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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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.

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.

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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]

<u>Note</u> - 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.

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

3. <u>Caution Signs and Labels</u>

(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. <u>Special Clothing</u>

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. <u>Work Practices</u>

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.

BIBLIOGRAPHY

1. Enterline, Philip E.: Pitfalls in Epidemiological Research: An Examination of the Asbestos Literature Journal of Occupational Medicine/Vol. 18, No. 3/March 1976.

2. Rajhans, G.S. and G.M. Bragg, Ph.D.: A Statistical Analysis of Asbestos Fiber Counting in the Laboratory and Industrial Environment, American Industrial Hygiene Association Journal, December 1975.

3. Edwards, G.H. and J.R. Lynch: The Method Used by the U.S. Public Health Service for Enumeration of Asbestos Dust on Membrane Filters, Ann. Occup. Hyg. Vol. 11 pp 1-6 (1968).

4. Code of Federal Regulations, Part 1910.1001
Occupational Safety and Health Administration, Department of Labour, U. S. A. Revised as of July 1, 1975.

5. Occupational Exposure to Asbestos
U. S. Department of Health, Education and Welfare
National Institute for Occupational Safety and Health, 1972.

6. Selikoff, I.J., Hammond, E.C., Churg, J.,: Mortality experiences of asbestos insulation workers 1943-1968 in Pneumoconiosis Proceedings of the International Conference, Johannesburg, 1969 - Oxford University Press, 1970.

7. I. Doniach, K.V. Swettenham and M.K.S. Hathorn: Prevalence of Asbestos Bodies in a Necropsy Series in East London, Association with Disease Occupations of Domicilliary Address
B. J. of Ind. Med. 32-16-30/75.

8. Selikoff, I.J., E.C. Hammond, J. Churg - Asbestos Exposure, Smoking and Neoplasia, JAMA 204/106-112/1968

9. Toll: The Age Distribution of Cancer. Implications for Models of Carcinogenesis, J.R. Stat. Soc. 134/1971

10. McDonald, J.C., McDonald, A.D., Gibbs, G.W., Liemiatiski, J. and Rossiter, C.E.: Mortality in Chrysotile Asbestos Mines and Mills in Quebec, Arch. Envir. Health 22-(677-686) 1971.

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.

APPENDIX II

ASBESTOS

DUST HAZARD

ASBESTOS DUST MAY BE HARMFUL TO YOUR HEALTH

AVOID BREATHING DUST

WEAR ASSIGNED PROTECTIVE EQUIPMENT

DO NOT REMAIN IN AREA UNLESS YOUR WORK REQUIRES IT

This study develops a decision method for evaluating the social acceptability of industrial controls on hazardous materials. Decisions are based on a "multiple criteria approach" that jointly considers measures such as risk-benefit tradeoff, minimum reducible health risk, maximum acceptable cost and implicit value of human life. Health risks are calculated by combining separate estimates of production and usage patterns, emissions to air and water, effectiveness of controls, pollutant dispersion and human susceptibility. Economic benefits consider employment, trade and consumer impacts, as well as direct costs of controls. The analysis focuses on asbestos as an example hazard. Relative values of hazard reduction alternatives are examined for asbestos manufacturing exhaust filters and for asbestos substitutes in brake linings. Preliminary calculations indicate risk reductions of these alternatives cannot justify their social costs.

Risk-benefit analysis for industrial and social needs

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The term risk-benefit analysis has become a commonplace expression as both the public and governmental agencies become increasingly concerned with environmental protection and the quality of life. Attendent with this concept is the notion that there is some sort of sheet used in the decision-making process for regulating environmental quality.

Informal comparisons of risks and benefits do indeed occur in setting most regulations. The underlying decision structure, however, does not always incorporate three crucial considerations: the necessity of making tradeoffs; the likelihood that tradeoff impacts are noncommensurate (that is not expressed in the same units, as dollar benefits vs. loss of life); and uncertainty about impacts of alternative decisions. Formal risk-benefit analysis is useful here because it systematically applies economic theory and decision analysis to help the policymaker understand the tradeoffs.

Risk-benefit analysis has different comparisons for different persons. Some ecologists, for example, value preservation of nature over costs of control; they might think it meaningless to compare ecological parameters with any economic concept. On the other hand, many industrialists place greater weight on the costs of preserving nature. Uncertainties or perhaps even ignorance of environmental consequences, can significantly affect an individual's value system. Fear of unknown risks often instills greater conservatism in action than is warranted by the objective situation. For instance, a minute but well publicized probability of death from exposure to a hazardous material might make an unknowing person think that he will be affected. Aggregated over all individuals, this risk could thus be exaggerated over its actual level.

