INTER ORGANIZATION COMMUNICATION

Raybestos Manhattan

Manheim, Pa.

DIVISION and LOCATION

TO: Messrs. G. D'Olier, J. F. Glennon, J. H. Perry, J. E. Day, R. L. Ramsey, J. R. Roe

DATE: May 4, 1977

SUBJECT:

Attached Data Sheet #18 from the Occupational Health Branch of the Ontario Ministry of Labor concerning asbestos may be of interest.

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att.
cc: Messrs. J. H. Marsh
G. F. Butt
E. W. Drislane, FMSI
R. H. Mereness, AIA
Dr. H. C. Lewinsohn

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Hennessy Mines
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(12)

FMSI 05864

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Ontario
Ministry of
Labour

Occupational Health Branch
Data Sheet No. 18

ASBESTOS

DESCRIPTION

The name comes from the Greek, "unquenchable" or "indestructible". It is a generic term applied to a number of naturally occurring silicates which can be separated from the parent rock in fibrous form. The common types fall into two categories

(a) Serpentine - chrysotile
$(Mg_6 (OH)_8 Si_4O_{10})$

(b) Amphiboles - amosite
$(Fe_5 Mg_2 Si_8 O_{22} (OH)_2)$

- actinolite
$(CaSiO_3.Mg SiO_3.FeSiO_3)$

- anthophyllite
$((MgFe)_7 Si_8O_{22}(OH)_2)$

- crocidolite
$(Na_2O.Fe_2O_3.3FeO.8SiO_2.H_2O)$

- tremolite
$(Ca_2Mg_5Si_8O_{22}(OH)_2)$

The fibres of the different forms have characteristics - in terms of length, flexibility, texture, tensile strength, resistance to heat or chemical reaction - which make each suitable for particular purposes. The characteristics which have been most exploited are flame resistance and tensile strength.

OCCUPATIONAL EXPOSURE

Exposure to asbestos fibres in air can occur in mining or milling or in any of hundreds of uses or processes. The fibrous material may be sprayed as insulation, as a fire retardant, or for acoustic effect. Asbestos is combined in cement asbestos board, shingles, brake linings, paints, floor tiling, water and sewer pipes, and is used in the production of moulded plastic products, in sheet form as lagging for insulation and in flame retardant cloth.

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SOURCE

A large proportion of the world's production of chrysotile is from Canada - mainly Quebec, with some from British Columbia, Yukon Territory, Ontario and Newfoundland. The USSR is also an important producer. The main source of amphiboles is South Africa. Canada imports some crocidolite (blue asbestos) and amosite (brown asbestos) for special processes. Altogether the world production consists of chrysotile 93%, crocidolite 4% and amosite 2% (approximate percentages). Tremolite and actinolite are of little commercial importance but are of health significance as they occur in some talcs.

HEALTH ASPECTS

When air containing asbestos fibres is inhaled, a number of effects can result. These will vary according to the type, concentration, size of fibre inhaled, the duration of exposure and in some cases to a combined effect with other inhaled contaminants.

The principal forms of asbestos-related disease or disorders are:

1. Asbestosis - a diffuse fibrosis (scarring and shrinking) of lung tissue.

2. Lung cancer.

3. Mesothelioma - a malignant tumour of the pleura or peritoneum (lining of chest and abdomen).

4. Cancer of organs other than the respiratory system e.g. gastro-intestinal tract.

5. Pleural thickening and calcification.

Asbestosis

The standard for asbestos control in air mentions fibres greater than 5 micrometers (5μm) in length because it is believed that smaller fibres are removed by the ordinary self-clearing mechanism of the lungs. The smaller fibres are generally engulfed by the so-called scavenger cells. Inside these cells the fibres become coated with proteinaceous material containing iron to form "ferruginous bodies" which, if coughed up, can be recognized in the sputum. The ferruginous bodies in sputum may be indicative of asbestos exposure but not necessarily of asbestos related disease. Fibres longer than 5μm have a tendency to be retained in the lung tissue where they may cause irritation and eventual scarring. Over years of exposure this may result in increasing shortness of breath. Advanced asbestosis can be diagnosed by chest x-rays but at a much earlier stage, the disease may be recognized by pulmonary function (breathing) tests.

Lung Cancer

The incidence of lung cancer is much higher in asbestos workers than in the general population. Lung cancer in asbestos workers is usually

preceded by fibrous changes in the lung tissue as occurs in asbestosis. It is claimed that an asbestos worker who smokes has 92 times greater chance of acquiring lung cancer than a non-smoking, non-asbestos worker.(8)

Note - There is evidence in the literature that mineral fibres other than those of asbestos e.g. - wollastonite, attapulgite, fibre glass and rock wool, may act on the respiratory organs in a manner similar to asbestos fibres.

