestosis" this committee means the earliest demonstrable effects on the lung due to asbestos.

It is probable that the risk of being affected to the extent of having such early clinical signs will be less than 1 per cent for an accumulated exposure of 100 fibre years per cm³. That is, for example, a concentration of 2 fibres per cm³ for 50 years, 4 fibres per cm³ for 25 years or 10 fibres per cm³ for 10 years.

3. It is recommended that exposures which lie in certain ranges of dustiness be designated by categories according to the following scheme:

DUST CATEGORY	CONCENTRATION AVERAGED OVER 3 MONTHS (FIBRES/CM³)
Negligible	0-0·4
Low	0·5–1·9
Medium	2·0–10·0
High	over 10·0

* Asbestosis Research Council.

as determined with the standard membrane filter method. Any other method can be used provided it is accompanied by appropriate evidence relating its results to those which would have been obtained with the standard membrane filter method.

5. When it is necessary to work intermittently in a "high dust" area an approved mask should be worn, provided that the concentration is no more than 50 fibres per cm^3 and the mask has been shown by test to be a good fit prior to entering the area. Should the concentration exceed 50 fibres per cm^3 a higher standard of respiratory protection should be provided, such as a pressure-fed breathing apparatus.

Additional recommendations

1. It is recommended that where practicable an up-to-date employment record card be kept of every person which indicates, every calendar quarter, the category or categories in which he or she has been employed and in which he or she is recommended to work.
2. All employees exposed to risk should be medically examined before employment. Periodic examinations should be made therafter, annually.

Notes

These hygiene standards are subject to review in the light of new evidence and improved methods of measurement.

The standards are, in our opinion, the best that can be drawn from the existing data. These data are scanty and based on factory experience of continuous exposure during working hours. Due caution should be exercised in applying these standards to other patterns of exposure. As far as possible the dust exposures have been estimated conservatively and, in particular, in the period 1933–1950 the average hours of work were substantially greater than 40 per week.

It is hoped to supplement the existing data in due course, when the standards will, if necessary, be modified. These standards will be formally reviewed in three years.

BACKGROUND

INTRODUCTION

THE COMMITTEE of the British Occupational Hygiene Society on Hygiene Standards has the following terms of reference:—

(a) To review those hygiene standards for air contaminants and other environmental factors which are considered to be unsatisfactory.
(b) To recommend hygiene standards in cases where these have not been established.
(c) To consider technical developments in environmental measurement and analytical techniques.
(d) To recommend sampling instruments, sampling procedures and analytical techniques for testing compliance with the standard.
(e) To indicate where appropriate the degree of protection associated with recommended standards.

The committee has reviewed the documentation of the Threshold Limit Value for asbestos dust in air recommended by the American Conference of Governmental Industrial Hygienists (COMMITTEE ON THRESHOLD LIMITS, 1966). The ACGIH Threshold Limit Value is based primarily on a recommendation made in a report of a survey in the U.S. Asbestos Textile Industry, in which the dust exposure of the workers was measured using the impinger (DREESSEN *et al.*, 1938).

In the thirty years since then, there have been developed new and better diagnostic

ST0001830

procedures, methods of dust measurement and methods for setting hygiene standards, with the result that the recommendation made in 1938 is out of date.

The results of recent work in this country using British practice have been made available to the committee by the Asbestos industry and it is on these recent results that the new standard is primarily based (see Appendix i).

The committee has also reviewed recent technical developments in the measurement of airborne asbestos and considered the degree of protection associated with hygiene standards. Its present views relating to chrysotile asbestos are summarised in the following sections.

THE TYPES OF ASBESTOS

The three principal types of asbestos used in this country are: chrysotile or "white" asbestos ($3MgO\ 2SiO_2\ 2H_2O$), crocidolite or "blue" asbestos ($Na_2O\ 3FeO\ Fe_2O_3\ 8SiO_2\ H_2O$) and amosite, a brownish-yellow to white asbestos ($3MgO\ 11FeO\ 16SiO_2\ 2H_2O$).

Information on the quantitative relationship between asbestos dust exposure and its effect on people, which is useful for setting a hygiene standard, is largely limited to asbestosis from chrysotile asbestos. Whether hygiene standards for other types of asbestos follow by analogy, that is by equating a standard to that of a similar compound, is uncertain. There are many instances of strikingly different effects from compounds which are physically and chemically very similar.

Further, there is some evidence that crocidolite asbestos, in particular, is more dangerous than chrysotile asbestos (WAGNER and SKIDMORE, 1965; GILSON, 1966; MORRIS, *et al.*, 1967). Even if this is so, there is at present insufficient information about exposure to other types of asbestos to be confident that a hygiene standard appropriate for chrysotile is equally appropriate for other kinds of asbestos.

ST0001831

ASBESTOSIS

Asbestosis is a fibrosis of the lung caused by asbestos dust. A majority of people exposed to the dust develop the disease if the dust concentration to which they have been exposed is high and the duration of their exposure is long (MEREWETHER and PRICE, 1930; FULTON *et al.*, 1935; DREESSEN *et al.*, 1938).

There are at present no definable characteristics of the individual which have been proved to be especially important in influencing the development of the disease. The onset of the disease is gradual and hence difficult to define.

The criteria at present used for diagnosis include: dyspnoea (without other causes), basal rales and finger clubbing. Also there is a characteristic pattern of alteration of lung function which includes reduced inspiratory capacity, reduced lung compliance, and an impaired transfer factor for carbon monoxide. The chest radiograph may also show changes. These include: pleural thickening and/or calcification; an abnormality of lung markings which obscures the normal lung architecture; also, in the later stages, an alteration of the outline of the cardiac shadow. Small and large opacities may also be present in some cases.

All these changes occur to varying degrees and, indeed, the severity of the alteration of the separate features may well be related to the type of past dust exposure. Thus the particular set of criteria used to decide whether asbestosis is present or absent will vary.

With increasing knowledge and with better methods for detecting early alteration of lung function, the disease is almost certainly diagnosable now at an earlier stage than was diagnosable 30 years ago.

It is not yet certain whether the improved methods of examination permit the detection of the disease at a stage where further progression will not occur if exposure ceases.

In the more advanced stages of the disease progression undoubtedly occurs after exposure to the dust has ceased.

CRITERIA OF RISK

As long as there is an appreciable amount of dust in the air, the committee recognises that there may be some risk to health.

If there is a threshold concentration, below which nobody is adversely affected, one could not argue from a limited number of dust measurements that a worker will never be exposed to this concentration, but only that the possibility is remote. Thus, in practice, one can show only that the risk of a worker's exposure exceeding such a threshold is small. Consequently, whether or not there is a threshold exposure, one can show only that the risk of a worker being affected by asbestos is minimal.

Knowledge of the relationship between airborne dust exposure and the risk of asbestosis is not in itself sufficient to establish a hygiene standard. Another important problem, and one which is very difficult to resolve, is that of balancing the risks to health against the consequences of demanding excessive dust reduction.

However, the committee believes that it is reasonable to reduce to 1 per cent the risk of getting asbestosis through having worked for a lifetime with asbestos. By "asbestosis" the committee has in mind the existence of the earliest demonstrable effects on the lung due to asbestos.

ESTIMATION OF THE STANDARD AIR CONCENTRATION

The way in which risk and dust concentration are related is not fully understood. However, it seems reasonable to assume that at zero concentration of asbestos there will be zero risk and that there will be an increase in risk corresponding to an increase in concentration. For other dusts a log-normal relationship between disease risk and dust exposure has been found to be valid (ROACH, 1953; HATCH, 1955). Such a relationship may be fitted to a set of data and a check on the assumption is given by the agreement of the fitted relationship with the observations. It is then possible to estimate the risk for any given exposure and vice-versa (Appendix ii).

In a recent study (see Appendix i) of two groups of men from a factory processing chrysotile asbestos and where thermal precipitators and membrane filter dust samplers were used, the average concentrations to which they were exposed were as follows:—

ST0001832

GROUP 1

Years employed	Number exposed	Mean dust concentration		Number affected		
		particles/cm³ (see Note 1)	fibres/cm³ (see Note 2)	Rhonchi	Basal rales	X-ray changes
10—	58	390	11	8	1	0
15—	72	390	11	11	1	1
20—	29	to	to	7	4	2
25—	46			14	8	3
30—	6	940	27	2	1	1

GROUP 2

Years employed	Number exposed	Mean dust concentration		Number affected		
		particles/cm³ (see Note 1)	fibres/cm³ (see Note 2)	Rhonchi	Basal rales	X-ray changes
10—	22	165	3·5	1	0	0
15—	20	165	3·5	3	0	0
20—	10	to	to	2	0	0
25—	20			1	1	1
30—	7	290	6·0	3	0	0

Note 1. Particles/cm³ in terms of thermal precipitator samples evaluated after incineration, under dark ground illumination, 2 mm objective and including all particles greater than 0·5 μ.