Publicity about risks and benefits could also be a poor indicator of individual values. Surveys are thus important in assessing variations of public opinion, patterns of risk-taking among members of the general population and perceptions of risks and benefits.

A large spread of personal evaluations should be expected given data deficiencies on risks and benefits. Information about ambient concentra-

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tions of hazardous materials and the degree of human exposure is not generally available. More fundamental is the lack of information on inherent biological effects of these chemicals on human health. Epidemiological studies have been outstripped by the technology to produce and distribute an ever growing number of hazardous materials. For some new chemicals, the regulatory agency relies on the manufacturer and developer of derived products to furnish health information. But without a character or checklist of needs for conducting risk assessments, the manufacturer cannot really be expected to assume this additional responsibility.

Insights on benefits of product use are typically as deficient as judgements on hazard levels. Conditions for optimality in regulation depend on the "welfare function" to be maximized. One criterion frequently employed is maximum value of total output, which in principle should include such non-monetary aspects as safety, aesthetic qualities and reductions in physic tension or anxiety. Economists generally contend that these benefits of controlling hazards can be assessed collectively as the sum of the "willingness-to-pay" of all individuals affected by the action. Analytically, this requires the formulation of a consumer demand curve for feasible controls. Benefit assessment then involves integration of the area under this curve.

Determination of the overall curve relating benefits to emission control policies requires a multi-step analysis, in which the economics input occurs only after exposures and health effects have been determined. Consequently, the lack of benefit estimates for regulations can be only partly blamed on economists. The lack of meaningful exposure and dose-response relationships falls in the domain of the life and physical sciences. Without accurate knowledge of these relationships, attachment of economic values is a misleading and perhaps futile exercise.

Most regulatory agencies as well as researchers lack an appreciation of the complexities underlying benefit estimation. As a result, they tend to establish controls which minimize risks without explicitly considering product benefits. "Zero-tolerance laws," which

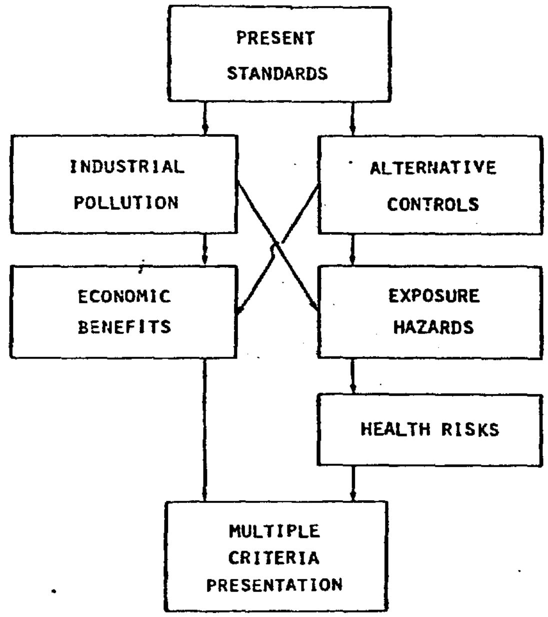

Figure 1 – Risk/benefit methodology: Analytical Steps.

prohibit any detectable amount of a hazardous material, are inflexible and can quickly become too costly. They may obligate large budgets; they may remain in effect over an extended time span; and they may adversely affect the lives of many individuals.

Although risk-benefit analysis should make decision-making more comprehensive, there are a number of limitations to its current usefulness. First, it represents an abstraction of reality and is usually simplistic. It may not be translatable into practice if it does not adequately account for all impacts. Second, the magnitude of uncertainity about both risks and benefits is typically much greater than the magnitude of their most likely values. This difficulty emerges as the most severe constraint of any formal analysis. Proxy measures are often used to measure impacts, and these proxies may be quite crude. Some authors, for example, represent risk in terms of death rates.[1] While vital, this measure fails to incorporate non-fatal results that are likely to be far more prevalent and in some cases more damaging in total than the number of deaths.