Mesothelioma

In the general population this is a rare malignant tumour. It has, however, been shown that a large proportion of the people who develop it have had some exposure to asbestos, though not always an occupational exposure. There appears to be a latent period of over 20 years between the first exposure and the appearance of the tumour. There is some evidence that mesothelioma is more likely to be caused by amphiboles (such as crocidolite and amosite) than by chrysotile.(10)

Cancer of Organs Other Than the Respiratory System

An increased occurrence of cancers in other locations than the respiratory system e.g. the gastro-intestinal tract, the breast(6,7), has been reported. This is apparently due to the capability of the asbestos fibre to penetrate the lung tissue and to reach other organs outside the chest cavity, or the asbestos fibres swallowed with mucous and food to penetrate the walls of the stomach and intestines.(9)

Pleural Thickening and Calcification

Asbestos fibres may cause irritation, inflammation and thickening of the pleura (pleural plaques). This is a condition that can be seen at x-ray examination. It is evidence of prolonged exposure to asbestos but is not necessarily associated with symptoms of ill-health.

STANDARD

The time-weighted average (TWA) refers to the airborne concentration of substances in the workplace air. It is the concentration for a normal 8-hour workday or 40-hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

The maximum allowable concentration (MAC) is the maximum concentration of airborne substances in the workplace air to which a worker may be exposed: such an exposure shall not exceed more than one 15-minute period per day.

For chrysotile -

TWA is 2 fibres greater than 5μm in length per cubic centimetre(cc).

MAC is 10 fibres greater than 5μm in length per cc.

For amphiboles -

TWA is 0.2 fibres greater than 5µm in length per cc.

MAC is 2.0 fibres greater than 5µm in length per cc.

The TWA of 2 fibres per cc. is intended to control the risk of asbestosis to less than 1%.

For sampling technique, see Appendix 1.

CONTROLS

A. General

1. Personal Hygiene

(a) Good personal hygiene is to be maintained. This includes washing before eating, drinking, smoking or use of toilet facilities.

*(b) Change Rooms - are to be provided by the employer at a fixed place of employment for workers working regularly at the place and who are exposed to airborne concentrations of asbestos fibres.

*(c) Clothes Lockers - two separate lockers for each worker so separated by a shower room that one locker for street clothes is in one room and a second locker for work clothes in another room. Contaminated clothing is to be placed in a covered impermeable container.

(d) Laundry

(i) Laundering of asbestos-contaminated clothing is to be done so as to prevent the release of airborne asbestos fibres in excess of the TWA.

(ii) An employer who gives asbestos-contaminated clothing to another person or company for laundering is to inform such person or company of the requirement in subsection (i) of the subdivision.

(iii) Contaminated clothing is to be transported in sealed impermeable bags, or other closed impermeable container and a caution label affixed (see Section 3(b)(i).

2. Food, Beverages and Tobacco

Food, beverages and tobacco are not to be kept nor consumed in the work area.

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*Note - For workers engaged in work other than at a fixed location, e.g. insulators, alternative suitable arrangements are to be provided.

3. Caution Signs and Labels

(a) Caution Signs -

Posting - Caution signs are to be provided and posted at the approaches to each location where there is significant exposure to asbestos fibres. The sign is to be printed in English and, as necessary, in other languages so that all workers understand the hazard. A typical asbestos card is shown as Appendix 2.

(b) Caution Labels -

(i) Labelling - Caution labels are to be affixed to all raw materials, mixtures, scrap, waste, debris and other products containing asbestos fibres, or to their containers, except that no label is required where asbestos fibres have been modified by a bonding agent, coating, binder or other material so that during any reasonably foreseeable use, handling, storage, disposal, processing or transportation, no airborne concentrations of asbestos fibres in excess of the TWA will be released.

(ii) Labels - All labels are to be in accordance with the Guidelines for the Labelling of Toxic Chemicals for Use in Ontario Industry.

4. Special Clothing

The employer is to provide and to require the use of special clothing, head coverings, gloves and foot coverings for workers exposed to airborne concentrations of asbestos fibres.

5. Work Practices

Work practices are to be followed, as completely as possible, that prevent the dissemination of dust.

Examples are:-

(a) When dumping bags of asbestos:

(i) Local exhaust is to be used.

(ii) Excessive shaking of bags is to be avoided.