Note 2. Fibres/cm³ in terms of membrane filter samples. A "fibre" is a particle longer than 5 μ and having ratio of length to breadth greater than 3 : 1.

Risk–exposure relationships have been fitted on the assumption that the exposures at which men may be observed to have demonstrable changes are log-normally distributed. Exposure has been taken as the sum of the mean concentration in each year of exposure, so that the units of exposure are fibre years/cm³.

Risk-exposure relationships have been fitted separately to the two findings; basal rales and X-ray changes. All the men with X-ray changes had basal rales but some with basal rales had no X-ray changes. The values of exposure giving an estimated risk of 1 per cent and the lower 90 per cent confidence limits of these values are given below:—

Finding	Exposure giving 1% risk	
	Exposure	Lower confidence limit
Basal rales	112 fibre years/cm³	51 fibre years/cm³
X-ray changes	130 fibre years/cm³	31 fibre years/cm³

Basal rales are considered as the key symptom since every subject exhibiting X-ray changes also exhibited basal rales whereas some subjects exhibited basal rales without showing X-ray changes.

ST0001833

One way of expressing the above results is that the concentration giving a risk of 1 per cent for a man working for 50 years in the industry is estimated as 2·2 fibres/cm³ as measured with the standard membrane filter method.

Good industrial hygiene practice tends towards controlling exposures below the hygienic maximum rather than maintenance at the maximum. In this connection it may be noted that the uncertainty of the estimate of the concentration for 1 per cent risk at 50 years is such that the concentration for which one could state with 95 per cent probability that the risk is less than 1 per cent is 1·0 fibres/cm³.

THE CUMULATIVE FACTOR

Asbestos dust may accumulate in the lungs over a period of time. Thus a standard which protects the older man may not be adequate for a younger man who has more years ahead of him before retirement and correspondingly longer time in which to accumulate dust in his lungs.

It is evident from British and American experience that the prevalence of asbestosis increases with duration of exposure when concentration is held constant.

The cumulative dose of dust received may be controlled by limiting either the concentration in the air inhaled or the period of exposure.

Some asbestos fibres may be found in the sputum of asbestos workers long after exposure has ceased and some dust may be dissolved, but the exact amount removed from the lungs in these ways is uncertain. Accordingly, the assumption is made that this is zero, that is, that the cumulative amount of asbestos remaining in the lungs from a given exposure is equally dependent on the dust concentration and on the duration of exposure to that concentration.

By making this assumption, we may be introducing a factor of safety when dealing with exposures to chrysotile, because there is evidence in man and in animals that chrysotile dissolves slowly from the lung.

The hygiene standards set out in the *Summary and Recommendations* seek to limit the accumulated dose of dust received over a full work span of years although, for practical reasons, the hygiene standards refer specifically to the time-weighted average concentration over 3 months. The committee is not aware of any convincing evidence that the magnitude of short period fluctuations within a 3-month period has special biological significance at dose-rates sufficiently low to protect individuals for a life-time of exposure.

Appropriate sampling procedures are discussed in Appendix iii. However, it has to be remembered that a sampling procedure designed to monitor the long-term average concentration to which individuals are exposed is not necessarily the best procedure for determining which machine or process is producing the most dust. The intelligent use of short-period sampling instruments located near specific machines or processes will usually be more informative in this respect.

SAMPLING INSTRUMENTS

There are two main classes of dust sampler; those in which a sample of particles is counted (number concentration) and those in which the sample is weighed (mass concentration).

ST0001834

are collected with different efficiencies and in particle counting there is usually further selection of the particles, which are counted according to their size and shape. Consequently, no two methods or types of instrument render identical results and their relationship may differ in different dust environments.

When the purpose of dust sampling is to provide results comparable with a hygiene standard, it has to be borne in mind that the standard is based upon work with specific instruments. The British data, discussed above, were obtained from two types of thermal precipitator and from membrane filters.

Different authorities favour different instruments, according to the purpose of the dust sampling and the importance given to the theoretical, practical, scientific, medical and economic advantages of the sampling system and to the availability of the instruments.

Instruments which are suitable for measuring mass concentration, and in particular "respirable" mass concentration, have as yet been little used in asbestos problems, but are gaining increasing favour.

The relative importance to health of number, area, and shape of the different sizes of chrysotile asbestos particles is not known in detail. Nevertheless, those large, long and heavy particles which are readily deposited in the upper respiratory tract are less likely to be important than others which deposit in the lower respiratory tract. While within this respirable dust fraction there may be a difference in effect due to fibre length, it is probable that methods based on the count of fibres longer than 5 μ and on the mass of "respirable" asbestos would have shown a similar relationship with prevalence of asbestosis.

The committee considers that the specification of one sampling technique alone would be unnecessarily restrictive and has made some provision for other methods (see Appendix iv).

S1000183

PERIODIC MEDICAL EXAMINATIONS

In all types of pneumoconiosis too little is known about the variability of the response of different individuals to a given dose of dust to allow complete reliance on dust monitoring as a means of reducing the risk to a specified level. The periodic medical examination must at present be used as an additional safeguard to the individual. This also provides the means for accumulating more extensive information about acceptable dust concentrations and times of exposure.

CANCER

The primary danger of inhaling asbestos dust is asbestosis. It is generally recognised that there is also significant risk of lung cancer associated with asbestosis, A risk of mesothelioma of the pleura and peritoneum exists in connection with the inhalation of crocidolite dust in particular.

There can be little doubt that these risks will be least in the lowest concentration (KNOX, DOLL and HILL 1965), but the quantitative relationship between asbestos and

cancer risk is not known, nor is it known exactly why these two are related, nor even whether all kinds of asbestos present a risk. Consequently it is not possible, at this time to specify an air concentration which is known will be free of risk in this respect.

Acknowledgements—All the members of the Asbestos Sub-Committee and others invited to attend particular meetings were jointly responsible for this document. Further the early drafts were considerably improved by the many useful comments received from colleagues.

Drs. KNOX and HOLMES were responsible for the study of health of a group of asbestos workers in relation to their dust exposure, described in Appendix (i).

Mr. BERRY was responsible for the statistical analysis described in Appendix (ii).

The committee is especially grateful to Dr. ROACH, for preparing this report.

REFERENCES

ADDINGLEY, C. G. (1965) Dust measurement and monitoring in the asbestos industry. *Ann. N.Y. Acad. Sci.* 132, 298.

AYER, H. E., LYNCH, J. R. and FANNEY, J. H. (1965) A comparison of impinger and membrane filter techniques for evaluating air samples in asbestos plants. *Ann. N.Y. Acad. Sci.* 132, 274.

COMMITTEE ON THRESHOLD LIMITS (1966) *Documentation of Threshold Limit Values* p. 15. American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio.

DREESSEN, W. C., DALLA VALLE, J. M., EDWARDS, T. I., MILLER, J. W., SAYERS, P. R, EASOM, H. F. and TRICE, M. F. (1938) A study of asbestosis in the asbestos textile industry. *Publ. Hlth Bull., Wash.* No. 241.

FULTON, W. B., DOOLEY, A., MATTHEWS, J. L. and HOUTZ, R. L. (1935) Asbestosis, Parts II and III. *Spec. Bull. Pa Dept. Lab. Ind.* 42

GILSON, J. C. (1966) Health hazards of asbestos—recent studies on its biological effects. *Trans. Soc. Occ. Med.* 16, 62.

HATCH, T. (1955) Permissible dustiness. *Am. ind. Hyg. Ass. Q.*, 16, 30.

HOLMES, S. (1965) Developments in dust sampling and counting techniques in the asbestos industry. *Ann. N.Y. Acad. Sci.* 132, 288.

KNOX, J. F., DOLL, R. S., and HILL, I. D. (1965) Cohort analysis of changes in incidence of bronchial carcinoma in a textile asbestos factory. *Ann. N.Y. Acad. Sci.* 132, 526.