Another limitation is that risks and benefits of various actions do not usually come in single pairs. Rather, each control level implies a diversity of beneficial and costly impacts. The analyst, with limited resources and time, must

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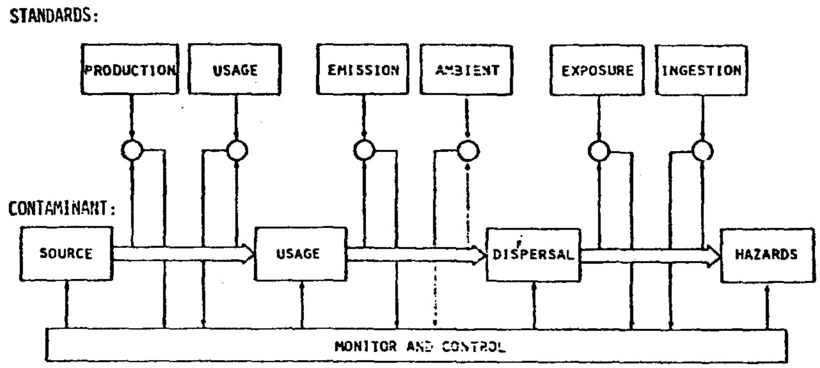

Figure 2–Hazardous waste system.

select the most important impacts and exclude those of hopefully less importance. As he learns more, he may change the list of impacts. Still another limitation concerns weights assigned to risks. Individuals seem to waver in their evaluation of generally low-probability events as needs and perspectives fluctuate.

There have been few attempts to consider such limitations in formal risk-benefit analyses. Because highway data are readily available, risk-benefit studies are most numerous for vehicular accidents and choices of safety features for automobiles, (e.g.).[2,3] One extensive investigation of risk-benefit ratios for a number of hazardous events, such as driving and being struck by lightning selected "fatalities per person-hour of exposure" as the measure of risk and a benefit index defined as "value to the individual" in the denominator of a risk-benefit ratio.[1] The benefit in most cases was quantified as the monetary investment that consumers are willing to support for a risky venture.

Another more formal, theoretical model represents benefits of an item as the price a consumer is willing to pay for it.[4] As hazards or risks increase with item use, its value declines correspondingly. However, there is an additional "non-pecuniary" part of risk, he claims, beyond which the consumer or general public refuses to buy or use the item. This implies the existence of a threshold level of risk acceptance. Whether such a level actually exists was not demonstrated.

In the remainder of this paper, we present a new approach toward risk-benefit analysis. It incorporates risk and benefit comparisons, as in the above referenced studies. But it goes beyond their scope by including uncertainty factors and by showing how various decision-making approaches can result in different priorities. The conceptual model to be presented was applied to a selection of feasible controls on hazardous materials, namely, cadmium and asbestos usage in the United States.[5]

The methodology follows very closely that recommended in the recent National Academy of Sciences report on Decision Making for Regulating Chemicals in the Environment.[6] The most significant aspect of this methodology is its reliance on a "multiple criteria" approach. A multiple criteria approach involves the consideration of many factors bearing on the decision in addition to those of "risk" and "benefit," such as "minimum reducible risk," "maximum socially acceptable risk," "maximum acceptable cost," and "value of human life."

As shown in Figure 1, the analysis starts with a review of present standards and proceeds to parallel examinations of the existing pollution system and alternative controls that might be applied to it. The parallel approach continues with second stage investigations of economic benefits on one branch and of population exposures and resultant health hazards on the other. Finally, the economic benefits and the health risks are combined with other relevant parameters in a graphical presentation of the multiple criteria affecting the decision. This presentation is applied under a variety of possible decision rules to derive acceptable standards and develop priority research needs for future improvement of the decisions.

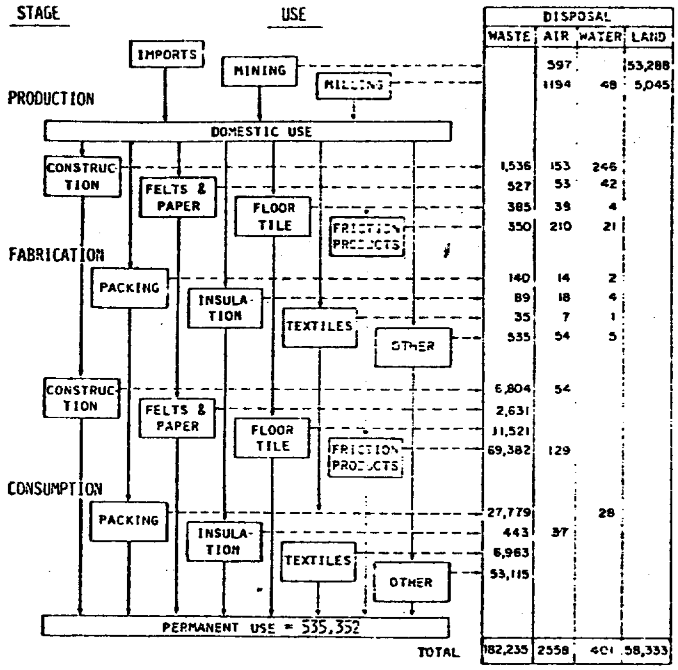

Figure 3—U. S. Asbestos flow (metric tons per year).