(iii) Bags are to be disposed of carefully using local exhaust, covered containers, plastic bags that can be sealed, etc.

(b) When sawing, drilling, grinding, machining asbestos-containing materials, etc.

(i) Local exhaust is to be used.

(ii) Products are to be vacuum cleaned, washed, or otherwise cleaned before further operations, storage or shipping.

Compressed air is not to be used for cleaning.

6. Housekeeping

Housekeeping includes prompt vacuum cleaning or wet sweeping of all scraps and spills, careful storage and disposal of asbestos-containing materials in plastic bags or other suitable containers, and frequent and regular cleaning of machines, floors, walls and other plant surfaces (by vacuum cleaning) where asbestos dust settles. Dry sweeping, dusting or compressed air are never acceptable.

7. Personal Protection

In certain circumstances and for limited periods of time, the worker may be protected by respiratory equipment. This should, however, never be allowed to take the place of adequate environmental control. It must be recognized that the wearing of a respirator for long periods of time is often uncomfortable and sometimes of questionable efficiency. Workers may, in some instances, be neglectful in the care and the use of their respirators, thus decreasing the reliability of this type of protection.

In general, air levels below the standard of 2 fibres per cubic centimetre are to be maintained. During process changes or while improvements are being made to a plant, workers may be required to wear replaceable filter type respirators of the type approved for control of respirable dust if fibre concentrations do not exceed 10 fibres per cubic centimetre. This is always to be considered a temporary measure and is not to be continued beyond three months. During such periods it is essential that the wearing and the maintenance of respirators be closely supervised by the employer.

B. Engineering

Normal procedures for the control of respirable dust apply to the control of the health hazard from asbestos.

1. Substitution

When feasible, asbestos should be replaced by less hazardous materials.

2. Segregation

It is possible with suitable planning to arrange that work producing high concentrations of asbestos dust is done in isolation. Where segregation is difficult, as in the case of asbestos spraying, it is possible with suitable scheduling to have the process carried out when other workers are either off the shift or when they are removed from the area.

Control booths, under positive pressure, may isolate the worker from exposure while allowing him to control a process. In certain circumstances, respirators may also be used (see "Personal Protection").

3. Ventilation

The use of adequate local exhaust is the most important method of dust control. This method captures the dust at the source and conveys it to a central dust collecting system.

Good general exhaust is to be provided so that any fibres not captured by local exhaust are eventually removed from the workroom air.

4. Dust Suppression

The use of water to suppress dust at the source has been universally accepted. Water sprays are perhaps the most common method of applying water to control both visible and respirable dust but it is not possible to control a dust cloud by means of water sprays once the dust has become airborne.

C. Medical Surveillance

1. First Aid

No acute poisoning due to asbestos has been recorded.

2. Preplacement Medical Examination

Preplacement medical examination is to be done within 30 days of the person's employment in an exposure to asbestos. The examination is to include a medical and occupational history including smoking habits; pulmonary, cardiovascular and gastro-intestinal symptoms; a physical examination; a chest x-ray (posterior - anterior, 14 inches x 17 inches); and pulmonary function tests to include forced vital capacity (FVC), and forced expiratory volume at one second ($FEV_{1.0}$).

3. Periodic Medical Examination

Periodic medical examination is to be done at least every two(2) years on each employee engaged in an occupation exposed to asbestos fibres. The examination is to follow the same procedures as outlined for a preplacement medical examination. It is to be noted, however, that those persons who

(a) have a history of 10 or more years of employment involving exposure to asbestos,

(b) show x-ray findings (such as small opacities, pleural plaques, pleural thickening, pleural calcification) which suggest or indicate pneumoconiosis or other reactions to asbestos, or

(c) have changes in pulmonary function which indicates restrictive or obstructive lung disease

are to have the chest x-rays and pulmonary function tests at least annually.

4. Termination Medical Examination

Within thirty(30) days before or after termination of employment, an employee engaged in an occupation exposed to significant airborne concentrations of asbestos fibre is to have a termination medical examination. The examination is to follow the same procedure as outlined for a preplacement medical examination.

5. Medical Records

Complete and accurate records of medical examinations are to be maintained. These confidential records are to be retained by the employer for a period of forty(40) years or length of employment plus 20 years whichever is longer.

ACTION LEVELS

Depending on the process, it may be difficult for an asbestos-producing or using industry to meet the standard at all times. It becomes necessary, therefore, to establish criteria on which certain actions are to be taken.