LYNCH, J. R. and AYER, H. E. (1967) Measurement of dust exposure in the asbestos textile industry. *Am. Ind. Hyg. Ass. J.* 27, 431.

MEREWEATHER, E. R. A. and PRICE, C. W. (1930) *Report on Effects of Asbestos Dust on the Lungs and Dust Suppression in the Asbestos Industry*, Home Office, H.M.S.O.

MORRIS, T. G., ROBERTS, W. H., SILVERTON, R. E., SKIDMORE, J. W. and WAGNER, J. C. (1967) in *Inhaled Particles and Vapours*—II. Edited by C. N. DAVIES, p. 205. Pergamon Press.

REGISTRAR GENERAL'S DECENNIAL SUPPLEMENT FOR ENGLAND AND WALES, 1949–1953. *Occupational Mortality*. Part II, Vol. 2. H.M.S.O., London (1958).

ROACH, S. A. (1953) A Method of Relating the Incidence of Pneumoconiosis to Airborne Dust Exposure. *Br. J. Ind. Med.*, 10, 220.

WAGNER, J. W. and SKIDMORE, J. W. (1965) Asbestos dust deposition and retention in rats. *Ann. N.Y. Acad. Sci.* 132, 77.

APPENDIX (i)

A STUDY OF THE HEALTH OF A GROUP OF ASBESTOS WORKERS IN RELATION TO DUST EXPOSURE

A group of men at an Asbestos Textile factory situated in a conurbation with a high prevalence of chronic bronchitis, who had worked at the factory for 10 years or more since 1st January 1933 were selected for further study. The situation was assessed as at 30th June, 1966, according to known clinical and radiological findings.

During the period under review a programme of dust control measures had been carried out in the factory, and for part of this time dust monitoring had been carried out.

ST0001836

ness of records, or because of significant asbestos dust exposure elsewhere.

In Table 1 the results are given of a clinical and radiological assessment. The presence of persistent rhonchi was regarded as evidence of some degree of chronic bronchitis and the recording of rales, principally in the basal and lower marginal areas of the lung, was taken as indicating a reaction to asbestos dust exposure. Concerning the X-rays of which it was recorded that changes were present

TABLE 1. CLINICAL AND RADIOLOGICAL ASSESSMENT OF TEXTILE ASBESTOS WORKERS FIRST EMPLOYED AFTER 1.1.1933 AND EMPLOYED FOR 10 YEARS AND UPWARDS

Number	Persistent rhonchi present	Per cent of group	Basal rales	Per cent of group	X-ray changes not asbestotic	X-ray changes possibly asbestotic	Per cent of group
290	52	17·8	16*	5·5	12	8*	2·7

*Includes 3 suspensions for asbestosis.

which were possibly asbestotic, the whole clinical picture was taken into consideration. Radiological changes considered significant included those of increased general opacity of the lower lobes, blurring of the cardiac outline, pleural thickening, and adhesions. Isolated areas of calcification, unconnected with the above changes, were not considered as necessarily or probably asbestotic in this series.

Table 2 gives a breakdown of the results of the observations on the workers recorded in Table 1 in 5-year groups from 10/14 years to 30/34 years. It is clear that with increasing years of exposure the percentage of positive findings in these three categories was greater. With regard to the 30/34-year group the number is small and it contains two workers with chronic bronchitis who are members of a local large bronchitic family.

TABLE 2. GROUP IN TABLE 1 IN RELATION TO LENGTH OF SERVICE

Years employed	Numbers	Persistent rhonchi present	Per cent of group	Basal rales	Per cent of group	X-ray changes possibly asbestotic	Per cent of group
10-14	80	9	11·2	1	1·2	0	0
15-19	92	14	15·2	1	1·1	1	1·1
20-24	39	9	23·1	4	10·2	2	5·1
25-29	66	15	22·7	9	13·6	4	6·0
30-34	13	5*	38·4	1	7·7	1	7·7

* Includes 2 brothers with chronic bronchitis being members of a local large bronchitic family.

In Table 3 the departments in which the workers were employed are grouped under four headings for comparison of the effects of dust conditions.

(1) *Fiberising*. The processes concerned comprise bag carrying, hopper filling with crude asbestos, attending mixing processes, and re-bagging.

(2) *Carding and Spinning*. These processes are considered together as they are for the most part conducted in the same room, and additional processes such as fibre rope braiding and doubling are including.

(3) *Weaving*. This includes beaming and all processes here are conducted with yarn.

(4) *Plaiting*. In this process rope-making machines are used to make asbestos ropes of different specifications. They are impregnated and formed into various products, mostly packings.

There would seem to be little difference as regards rhonchi, rales and X-ray changes between Fiberising and Carding and Spinning, but the figures for Weaving and Plaiting are considerably lower. With regard to persistent rhonchi the percentage declined from Fiberising with 31·0 per cent to weaving at 10.0 per cent.

ST0001837

TABLE 3. GROUP IN TABLE 1 IN RELATION TO EMPLOYMENT AREAS

Trade	Years employed	Numbers	Persistent rhonchi	Basal rales	X-ray changes possibly asbestotic	Mean age at first employment
Fiberising	10–14	13	4	1	0	37·1
	15–19	21	6	1	1	32·7
	20–24	9	1	2	1	31·4
	25–29	15	7	1	0	28·7
	30–34	0	0	0	0	
		58	18 (31·0%)	5 (8·6%)	2 (3·4%)	
Carding and Spinning	10–14	45	4	0	0	37·0
	15–19	51	5	0	0	34·0
	20–24	20	6	2	1	31·9
	25–29	31	7	7	3	29·5
	30–34	6	2	1	1	22·6
		153	24 (15·6%)	10 (6·5%)	5 (3·2%)	
Weaving	10–14	18	1	0	0	32·8
	15–19	16	2	0	0	31·4
	20–24	8	2	0	0	33·2
	25–29	13	0	1	1	30·6
	30–34	5	1	0	0	30·6
		60	6 (10·0%)	1 (1·6%)	1 (1·6%)	
Plaiting	10–14	4	0	0	0	27·5
	15–19	4	1	0	0	38·0
	20–24	2	0	0	0	32·0
	25–29	7	1	0	0	26·4
	30–34	2	2	0	0	15·0
		19	4* (21·0%)	0	0	

* Includes 2 brothers with chronic bronchitis being members of a local large bronchitic family.

The group percentages of rales show some important differences. Fiberising and Carding and Spinning have percentages which are little different at 8·6 and 6·5 respectively, but Weaving reaches only 1·6 per cent and Plaiting has nil.

The percentage of X-ray changes is similar in Fiberising and Carding and Spinning, but Weaving is only half of this at 1·6 per cent and the Plaiting percentage is nil.

The good record of Plaiting may result from several factors. These are that only yarn is handled here, that the machines need little attention, and that the work includes impregnation of the plaited ropes with oils and resins.

In some cases exposure began in 1933 and dust records did not start until 1951. Furthermore, in the 34 years under review, many changes have been made which have resulted in a steady improvement in working conditions, and therefore in no area can the dust concentration be taken as constant over the whole period.

The important landmarks in this drive to improve the working environment are worth noting. The Asbestos Industry Regulations can be said to have had their first effect in 1933, when ventilation systems in Carding and Weaving were introduced. In 1939, damping techniques were established in the Weaving process, and it can be said that the improvement here was considerable, conditions remaining reasonably constant from that time to the present day. In 1942 the dust settling chambers in the ventilation system were replaced by sleeve filters. This immediately removed the need for cleaning out the chambers, undoubtedly a very hazardous operation. In the years immediately

ST0001838

following the war damping was extended to yarn doubling and in the period 1953–1957 the design of the card extraction system was improved. During this period oiling of the fibre was introduced at the mixing stage to suppress dust during its subsequent processing. Prior to 1958 fibre had been blended on an open floor under dust exhaust hoods, but at this time an entirely new, totally enclosed system covering the whole fiberising process before carding, came into operation. In addition to the benefits derived from the enclosure, it was now possible to add the optimum amount of oil considered necessary for dust suppression. This could not be done on the old mixing floor.