It is desirable that work places be monitored and exposure of personnel be determined regularly. The aim must be to keep both area and personal samples below the TWA. Whenever the standard is exceeded, personnel are to be protected by the wearing of approved respirators until the conditions are corrected.

As indicated above (see Personal Protection), this action is acceptable for limited periods of time, when concentrations are between the TWA and the MAC. At the same time, it is the responsibility of management to advise the representative of the Ministry of Labour that a state of non-compliance exists.

When the concentration exceeds the MAC the process is to be shut-down while corrective action is taken. At such times only workers with positive pressure air-supplied respirators are to be engaged in repair or corrective work. The representative of the Ministry of Labour is to be notified and will decide whether or not the work may resume.

As a general rule, the mill or plant will not be allowed to maintain production if the asbestos exposure exceeds the MAC. At levels between TWA and MAC production may be allowed to continue on condition that the workers wear appropriate respiratory protection, that positive action is undertaken by the firm to correct the situation and that the period of corrective action does not exceed three months.

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APPENDIX I

Sampling Technique for Asbestos in Workplace Air

The ideal sampling period to determine a TWA is a full shift, however, this is rarely practicable. It has been demonstrated that a 90 minute sample gives a reasonably accurate estimate of the TWA particularly if the process is a constant one. The more continuous the process, the more representative a short term sampling will be. It is evident that the skill of the sampler operator and a familiarity with the process are important factors in the assessment of an asbestos exposure. The rate of sampling may vary between 1.8 and 3.0 litres per minute depending on the airborne concentration of asbestos fibres.

The counting method used is that of Edwards and Lynch.[3] A segment of the filter is placed on a glass slide and treated to make the filter transparent. Counting of the fibres is done with an optical microscope using phase contrast illumination at 400 to 430 X magnification. The special counting graticule has reference marks which permit a rapid classification of fibres (a "fibre" is described as being over 5μm in length and having an aspect ratio of 3 to 1). The procedure is to count 100 fibres or 20 fields, whichever is less. A simple conversion is then made from the counts per field of view to fibres per cubic centimetre.

Sampling frequency is to be adapted to meet the needs of the local situation. During a start-up period or during a process change, frequent sampling may be required. The actual time interval will depend on the judgment of the person making the assessment.

NOTE: The Ministry of Labour recognizes that there can be considerable variability of fibre counts done by different operators in the same situation. In the hands of a skilled operator the reproducibility of the results can be expected to be at least 25% (plus or minus).[2] However, the actual fibre concentration in the air will also vary throughout a workday and the results of a sampling period of less than a full 8-hours requires interpretation by an experienced industrial hygienist. The Ministry recognizes, also, that there is a need for additional research to establish the validity of counting procedures as well as the relative significance of area and personal samples.

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Physical Parameters of Airborne Asbestos Fibres in Various Work Environments—Preliminary Findings

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The results of a pilot investigation to describe the physical parameters, length, aspect ratio, mass and shape of airborne fibres in a variety of industries producing processing and handling chrysotile, amosite and crocidolite are described. Samples of airborne dust were collected on nucleopore membrane filters and examined by scanning electron microscopy. The diameters and lengths of airborne fibres collected during the dumping of raw amosite at an asbestos products plant were greater than those of fibres collected during the application of amosite insulation. Chrysotile fibres collected in the carding area of an asbestos textile plant also tended to have smaller diameters than fibres collected in the dryer and bagging areas of an asbestos mill. The measurements of fibre dimensions indicate that the degree of protection afforded a worker by optical counts using the membrane filter technique is likely to depend on variety of asbestos and stage of processing. Preliminary results are not in conflict with experimental data suggesting that asbestosis might be related to the mass of airborne dust and primary malignant mesothelial tumors to exposure to fibres in a specific range of fibre diameter and length.

Introduction

ALTHOUGH ALL COMMERCIAL VARIETIES OF asbestos have been shown to produce mesothelomas when inoculated intra-pleurally into rats,[1] primary malignant mesothelial tumours do not appear to occur with equal frequency among men working with asbestos (Table 1). There is some indication that the prevalence of radiological changes (asbestosis) and lung cancer mortality also vary with occupation.[2,3,8-11] These differences in health experience might be explained by differences in fibre type and the quality and quantity of exposure. Epidemiological investigations in several occupational groups indicate that radiological changes and lung cancer are related to level of exposure.[3,5,9,11] Smoking appears to be an additional factor which complicates the asbestos lung cancer relationship.[12] The relationship between primary malignant mesothelial tumours and levels of exposure are not clear and it seems probable that some other factor or factors must be sought in order to explain the uneven distribution of this tumour among occupational groups.

The ability of a fibre to initiate a disease process in the lung or on the pleura depends on its penetration, deposition, retention, and biological activity. These depend mainly on the physical characteristics of the fibre. First, the settling velocity of a fibre depends on its actual diameter,[13] and explains why fibres as long as 200 μm are sometimes found in lung at autopsy. Second, straight fibres are more likely to penetrate deeper into the respiratory airways than curly fibres.[14] Third, diameter and length might both be important in the ability of asbestos and other fibres to induce mesothelial tumours.[15,16]

These physical parameters of airborne fibres in the work environment have not been previously reported. The possibility that the characteristics of asbestos fibres such as diameter and shape might change during processing prompted a pilot investigation to determine the physical parameters of air-

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TABLE I
Primary Malignant Mesothelial Tumours Reported in Studies of Various Occupational Groups.

Study Group	Total Deaths	No. Mesothelioma
Insulation Workers (USA) (mixed exposures) Selikoff *et al* (1969)[2]	380	22
Chrysotile Miners and Millers (Canada) McDonald *et al* (1971)[3]	3,270	5
Anthophyllite Mining (Finland) Meurman *et al* (1972)[4]	248	0*
Asbestos Textile Industry (UK) (mixed exposures) Newhouse (1969)[5]	436	20
Crocidolite Mining (S. Africa) Webster (1972)[6]	—	88
Amosite Mining (S. Africa) Webster (1972)[6]	—	2**
Amosite Factory (USA) Selikoff (1972)[7]	105	5

*One suspected case
**Amosite mining only

borne asbestos fibres to which workers in different occupations are probably exposed.

Methods

Conventionally submicron airborne asbestos fibres have been examined by transmission electron microscopy. This has involved considerable handling of the dust samples and the original fibre diameter distributions in the samples may have been altered in the process. In this study, samples were examined by scanning electron microscopy, which required much less laboratory manipulation.

Samples of airborne asbestos dust were collected at the following locations using nucleopore membrane filters (G.E. 40, 37 mm diameter, pore size 0.4 μm):

(1) at the carding machine in an asbestos textile plant which used chrysotile only.

(2) at an asbestos products plant during the emptying of bags of amosite and crocidolite into hoppers "dumping".

(3) at a local oil refinery during the application of insulation materials containing mainly amosite.

(4) in the dryer and bagging areas of a chrysotile mill.

Two samples of airborne dust were examined from each location.

Preparation of Samples for Analysis

A circular portion of the nucleopore filter was coated with 150 Å layer of gold-palladium (60-40) and examined on a stereoscan electron microscope (SEM) type 96113 Mark 2A. Scans were performed across the diameter of the filter beginning at the centre of the original filter which was on circumference of the mount. High resolution electron photomicrographs of the fibres in random fields were taken.

The magnifications on the SEM were identical to those used by Timbrell[17] for the measurement of fibres using transmission electron microscopy, i.e. 2,500x for amosite, and 6,000x for crocidolite. We also used 6,000x for chrysotile. Measurements were made from photographs using a magnified scale and for each fibre we measured:

(1) true diameter (d_t)—(the width of the central portion of a fibre excluding particles attached to the fibre)

(2) coil diameter (d_c)—(the maximum fibre diameter including attached particles or widest diameter of coil)

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(3) coil length (l_c)—(the length of the fibre as it appeared on the filter)

(4) true length (l_t)—(the length of a fibre after straightening)

(5) coil-aspect ratio (l_c/d_c)—(the ratio of coil length to coil diameter)

(6) aspect-ratio (l_t/d_t)—(the true length to true diameter ratio)

(7) mass (m)—calculated from the true fibre diameter and stretched fibre length by assuming that all fibres have a circular cross-section. This assumption was not strictly valid for amosite in which it is rectangular but was a close approximation for crocidolite in which it is eliptical or circular and for chrysotile which in cross-section has a swiss roll appearance.

As the way in which amosite fibres would be orientated on the filter was not known, it was probably reasonable to use a circular cross-sectional area for calculation of average mass. The densities used in the calculation of mass were 3.45 g/cc for amosite, 3.37 g/cc for crocidolite and 2.55 g/cc for chrysotile.

Measurements of the parameters of fibres taken from various regions of the filter showed that the distribution was reasonably uniform.

Results

The ranges and median diameters, lengths, mass and aspect ratios of airborne asbestos fibres by fibre type and process are summarized in Table II.