Although various methods had been used at irregular intervals before that date, routine dust sampling in the various factory locations did not commence until 1951. The instrument chosen was the Casella thermal precipitator and the samples were incinerated before being counted (1000 × -dark field). By this means particles down to the limit of visibility were included in the count. This system was in use until 1960 and was invaluable in assisting the engineers in the many improvements then being made. Unfortunately the instrument was not efficient in capturing the large fibres (above 10 μ) and an alternative sampler was sought. The device chosen was the long-running thermal precipitator, which collected the sample by a combination of settlement and thermal precipitation, and the long fibres now appeared in the sample. Counting was done without incineration at a magnification of 500 × -light field, and only fibres were counted which were between 5 and 100 μ long and whose length–diameter ratio was at least 3 : 1. Any correlation between the results for the two sampling systems proved difficult to define, because the "fibre count" was in a part of the dust spectrum only partly included in the old T.P. sample. The later change (1965) from L.R.T.P. to cellulose membrane sampling did not require a correlation factor as, when properly established, the results from the membrane were comparable with those from the L.R.T.P.

The operations specified in Table 3 each cover a considerable factory area, and over the years sampling positions may have changed and, furthermore, the subjects to which the Table refers have moved around to some extent, especially in the Carding and Spinning Department. Table 4 gives average dust levels in the areas concerned at the beginning (1952) and at the end (1960) of the thermal

TABLE 4. DUST LEVELS AT VARIOUS TEXTILE PROCESSES, 1952–66

Department	Process	Yearly mean dust levels			
		T.P. (Particles/cm³)		LRTP and membrane (fibres/cm³)	
		1952	1960	1961	1966
Fiberising	Mixing Floor	500	–	–	–
	Opening	440		Now totally enclosed	
	Bag Slitting	–	110	4·5	4
	Mechanical Bagging	–	120	4	4·5
Carding	Fine Cards	200	200	5·5	5·5
	Medium Cards	810	400	7·5	8
	Coarse Cards	1140	420	7	7·5
	Electrical Sliver Cards	490	260	5	2
Spinning	Fine Spinning	170	110	4	3·5
	Roving Frames	510	150	5·5	5·5
	Intermediate Frames	530	100	5·5	5·5
Weaving	Beaming	190	220	8	3·5
	Pirn Winding	350	130	3	2·5
	Cloth Weaving	180	140	3	2
	Listing Weaving	130	110	2	1
Plaiting	Medium Plaiting	140	80	4	4

precipitator period (particle counts), at the beginning (1961) of the L.R.T.P. period and the present-day (1966) membrane fibre counts. It must be realised that there were probably considerable deviations from the mean figure in the various locations from time to time, and indeed the location of the process itself was in some cases changed during the period under review. Sampling points themselves could also have changed over the years and it should be further noted that the sampling strategy in the past has been geared to the engineering work in progress and not specifically towards an assessment of the biological hazard.

ST0001839

The fibre count results in Table 4 have been rounded off to the nearest 0.5 fibres/cm³. It will be seen that, as already mentioned, the major changes in the Fiberising process make comparison difficult. The opening operation is now totally enclosed and the main sources of dust remaining are at bag slitting, where the crude fibre is fed to the blender, and mechanical bagging, where the blended and opened fibre is bagged for transport to carding. In general it will be seen that considerable improvements were made in the period 1952 to 1960, during which time the factory was modernised. Since then the conditions have remained reasonably steady, although work on dust control has continued in certain directions. In particular, engineering changes at the Electrical Sliver Cards and at Beaming have had a significant effect. The consistently low figures obtained at Weaving will be noted. In particular, the level at Listing Weaving where, as already mentioned, no health problems have arisen, will be seen to be the lowest in the factory.

The data shown on p. 51 were derived as follows.

The data on the subjects were first assembled into two groups; by combining those who had worked in Fiberising with those who had worked in Carding and Spinning (Group 1) and by combining those who had worked in Weaving with those who had worked in Plaiting (Group 2).

The mean dust concentration applicable to those who had worked from 10 to 15 years was estimated by weighting the dust concentrations given in Table 4 according to the total number of men who are employed on the different tasks and according to the number of years that the process remained roughly constant. For example, there are 20, 55, 50 and 3 men presently employed on Fine, Medium, Coarse and Sliver Cards respectively so that the concentration in 1952 for an average carding operative is estimated as

$$\frac{(20\times 200) + (55\times 810) + (50\times 1140) + (3\times 490)}{128} = 840 \text{ particles/cm}^3$$

Similarly the concentration in 1960 for an average carding operative is estimated as 370 particles/cm³. For the purpose of estimating the average concentration to which these operatives were exposed over their whole period of employment these are weighted 1 : 2, i.e. 840 particles/cm³ for one-third of the 10–15 years period of exposure and 370 particles/cm³ for two-thirds of this period. Thus the average concentration to which those carding operatives with 10 to 15 years of employment were exposed is estimated as

$$\frac{(1\times 840) + (2\times 370)}{3} = 530 \text{ particles/cm}^3$$

The average fibre counts were worked out similarly for 1961 and 1960 and the relationship between the fibre counts in 1961 and T.P. particles/cm³ for 1960 was used to relate the two dust sampling methods in the different departments.

It was further estimated that on the average the concentration in 1933 was at least 1½ times what it was 15 years ago and this gives a lower limit to the exposure for workers with the longest durations.

ST0001840

APPENDIX (ii)

STATISTICAL METHODS USED IN ESTIMATING THE STANDARD EXPOSURES

The risk–exposure relationship

In order to estimate the relationship between risk and exposure, the functional form of the risk-exposure relationship should be known and data from all, or a representative sample of exposed men, should be available.

In the type of data under consideration the response is quantal; a man either has contracted asbestosis (or some physical sign) or he has not. Within a group of men exposed to the same conditions the time it takes before contracting asbestosis will differ from one man to another and the way in which it differs determines the risk–exposure relationship.

Two assumptions seem reasonable: first, that at zero exposure there is zero risk, and secondly, that increasing the exposure increases the risk. It is also necessary to make a more restrictive assumption specifying the mathematical form of the relationship in terms of one or more parameters. The situation is analogous to biological assay, where it has frequently been found that within a population the distribution of doses at which some response occurs is log-normal. In the present context this would mean that the distribution of the logarithms of the exposures, for which a physical sign may be first observed, is a normal distribution. The above form of relationship may be fitted

to a set of data by the method of probit analysis, a form of analysis developed for biological assay work, and a check on the assumed form of relationship is given by how well the fitted relationship agrees with the observations. It is then possible to estimate the risk for any given exposure and *vice-versa* and also the errors of such estimates.

The sample

In order that the conclusions are unbiased the data must have come from a random sample of a population, the composition of which has the same form as that about which one wishes to make inferences. The population sampled may, for example, consist of all workers joining a particular factory in a particular period. It may be more efficient to have a stratified random sample. That is, a sample made up of random samples from each of several strata, each stratum representing different levels of exposure, for example.

Applications

(i) *Asbestos textile factory* (*Appendix* (*i*)). The two groups of workers were combined and the exposure taken as the sum of the concentrations in each year of exposure. A satisfactory fit was obtained, both for basal rales and X-ray changes. Rhonchi were not considered since this is not a condition specific to asbestos. For basal rales a 1 per cent risk is estimated for an exposure of 112 fibre years per cm³, i.e. for a concentration of 2·2 fibres/cm³ for 50 years. At this concentration there is a reasonable chance that the risk is as high as 3 per cent and to be reasonably certain (i.e. 95 per cent) that the risk was less than 1 per cent the concentration would have to be kept at not more than 1·0 fibres/cm³. For X-ray changes a 1 per cent risk is estimated at 2·6 fibres/cm³ for 50 years, but this estimate is less well determined as only 8 men were observed with X-ray changes compared with 16 with basal rales.

(ii) *USPHS Data.* The procedure may be applied to the 1938 USPHS survey data which were as follows:

mppcf	No. exposed	No. affected
0–2·4	39	0
2·5–4·9	69	(3)
5·0–9·9	126	19
over 10	213	51

Three "doubtful" cases of asbestosis fell in the range 2·5–4·9 million particles and these have been accepted as probably being genuine cases by present-day standards.

An additional difficulty is that the concentrations are imprecisely defined: for almost half the sample we only know that the concentration was greater than 10 mppcf. (350 particles/cm³). However, the numbers of men within each group of concentrations suggest that the distribution of concentrations within the sampled population is log-normal and accepting this a risk-exposure relationship may be fitted, although because of this extra assumption the complexity of the calculations was considerably increased.

A satisfactory fit was obtained and the concentration giving a risk of 1 per cent for 50 years' exposure is estimated as 25 particles/cm³ by the impinger. The error of this estimate is such that there is a reasonable chance that the risk is as high as 3½ per cent and in order to be reasonably certain that the risk is less than 1 per cent the concentration would have to be reduced to 6 particles/cm³ by the impinger.