True Fibre Diameter (d_t)

The median diameter of amosite fibres during the emptying of bags (dumping) of raw amosite at the asbestos products plant (0.415 μm) was greater than during application of amosite insulation (0.370 μm), but the range was almost the same. The minimum diameter of the fibres was slightly less than reported by Timbrell *et al*[18] (0.098 μm). Cumulative frequency distributions showed a tendency for airborne amosite to be finer during the application of insulation.

The median true fibre diameter for crocidolite during dumping was 0.248 μm (range 0.011 to 1.347 μm), which was less than for the amosite fibres (Table II), collected during the application of insulation. The presence of fibres with diameters as small as 0.01 μm indicated that a small amount of chrysotile may have contaminated the sample; amosite and chrysotile were also used at this plant. The modal diameter for crocidolite was 0.25 μm which was greater than the peak reported for the UICC standard reference samples of crocidolite by Timbrell *et al* (0.16 μm).[18] This difference may be related to the source of the fibre and methods of treatment before measurement.

For chrysotile, the median diameter was 0.17 μm in the dryer, 0.16 μm in the bag-

TABLE II
Physical Parameters of Asbestos Fibres

		d_t (μm)	l_t (μm)	d_c (μm)	l_c (μm)	Mass (x 10^{-12} gm)	Aspect ratio, l_t/d_t
Amosite	median	0.415	3.90	0.510	3.60	2.200	8.00
Dumping	range	0.072–2.922	0.57–38.04	0.072–3.00	0.57–38.04	0.011–251.278	3.06–50.16
Amosite	median	0.370	2.50	0.428	2.93	1.000	7.20
Application	range	0.071–2.482	0.47–30.94	0.075–3.36	0.47–33.39	0.006–126.033	3.10–50.81
Crocidolite	median	0.248	2.50	0.292	2.49	0.538	9.65
Dumping	range	0.011–1.347	0.17–16.18	0.051–1.347	0.17–16.18	0.0001– 38.714	3.22–56.18
Chrysotile	median	0.173	1.25	0.317	1.18	0.126	6.30
Drying	range	0.011–1.446	0.22–14.88	0.052–2.265	0.22–16.12	0.0012– 25.866	3.07–64.41
Chrysotile	median	0.158	1.35	0.264	1.24	0.128	7.25
Bagging	range	0.013–1.135	0.34–9.81	0.013–1.551	0.27–15.01	0.0017– 23.011	3.07–36.76
Chrysotile	median	0.150	1.00	0.233	0.93	0.068	6.60
Carding	range	0.011–1.251	0.26–12.24	0.011–1.829	0.23–12.16	0.0001– 15.432	3.04–81.95

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ging area and 0.15 μm during carding. The percentage of fibres less or equal to 0.5 μm in diameter was 67, 82, and 88 respectively in the dryer, bagging and carding areas.

Coil Diameter (d_c)

There were 3.3 per cent of airborne fibres collected during the dumping of amosite and 0.5 per cent during the application of amosite insulation which were classified as not straight. These deviations from straightness were due mainly to the irregular margins of fibres resulting from attached particles. The coil diameters of amosite were larger than the true diameters (Table II). Crocidolite fibres were generally straight and their median coil diameter only very slightly larger than the median true diameter. In contrast, chrysotile fibres had narrower coil diameters at the later stages of processing.

True Fibre Length (l_t)

As there were few "curly" amosite fibres, the median true or stretched lengths were virtualy identical to "coil lengths". The true lengths of fibres ranged from 0.57 μm to 38.04 μm (median 3.90 μm) in the manufacturing plant and from 0.47 μm to 30.94 μm (median 2.50 μm) during the application of insulation. A cumulative frequency distribution showed that insulation workers were exposed to shorter fibres.

Crocidolite fibres during dumping ranged in length from 0.17 μm to 16.18 μm with a median length of 2.50 μm.

The median true lengths of chrysotile fibres collected in the dryer, bagging and carding areas were 1.25 μm (range 0.22-14.88), 1.25 μm (range 0.34-9.81) and 1.0 μm (range 0.26-12.24) respectively. The distributions of fibre lengths showed that fibres in the dryer area were longer than elsewhere. The percentages of fibres with lengths greater than 5 μm in the dryer samples were 11.1 in the bagging area 4.8, and in the carding areas, 2.3.

Coil lengths also decreased from dryer to carding operations.

Aspect Ratios (l_t/d_t)

Aspect ratios for amosite ranged from 3.1 to 50.2; fibres were defined as having a length to diameter ratio of 3:1. The median ratio for airborne amosite collected in the manufacturing plant was 8.0 and for that collected during the application of insulation was 7.2. The median aspect ratio for crocidolite was 9.7, which was slightly greater than for amosite, although ranges were similar. Although there were differences in the ranges and median aspect ratios (l_t/d_t) of fibres collected in the dryer, bagging and carding areas (Table II), the median coil aspect ratios in the dryer, bagging area and textile plant were similar, 4.4, 5.0, 4.4 respectively.

Eight per cent of fibres collected at the dryer, 9 per cent of fibres collected during bagging and 12 per cent of all chrysotile fibres collected during carding were considered to be curly (i.e. not straight).

Mass

The range and median mass of the various fibre types by process are shown in Table II.

Length-diameter Matrices

Recently experimental evidence has suggested that fibres with diameters less than 0.5 μm and with lengths greater than 5 μm to 10 μm might be responsible for the production of mesothelial tumours.[15] Length-diameter matrices for airborne amosite, crocidiolite and chrysotile fibres are shown in Figure 1.

The percentages of fibres with diameters less than 0.5 μm and of length greater than 5 μm during the handling of raw amosite and during the application of insulation were 17.0 and 18.3 respectively. The results for crocidolite were very similar to the results

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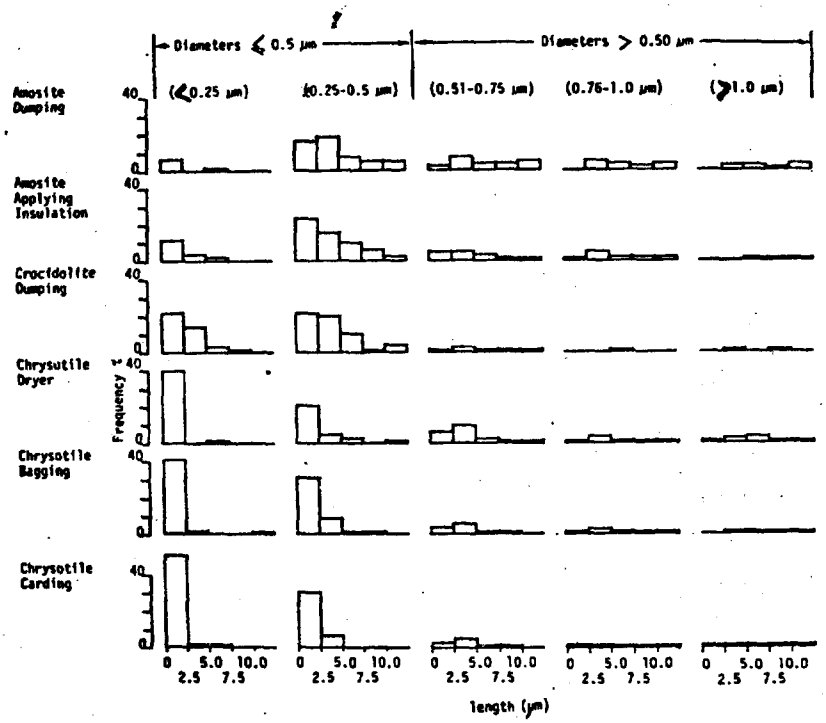

Figure 1. Length and diameter distributions of fibres collected during various asbestos processes.

for amosite with 17.5% of fibres in this size range.

The percentages of chrysotile fibres in the dryer, bagging, and carding areas with coil diameters less than 0.5 μm and coil lengths greater than 5 μm, were 1.45, 1.0 and 0.4 respectively. The proportion of fibres with these dimensions decreased from the dryer through to the carding operation, but the number of fibres examined was too small for differences to be reliably assessed.

When true lengths and true diameters of chrysotile were considered the percentage of fibres greater than 5 μm in length and less than 0.5 μm in diameter measured on two samples of dust from each area was 4.7 and 8.0 per cent at the dryer and 2.8 and 3.4 per cent in the bagging area and 1.1 and 2.0 per cent in the carding area. This trend was similar to that shown by the coil lengths and coil diameters.

The total fibre concentrations in the various areas studied were quite varied, being generally highest in the carding area.

Submicron Diameter Fibres

If we assume that the optical count of fibres by membrane filter technique is limited to fibres more than 0.5 μm diameter and more than 5 μm length, the percentage of the total fibre count that would be observed by optical methods is shown in Table III. Considerably more amosite fibres would be observed optically than chrysotile or crocidolite.