Discussion

Both the above sets of data were obtained from men working at particular mills at a particular time. Such groups of men are the result of selection, voluntary or imposed, as workers leave the industry and do not, therefore, form a sample of the required type. If the men who have left the industry differ in their susceptibility to asbestosis, then our conclusions will be biased to this extent.

Thus both sets of data have certain disadvantages in common: firstly they may not be representative of the populations to which we wish to apply the results, and secondly the estimate of the exposure giving a 1 per cent risk may only be estimated imprecisely.

The first disadvantage might be overcome in future work by studying a random sample satisfying the condition, given earlier, that it is representative of the population about which one intends to make inferences. In order to remove any effect of selection it would be necessary to include former workers in such a sample. The second disadvantage demands more information, i.e. not only data from more men but also from a sample stratified so as to improve the precision of the estimate of exposure giving a risk of 1 per cent. Both disadvantages would be overcome, or reduced, by choosing a larger sample of past and present workers.

ST0001841

APPENDIX (iii)

SAMPLING PROCEDURES

It is suggested that a work-place is assigned its dust category according to the time weighted average concentration determined by sampling continuously or at representative intervals during the previous quarter.

Time weighted average concentration =

$$\frac{\text{Average concentration during working hours} \times \text{No. of hours worked per quarter}}{520}$$

As a practical matter, 3 months is sometimes an inconveniently long time to wait in uncertainty; in a new environment, for example, or in a work-place where the use of asbestos has just begun or dust measurements have not previously been made.

There may be three distinct types of situation.

The first is where asbestos is used, worked or handled regularly and is likely to continue in use for some time. In such a situation a procedure is needed which develops into a regular 3-monthly schedule of sampling.

Secondly, there are other situations in which asbestos is used rarely or sporadically or for only a short period, possibly for a few days, with no expectation of repeated use. For these cases, there is a need for guidance on the maximum concentration for short periods.

Thirdly, there are large numbers of work-places where asbestos is present but it is doubtful whether it is present in the air in more than minimal quantity and a short objective test of this is needed to give assurance. Similarly, there are some work-places where there is little doubt that exceedingly high concentrations exist and a rapid test is needed to indicate whether work should cease immediately or further sampling be undertaken.

For a new work-place, in order to give early warning should it be especially dusty, it is suggested that it is first assigned a category according to the time weighted average concentration over a full shift.

After one week of sampling it would then be reclassified according to the time-weighted average concentration adjusted to 40 hr.

Subsequent reclassification might then be made quarterly and be based upon the results from samples taken during the previous quarter.

The spacing of the samples over a 13-week sampling period should be planned in advance. The samples could be taken at regular intervals or at times chosen at random beforehand and the duration of each sample may be a few minutes, a shift, a week or even 13 weeks. The longer the duration of each sample and the more samples that are taken the more accurately will the average concentration be estimated. Sufficient assurance that the average concentration lies below a given limit would be gained by showing that the upper 90 per cent confidence limit of the average lies below that limit.

It is recognised that in a work-place where the long-term average exposure lies in a particular category an occasional quarterly average may exceed the upper limit of that category. Accordingly, even though the most recent quarterly average exposure exceeds the upper limit for a particular category, an environment would be classified in that category if the average of the last four successive quarterly averages lies in the range of exposures in that category.

There will be work-places where the conditions have changed through applying new methods of work, or through replacing machines or through making changes in the general or local exhaust ventilation systems.

It is recommended that any environment that has undergone such changes which may effect its classification ought to be regarded as a new one.

Further, a work-place where asbestos is used irregularly, or for a few days at a time, or where its regular use cannot be foreseen, could be assigned a category according to the time-weighted average concentration over a full shift.

It is suggested that a work-place where the air concentration is less than 0·5 fibres/cm³ at a time of maximum dust production need not be investigated further and could be assigned the "negligible" category.

It is also suggested that a work-place where a single measurement exceeds 50 fibres/cm³ be immediately assigned a "High" category until and subject to further investigation.

ST0001842

APPENDIX (iv)

CHOICE OF SAMPLING METHODS

Chrysotile may be only a small proportion of the dust and there is no simple, specific test for chrysotile.

Further, only a proportion of the dust will be sufficiently fine to penetrate to the lung, and it takes specialised apparatus to separate the fine dust from the remainder in a satisfactory manner. However, suppose, example, the proportion of fine chrysotile in the airborne dust was known. The concentration of fine chrysotile in the air could then be inferred from a simple measurement of the concentration of all the dust in the air (total dust).

In particular cases, evidence may be available to enable at least an upper limit to be placed on the proportion of fine chrysotile, recognising that in effect an additional factor of safety is thereby incorporated. Again, in the absence of any precise information on the proportion of fine chrysotile, the total dust concentration may be used as a working limit. Obviously, if the total dust concentration is less than a certain value, any fraction of it will also be less than this same value.

Thus, lack of specialised equipment, analytical techniques or great expertise in dust measurement need not necessarily be a bar to proceeding with dust control in an orderly and effective manner. In many cases the simplest of measurements will suffice. In others dust control may be so difficult or expensive, or the proportion of fine chrysotile so small, that a more sensitive and precise method of measurement is justified.

The sampling equipment available for total dust measurements is simpler and less expensive than that for respirable dust, while analyses for ash, silicates or magnesium are more complicated techniques, but are increasingly more specific measurements of chrysotile.

Similarly, the thermal precipitator, impinger and Royco particle count are progressively simpler techniques, but less easily related to the membrane filter fibre count.

The counting of particles by eye under the microscope is tedious and difficult. It can only be accomplished reliably by a skilled dust microscopist.

With such considerations in mind, the committee have constructed a table of indices which may be used in place of the membrane filter fibre count and still carry a similar degree of assurance against risk of asbestosis due to chrysotile dust. In doing this the investigator should bear in mind that the committee's basic data relating dust with asbestosis were in terms of membrane filter fibre counts.

Where there is a choice open to the investigator he may nevertheless choose another method on grounds of convenience, practicability or cost, and favour a particular method because it is not likely to be unduly influenced by materials other than chrysotile.

In an overall industrial hygiene programme it is recognised that chrysotile asbestos may not be the only dust of concern and a less specific index, like total dust concentration, may, for example, be chosen so as to include a degree of protection against other dusts.

TABLE OF ALTERNATIVE INDICES

Method	Concentration
Membrane filter	2 fibres/cm³
"Respirable" mass	0·03 mg magnesium/m³ 0·04 mg SiO_2/m³ 0·10 mg ash/m³ 0·12 mg asbestos/m³
Thermal precipitator	25 particles/cm³ greater than 1 μ after incineration
Impinger	10 particles/cm³
Royco particle count	2 particles/cm³ greater than 4 μ

Alternative indices to 0·5 and 10 fibres/cm³ are found by multiplying the above values by 0·25 and 5 respectively.

The choice of method open to the investigator is not limited to those listed in the above table. Other methods old or new may be used. These are provided for in Section 4 of the *Summary and Recommendations*.

The size distribution of the dust in thermal precipitator samples obtained in 1960 at the works discussed in Appendix (i) showed that the proportion of particles below 1 μ varied between 60 per

SI0001843

cent and 80 per cent in different processses. The mean percent below 1 μ weighted according to the number of workers in each process was 69 per cent.

The mean ratio of particles/cm³ in 1960 to fibres/cm³ in 1961, weighted according to the number of workers in each process was 38. Accordingly, the corresponding thermal precipitator count greater than 1 μ corresponding to a membrane filter count of 2 fibres/cm³ might be estimated as approximately

$$\frac{2 \times 38 \times 31}{100} = 24 \text{ particles/cm}^3.$$

All visible particles are counted with standard impinger counting but the efficiency of collection relative to the thermal precipitator falls off rapidly for particles below 1 μ dia. and the resolving power of the objective is low with the result that relatively few of those particles below 1 μ that are collected are visible. The impinger count would therefore not be expected to be greater than the thermal precipitator count over 1 μ. In a side-by-side comparison of the membrane filter and impinger methods in asbestos plants AYER, LYNCH and FANNEY (1965) found that 6 fibres/cm³ corresponded to an impinger count of approximately 35 particles/cm³. Further, LYNCH and AYER (1967) found that 10 fibres/cm³ by the membrane filter method corresponded to approximately 0·6–1·0 mg/m³ of respirable asbestos.