Discussion

This pilot investigation showed that differences in the physical parameters of airborne fibres at various stages of processing could be detected. Although the number of samples examined was small and the results

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TABLE III
Percentage of Fibres Greater than 0.5 μm Diameter and 5μm Length

Operation	Percentage of total fibres of diameters >0.5 μm diameter and length >5 μm
Dumping amosite	27%
Applying amosite insulation	13%
Dumping crocidolite	4%
Drying chrysotile	10%
Bagging chrysotile asbestos	4%
Carding chrysotile in a textile plant	2.1%

require confirmation, certain observations were worthy of note . . .

(1) The number of fibres visible by optical microscopy depends on the fibre type. In the control of asbestos exposure and in the investigation of dose-response relationships these differences could be important. Counts would tend to be underestimated when fibre diameters were fine, and, hence, more respirable. Existing environmental standards take no account of this.

(2) Amosite fibres tended to decrease in diameter from the raw amosite dumping stage to the application of insulation stage while the lengths of fibres were distinctly less in airborne dust collected during the application of amosite insulation. Chrysotile fibres also tended to be smaller in diameter and length at the later stages of processing. As the settling velocity of a fibre depends on its fibre diameter, the median diameters and the overall diameter distributions suggested that *on diameter criteria only* (i.e. excluding factors which might influence interception and diffusion), chrysotile encountered during carding was potentially the more respirable of the fibres examined.

(3) The results suggest that for the same airborne mass concentration the total number of fibres to which persons working in a chrysotile textile plant on a carding machine would be exposed would be about 30 times that of a man dumping amosite. Experimentally, chrysotile fibres do not readily penetrate the lung because they are intercepted. However, the chrysotile fibres in these airborne dust samples had coil diameters less than 3 μm (the limit of respirability). It seems likely, that once airborne, chrysotile fibres such as those encountered in this study are capable of penetrating deep into the respiratory system.

The lower prevalence of radiological change among chrysotile asbestos workers than among insulation workers would suggest that asbestosis is related to mass rather than fibre concentrations. Experimental evidence supports this for amphibole fibres.[19] For the same concentration, amosite workers would potentially inhale up to 31 times more asbestos in mass than chrysotile workers. Other factors such as solubility, translocation and fibre length are also likely to play a role, once the fibre has entered the lung or penetrated to the pleura.

(4) Consideration of fibre diameter alone indicates that chrysotile encountered during carding is potentially more respirable than chrysotile or other fibres at different stages of processing. The rarity of mesothelial tumours among chrysotile miners and millers, when compared to insulation workers (Table I), is probably related to some additional factor such as fibre type or the proportion of long fibre in the airborne dust.

The length-diameter matrices for the vari-

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ous types of asbestos provided some information concerning this. When the fibre types and areas where samples were taken were ranked according to the percentages of fibres with diameter less than 0.5 μm and length greater than 5 μm present in airborne dust, the following was the result.

	Percentage of fibres with diameters <0.5 μm and length >5 μm.
Amosite application of insulation	18.3%
Crocidolite	17.5%
Amosite Dumping	17.0%
Chrysotile Dryer	1.45%
Bagging	1.0%
Carding	0.4%

If the combination of length and diameter (<0.5 μm diameter >5 μm length) was the only factor responsible for the production of mesothelial tumours, the results presented here would suggest that the hazard for the manufacturer and insulation worker using amosite would be similar, but considerably greater than for chrysotile workers. Taking penetration into account, there might only be a slightly increased risk for insulation workers over factory workers using amosite. This is supported by epidemiological studies of insulation workers and workers in an amosite plant.[2,7]

Conclusion

In conclusion, we recognize that the inferences made in this report are based on limited data and may not be supported by more extensive measurement. Nevertheless, the findings are sufficient to show the complexity of interpreting variations in the physical characteristics of fibres. The measurement of physical parameters of fibres in various industries is feasible and observations to test a physical parameter hypothesis are not in conflict with experimental or epidemiological evidence. Our results so far support the experimental work on animals suggesting that asbestosis is related to the mass of airborne dust inhaled and that primary malignant mesothelial tumours are related to exposure to fibres in a specific range of fibre diameters and lengths.

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Seventeenth Graduate Summer Session of Statistics in the Health Sciences

The seventeenth annual Graduate Summer Session of Statistics in the Health Sciences will be held at Vanderbilt University, Nashville, Tennessee, June 22 to August 1, 1975.

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For further information, write to Dr. Charles F. Federspiel, Summer Session of Statistics, Division of Biostatistics, Department of Preventive Medicine, Vanderbilt University, Nashville, Tennessee 37232.

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