ADDINGLEY (1965) found that the Royco particle counter when set to count particles larger than 4 μ produced results comparable with the membrane filter fibre count.

Brief notes are given below on the alternative sampling systems for obtaining concentrations comparable with the indices in the above table.

Membrane Filters

Membrane filters consist of thin porous membranes of cellulose esters. They vary in average pore size from 0·01 to 10 μ. Their collection efficiency is very high and increases with decreasing pore size. The separation of particles occurs almost exclusively at the upper surface, so the particles can be counted microscopically directly on the filter. The filter becomes transparent by using an immersion oil having the same refractive index as the filter. The membrane filter can thus be used to make a simple sampling instrument for collecting dust for examination under the microscope. The flow rate is limited only by the resistance of the filter. In order to view the dust under the microscope it is, however, necessary to use immersion oil to render the filter transparent. The refractive index of membrane filters is about 1·5, close to that of chrysotile (R.I. 1·55), so that under ordinary illumination the chrysotile may itself be very nearly invisible when using an immersion oil closely matched to the filter. A phase contrast microscope is therefore used to increase the visibility of the chrysotile.

The method given below is based upon the standard methods which have been recommended by the Asbestosis Research Council.

Equipment

White millipore type "HA" or "DA" membrane filters are preferred. (Diameter = 25 mm). The latter are used where aspiration is by means of a Draeger hand pump, as the "HA" type tend to rupture. (Pore sizes: "HA" = 0·45 μ, "DA" = 0·65 μ).

A 1 in. dia. Gelman aluminium sampling head is used in which the sampling orifice diameter is 20 mm. A P.T.F.E. washer must be placed at all metal-to-metal seals to render the head leakproof.

The unexposed annulus of the filter may be covered by a thin washer made of metallic-coated Melinex. Sealing the head causes this washer to adhere to the membrane, thus forming an annular boundary to the deposit. This is not necessary for the denser dust samples.

The pump employed is a sealed Austen Dymax Mark II pump. The flow rate is controlled by a Hostat Minor device or suitable needle valve and rotameter. For the former method a gas meter must be used for initial calibration.

The Draeger hand bellows pump is suitable for short-period ("snap") samples.

Sampling

The sampling orifice is positioned at approximately head height. The filter surface should be in a vertical plane.

Sampling at a constant rate of 300 cm³/min is recommended when continuous sampling is employed. The sampling period is varied according to the dust level to be expected.

ST0001844

For short period samples the Draeger pump incorporating the sampling head is held at the required position. With each stroke, the pump sucks in a volume of $100 \pm 5\ cm^3$ through the membrane. Again the volume of sample depends upon the environment.

After the sample has been taken the sampling orifice is covered by a plastic cap or other convenient means.

Mounting the samples

The procedure adopted for mounting and clearing the white membrane samples before counting is as follows:

The dust deposit is first "fixed" to the membrane surface by applying several drops of Perspex solution (0·025 per cent in chloroform) to the membrane, whilst pulling "clean" air through it, by means of a suitable pump.

A few drops of filtered Triacetin (Glycerol Triacetate) are dropped on a clean 3 × 1 in. microscope slide. Then, using tweezers, the filter is carefully removed from the sampling head and placed on top of the Triacetin, dust side uppermost, ensuring that the metallised washer is not displaced.

In order to clear the sample completely it may be necessary to add a further drop or two of Triacetin.

The sample is then covered with a *clean* 25 mm dia. (No. 1½) cover slip, making sure that no air bubbles are trapped underneath its surface.

A period of 30 minutes is usually sufficient to completely clear the filter.

Counting technique

The cleared samples are observed in transmitted light under phase contrast conditions at a magnification of approximately 500 ×. (An initial scan using a low-power objective must be carried out to ensure that the dust deposit is evenly distributed.) Random fields are observed, the number of fields needed to count 200 fibres being noted. Only fibres of length 5–100 μ and length to breadth ratio equal to or greater than 3 to 1 are counted.

Thermal Precipitators

Two types of thermal precipitator are at present in use for the routine monitoring of airborne dust, namely the "standard" thermal precipitator, manufactured by Casella, and the "long running thermal precipitator", designed and developed at the Mining Research Establishment, and manufactured in clockwork pump form by Ottway and Casella, and in an all electric form by Casella.

In the standard thermal precipitator dust-laden air is drawn vertically into the sampling head and down a narrow vertical channel between two circular glass coverslips. Halfway between these two coverslips is stretched a horizontal wire, heated electrically. Dust is deposited by a thermal effect, opposite the wire, in two strips on the coverslips.

The coverslips are then mounted, dust side down, on microscope slides and the dust can be viewed under the microscope, through the coverslip. The samples may be incinerated before mounting, to remove combustible matter.

In the "long running" thermal precipitator the dust-laden air is drawn from a vertical passage, and along a horizontal channel, the floor of which is formed by a glass coverslip. At first, particles settle out from the air by gravity and the remainder are precipitated thermally beneath a heated wire. A sample of up to 8 hours' duration can be obtained with this instrument, compared with 10–30 min for a sample using the standard instrument.

The dimensions and geometrical arrangement in the sampling head are critical in a thermal precipitator, and the flow-rate is limited, although insofar as the sample is collected on a glass coverslip and viewed dry, the visibility of the particles under an orthodox light microscope is better than obtained with a membrane filter.

The standard thermal precipitator

At the sampling site, the instrument is assembled in the sampling position so that the air channel through the head is vertical.

Current for the heating wire is supplied by a 6 V battery. Alternatively, mains supply may be used with a transformer having a 6 V outlet in series with a rheostat and AC ammeter. Air is drawn through the sampling head at 5–7 cm^3 min.

ST0001845

The long running thermal precipitator (LRTP)

The LRTP is hung or supported in the sampling position, with the top surface approximately horizontal. To reduce contamination, the sampling head may be sealed with a small piece of drafting tape during the journey to and from the sampling position. Care should be taken that the instrument is not subjected to excessive bumping during the journey back to the laboratory and that it remains in an upright position until the sample can be removed.

Sample volume

In the standard thermal precipitator the airborne dust is deposited over a very small area on the coverglasses and to avoid overcrowding it is necessary to restrict the volume of air sampled.

An endeavour should be made to obtain slides with an optimum density of 350 particles/60 μ traverse with outside limits of 200–500. Slides with densities above and below these limits are liable to give a seriously inaccurate estimate of the dust concentration.

Microscope

Efficient illumination is an important factor in obtaining the best result from a microscope. The recommended method of illumination is the Kohler system.

Microscope graticule and magnification

The recommended eyepiece graticule for counting is the M.R.E. type.

The magnification is adjusted using a 4 mm objective so that the short dimension of the grid is 60 μ, in which case the reference circles have diameters of 10, 5, 2 and 1 μ respectively.

The eye-piece recommended for use with the achromatic type objective is a compensating × 15 or × 17. The dimensions of the M.R.E. eyepiece graticule have been arranged (grid length 4·0 mm) so that the required magnification is readily obtainable with a positive (Ramsden) eyepiece.

Counting procedure for standard thermal precipitator samples

The slide should first be examined under the 16 mm objective for any unevenness in density along its length and any contamination of the coverglass in areas remote from the deposit. The extent of the deposit should be clearly defined, and if, owing to heavy contamination, the edge of the deposit is not easily seen, the sample should be rejected.

The length of the deposit should be measured with the Stage Vernier under the 16 mm objective. A traverse should be selected either centrally or 2 mm from either end.

If the examination of the deposit under the 16 mm objective has shown that there is a defect where a traverse would normally be made, a new position should be chosen which is clear of defect, yet as near as possible to the original position.

The total length of the traverse counted should be 2 mm; 1 mm either side of the centre of the dust deposit.

The particles are sized by making comparison between their projected areas, as seen in the microscope, and the areas of the globes or circles inscribed above and below the M.R.E. eyepiece graticule. All particles whose sizes are greater than the 1 μ circle should be counted. These may be either single particles or aggregates, that is, groups of particles adhering together. The criteria for including an individual particle or aggregate in the count are as follows:

(i) that it falls within the specified size range, and

(ii) that at some stage in focusing, a clear margin of separation is visible between the particle and all its neighbours.

Counting procedure for long-running thermal precipitator samples

The counting procedure to be followed for LRTP samples is generally the same as described for Standard Thermal Precipitator samples, the following being the main points of difference:

(i) the slides should be set up on the microscope with the thermally precipitated zone to the left of the microscope stage;

(ii) the length of the traverse to be counted should be estimated by marking the position of the thermally precipitated zone under the 16 mm objective and then moving the microscope stage 1 mm to the left of this position and counting 14·5 mm to the right of this point—any particles outside these limits are to be regarded as contamination;

(iii) the traverse to be counted should be 6 mm from the most clearly defined end of the thermally precipitated zone;

ST0001846

(iv) the width of the deposit, to be used in calculating the result, should be measured at the thermally precipitated zone;
(v) the dust deposits on these slides are occasionally heavy and the use of the full 60 μ graticule width may entail prolonged counts, producing fatigue and a falling-off in counting accuracy. In such cases use may be made of the sub-division of the graticule to count either 40 μ or 20 μ traverses.

Impinger

The impinger is the instrument used in the series of studies by the U.S. Public Health Service 1925–1940 in dusty trades on which the Threshold Limit Values of the American Conference of Governmental Industrial Hygienists for Mineral Dusts were largely based. It is still the most common method for mineral dust sampling in the U.S.A.

The dust-laden air is drawn through a glass jet set a fixed distance from the bottom of a flask. The jet is immersed in water or alcohol and the particles strike the bottom of the flask and become suspended in the liquid.

A sample of the liquid is then placed in a counting cell and the particles are counted using a low-power microscope.

The sampling time may be 10–30 min or more. There is no upper limit to the sampling time, since the suspension can be diluted to the point where coincidence errors are insignificant. However, the impingement system is inefficient and the sample cannot conveniently be incinerated.

The following method is based on the standard method of the American Conference of Governmental Industrial Hygienists.

Sampling instrument

The sampling instrument is the standard impinger, operated at a rate of 1·0 ft^3/min. ± 5 per cent at 3 in. Hg negative pressure, or the midget impinger operated at 0·1 ft^3/min ± 5 per cent at 12 in. H_2O negative pressure. The sampling instrument and the indicating gauge on the flow-producing apparatus should be calibrated at regular intervals.

Counting cell

The counting cell should be no more than 1·0 mm and no less than 0·25 mm in depth with an allowable variation of ± 5 per cent from the nominal depth.

Optical system

A. The microscope should be equipped with the following:

objective	10 ×. (16 mm) 0·25 N.A.
ocular (eyepiece)	20×
condenser	0·25 N.A.

B. The counting area is defined by an ocular grid such as a Whipple disc and should be accurately measured by means of a stage micrometer.

C. Kohler illumination is used except that after this has been achieved the eyepiece is removed and the iris diaphragm of the microscope condenser is closed until the diameter of the disc of light seen in the back lens of the objective is about one-half that of the lens.

Further reduction of brightness may be accomplished, if desired, with neutral density filters.

Collecting liquid

The collecting liquid should be 95 per cent ethyl alcohol; mixtures with other liquids should not be used.

Treatment of collected samples

A. All glassware must be clean and the equipment protected against dust contamination in the field. One impinger flask, a "blank" flask, is treated exactly like the others except that no air is drawn through it.

B. The diluting liquid should be 95 per cent ethyl alcohol.

C. The impinger nozzle is rinsed down inside and out with diluting liquid as the sample is made up to a known value. Samples having a low concentration of dust are diluted as little as possible. Dense samples are diluted so that no more than about 2000 particles mm^2 will appear in the counting area of the cell

ST0001847

Not less than 5 ml of original or diluted sample should be taken for further dilution, and dilutions should be made in steps not exceeding 10 parts of dilution liquid to 1 part of original or diluted sample. The dust suspension must be shaken vigorously by hand for at least 30 sec before a portion is removed for dilution.

Preparation for counting

A. The sample to be counted is shaken to ensure a uniform suspension and a portion is transferred immediately to a clean cell by means of a clean pipette, taking care to prevent the inclusion of air bubble

B. Two cells are filled from each sample and from a "blank" flask.

C. Sample counting should start at the end of the settling time and should be completed in 10 min. The settling time should be 30 min/mm of cell depth.

Counting

A. Before counting, the field of the microscope should be examined and, if necessary, the ocular grid cleaned to remove dust particles.

B. The counting plane is the bottom liquid–glass interface of the cell. The microscope is focused up and down slightly with the fine focus adjustment in order to bring individual particles in and out of focus for more positive detection and counting.

C. Fields selected for counting should be uniformly distributed over the counting plane of the cell. Observation should not be made through the microscope while fields are being selected.

D. At least five fields of equal area should be counted in each of two cells. For a dust sample, when the first five fields of the first cell counted yield a total count of less than 100 particles, additional fields of known area should be counted; the total area counted is recorded and used in calculation of concentration. For each cell from the blank flask only five fields need be counted.

E. The same total area should be counted in the second cell as is counted in the first.

F. Total counts from the two cells of the same sample should be compared, and when the ratio of the greater to the lesser count is larger than 1·2 additional pairs of cells should be counted until a pair yields counts which satisfy this criterion. The count of this pair should be used for calculating the concentration of the sample.

G. Five fields of the same area as that used for dust sample counting should be counted in each of two cells from a "blank" flask. The average blank count should be used in calculation of net count. If the blank count exceeds 30 particles/mm^2 of counted area, all the samples should be rejected.

H. Observers are cautioned that their ability to see particles probably improves during the first few minutes of counting as their eyes become accustomed to the task. A brief period of counting is suggested prior to recording data. Fatigue can cause a deterioration in counting efficacy; conservative judgement should be exercised on when to discontinue counting because of fatigue.

ST0018h8

Royco Particle Count Method

In the Royco particle counter a thin filament of the dust-laden air is drawn past an intense light beam and the light scattered at right-angles is sensed by a photo cell.

Air is drawn continuously through the centre of a hollow cube or chamber with windows in the sides. Particles in suspension scatter light from a tungsten filament lamp focused on the centre of the chamber.

The light scattered at right-angles by the particles is viewed by a lens system and photomultiplier. The pulse train from the photomultiplier passes to a linear variable-gain amplifier and fixed-level discriminator and then to a decade counter.

Time switches automatically switch a sequence of size discrimination channels so that the count may be restricted to successive size ranges or to all particles above a lower size-limit. The standard model counts above 0·3 μ and in 14 stages up to 10 μ at 0·3, 1, 3 or 10 min intervals.

The counts may be read off, plotted on a pen recorder, or printed out.

An optional filtered dilution system can be incorporated to reduce coincidence errors in high concentrations.

Overall calibration is performed against monodisperse polystyrene latex spheres. The air is filtered through a membrane filter in the sampling train after passing the counting chamber so that the sample may be subsequently check-counted by eye, under the microscope.

The instrument is extremely expensive, large, complicated and not very portable.

Method

The following routine is based on one worked out in the asbestos industry for a Royco counter with print-out facility:—

1. Mode indicator to SINGLE and Scan indicator to MANUAL.
2. Power switch and Calibrate switch (Particle Size panel) to INCLUDE.
   Leave the machine for approximately 10 minutes to warm up.
3. Power switch (Print Out Section) to be put ON.
4. Set Scan indicator to 0·3 MINUTE, press Calibrate Button and allow the machine to operate until the count is 1910 or ABOVE. If calibration number is to be recorded, put Record On Switch (Print Out Section) to ON.
   The machine is now ready for use. Turn Scan indicator to MANUAL and Record On Switch to OFF.
5. Turn ON Sample Air Pump and set at the number of cm^3/min. to be sampled (300), this having been checked previously using a Flowmeter; 1000 cm^3 of air are sampled at each sampling position.
6. Select particle size to be counted at 4 μ (Particle Size panel) and turn the Mode indicator to TOTAL.
7. Turn Scan indicator to MANUAL. Record ON switch (Print Out Section) to be put ON.
8. The particle size panel should still be on CALIBRATE. This switch should be put on EXCLUDE when the scan has been changed to the particle size to be counted, using the Manual button.
9. When counting the last scan put the Calibrate switch (Particle Size panel) to INCLUDE. When the scan is completed and the Calibrate indicator is lit, turn OFF Sample Air Pump, Record On Switch to OFF and Particle Size Switch to EXCLUDE. Mode indicator to read SINGLE, the Scan indicator set to 0·3 MINUTE. The machine is now ready to re-calibrate. The machine is calibrated after each test, this being done *after* the machine has been moved to the new sampling position. The scans are timed using a stop-watch and the numbers printed by using the Print Button at the rear of the Royco Counter.

ST0001849

Mass Concentration Methods

Introduction

A mass sampling system may include either all or some of the following: a sampling nozzle, size selector, filter holder, filter, flow meter, air mover, and a means of regulating the flow. The filter and holder may be replaced by an electrostatic precipitator.

Respirable mass concentration methods

Respirable dust samplers collect only the finer particles believed to deposit in the lower respiratory tract. Their efficiency falls away in a controlled fashion with increasing size. There are two principal types in common use, those based on a horizontal eluctriator and those based on a small cyclone. A horizontal elutriator consists of one or more horizontal tubes upstream of the filter paper or other collector and particles fall to the floor of the tubes under gravity. The coarse particles fall faster than the fine ones and the flow area of the tube is chosen so as to collect particles down to about 5 μ, allowing most of the finer particles to pass to the filter.

In the Casella Gravimetric Dust Sampler Type 113A the flow-rate is 2·5 l/min through a stack of horizontal channels. The Casella Hexhlet has a flow-rate of 50 l/min through a stack of horizontal channels. In both instruments the dust is collected on a filter.

In the UNICO Respirable Dust Samplers the size selection is achieved by using a small cyclone upstream of a filter. Models are available for flow-rates of 2·8 l/min, 18 l/min or 240 l/min.

The conicycle made by Langham Thompson is also used for respirable mass determinations. In this instrument the coarse particles are rejected by centrifugal force at an entry slit and the dust carried into the sampling head is deposited on a metal collecting ring. The flow-rate is 8 l/min.

With all respirable dust samples, it is particularly important to maintain a constant sampling flow rate to ensure correct size selection characteristics.

Filter holders

A filter or other collector should be upstream of everything in the system except the size selector or entry nozzle, so that any dirt in the system, manometer liquid, or pump oil will not be carried accidentally on to the filter.

A filter holder must be so designed as to provide a positive seal at the edge, without leakage. It must not abrade or tear the filter. A screen or other mechanical support may be required for the filter, to prevent rupture or displacement in service. A back-up screen is necessary with glass fibre polystyrene and membrane filters.

Filter media

Collection efficiency varies with particle size and with face velocity. Most high efficiency filter media have a relatively high flow resistance. When using pumps such as turbine blowers and ejectors, which are highly sensitive to resistance pressure, it is necessary to select a filter with a low enough flow resistance to guarantee the desired sampling rate.

In many instances the limited sensitivity of an analytical method, when combined with a low air concentration, makes it necessary for large volumes of air to be sampled in order to collect sufficient material for an accurate analysis. In addition to the material being studied, background dust and other contaminants must, unavoidably, also be collected.

The mass of the filter itself is important in gravimetric determinations. In determining the mass of collected aerosol, the mass of the filter should be as small as possible, relative to the mass of the sample. Also, other things being equal, the less the filter weighs and/or the smaller it is, the simpler the sample handling and processing.

Cellulose fibre filter papers are relatively inexpensive, are obtainable in an almost unlimited range of sizes, have excellent tensile strength, show little tendency to fray during handling, are low in ash content, and are readily obtainable. Their disadvantages include hygroscopicity, which makes for difficulty in accurate gravimetric determinations and non-uniformity resulting in variable flow resistance. Whatman No. 41 is the most widely used cellulose fibre filter paper. It has the advantage of relatively low flow resistance.

Glass fibre filters are able to withstand high temperatures, are non-hygroscopic and have a high collection efficiency. Glass fibre papers are thus very well suited to simple gravimetric determinations because they maintain the same blank weight independent of the ambient humidity. These filters are composed of mats of very finely spun glass fibres and are available either with or without an organic binder. Removal of the binder decreases the mechanical strength of the paper. Glass paper is used without binder when the binder would constitute an interference in the analysis. Despite the loss of tensile strength the binderfree paper can be used if handled carefully and supported by a wire-gauze screen or other suitable support. Even with binder the filter is quite friable and must be handled with care. Analyses for Fe, Al, Mg, Na and K are not possible because of large amounts of these elements present in the glass fibres.

Polystyrene fibre filters such as the Microsorban filter, are made of mats of polystyrene fibres of submicron diameter. Their flow resistance is relatively low, being comparable to Whatman No. 41, while their efficiency of collection is relatively high and is comparable to that of glass filters. Their mechanical strength is very poor, and they must be well supported in the filter holder. Polystyrene filters have the advantage that they are soluble in aromatic hydrocarbon solvents.

The possibility of dissolving the filter, provides a means of recovery by which all of the collected material can be concentrated within a very small volume for subsequent analysis.

Membrane filters have a low mass and their ash content is negligible, but they have a high flow resistance. They are soluble in many organic solvents, such as esters and ketones. Particle collection takes place almost exclusively at the surface of the filter and while this accounts for the special advantage of membrane filters for number count determinations it also makes for disadvantages in mass determinations.

When more than a single layer of dust particles is collected on a membrane filter, the resistance rapidly increases and there is a tendency for the deposit to slough off the paper.

Filter thimbles are available in cellulose fibre, glass fibre and cloth. They are sometimes filled with loose cotton wool to reduce clogging. The advantage of a filter thimble is that large samples can be collected before clogging.

Weighing cellulose papers

The two principal sources of error in weighing cellulose papers arise from the hygroscopic nature of the paper and losses due to the paper being abraded or torn in the filter holder. The former error

ST0001850

can be kept within bounds by strict observance to a drying and weighing routine and the latter can be largely avoided by care in filter-holder design.

The flow-rate, sampling interval and size of filter are then chosen to yield a weight of dust amounting to at least 1 per cent of the paper and preferably more than 2 per cent.

The following weighing procedure gives the weight of a clean or dirty paper to within 0·1 per cent. The weighing vessels used are light screw-top tins with a pin-hole in the lid.

1. Unscrew the lid from a weighing vessel, place the filter inside and place the weighing vessel in a drying oven at 111°C with its lid. Dry for 2 hr exactly.
2. Screw the lid on the weighing vessel and cool it in a dessicator with silica gel for 20 min exactly.
3. Weigh immediately.
4. Repeat steps 1 to 3. The two weights should check to 0·1 per cent. Otherwise repeat the procedure.

Analysis of the dust

For most chemical analyses, it is necessary either to remove the sample from the filter, or to destroy the filter. Inorganic particles are usually recovered from cellulose paper filters by wet ashing (digesting in concentrated acid) or muffling (incinerating) the filter. Samples can be recovered from polystyrene and membrane filters by disolving the filter in a suitable solvent.

The filter's background level of the material to be analysed must be determined. All filters contain various elements as major, minor and trace constituents, and the filter medium of choice for analysing particular elements must be one with little or no background level for the elements being analysed.

Electrostatic precipitators

Electrostatic precipitators have the advantages of negligible flow resistance, no clogging and the dust is precipitated on a metal cylinder whose weight is unaffected by humidity. However, a power pack is needed to supply the high voltage and precautions have to be taken to guard against electric shock.

Electrostatic samplers are not commonly used in this country but are popular in U.S.A.

The two types commercially available are the Mines Safety Appliances Electrostatic Sampler and the Bendix Electrostatic Air Sampling System. The former has a fixed flow-rate of 66 l/min from a 50 c/s frequency supply and the latter is variable between 90 l/min and 200 l/min.

A high d.c. voltage, between 10 kV and 20 kV is applied to a central electrode supported in the centre of a collecting tube about 6 in. long and 1¼ in. dia. The tube is earthed.

The corona discharge from the tip of the electrode charges dust particles drawn into the tube and they migrate to the inside walls of the tube.

In use the ionizing voltage should be maintained sufficiently high to collect all the particles but not so high as to produce arcing between the central electrode and the collecting tube. A check that the dust has all been collected is to observe that the downstream end of the collecting tube is clear of dust, which should all be deposited in the first three-quarters of the tube. There is a practical limit (about 100 mg) to the amount of dust that can be collected on each tube as a thick layer of dust is easily dislodged and may be lost on handling.

The ends of the sampling tube should be capped when the sample has been collected and the outside of the tube wiped clean.

The dust may be washed or wiped off the tube. If the tube is washed, care should be taken to allow the tube to return to room temperature before weighing or balance errors will occur.

The tube can be weighed on a semi-micro balance to ½ mg.

SI 0001851