When we examine the top box, Present Standards, in more detail, we discover the kind of control system illustrated in Figure 2. This figure shows how various types of standards impinge on the hazardous waste system and on the monitoring and control mechanisms that accompany it. Standards must be compared with the actual amount of hazardous waste present at a given point in the hazardous waste flow system. For example, production standards must be compared with some measure of the actual production. The difference between the standard and actual production is used as a signal for the monitor and its control system to implement corrective measures if necessary. The same kind of feedback control must operate for usage standards, emission standards, ambient air or water standards, exposure standards and ingestion standards. Note from the figure however, that controls do not have to be applied at the same point that the monitoring signal is observed. Excessive exposures, for example, could be corrected by more restrictive controls over emissions concentrations. These multiple feedback possibilities allow for very complex control systems.

The multiple feedback loops do impose two requirements on the monitoring and control systems. Whatever standards are developed must be measureable and they must be consistent with other standards that they may be applied at other points in the control process. For example, the OSHA asbestos standard was reduced from 5 visible fibers to 2 fibers per milliliter on July 1, 1976. However, the visual methods currently used to count asbestos concentrations account for less than 5% of total fibers and no one knows whether the visual identifiable fibers affect health more than the smaller fibers.[7] Standards cannot be made very precise until this conversion problem is solved.

When we decide that some measure of pollution, say weight, is most meaningful, then the second step is to analyze the industrial pollution of various media (air, water, and land) that occurs at different stages of the system, from extraction to final disposal. These amounts are shown in Figure 3. We have used a materials balance approach to estimate the amounts of asbestos going to each use and each disposal media and reconcile their totals with our best estimates of overall use and disposal. The quantities (not all of which are shown in the figure) therefore are additive both vertically and horizonatally along the different flow paths. This requires some very difficult data search and

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EMISSION SOURCE:	MANUFACTURING FACILITIES	AUTOMOBILE BRAKES
CONTROL METHOD:	FABRIC FILTERS	SUBSTITUTE MATERIAL
ORIGINAL EMISSIONS:	547 METRIC TONS	129 METRIC TONS
CONTROL EFFECTIVENESS:	96%	100%
NATIONAL COST:		
LOW	$2.5 MILLION	$52 MILLION
MEAN	$3	$65
HIGH	$3.6	$81

Figure 4–Asbestos control costs and effectiveness.

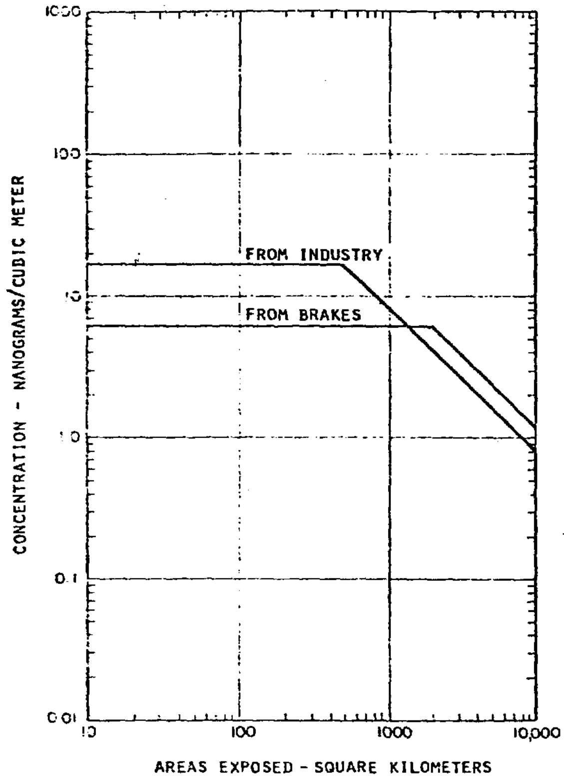

Figure 5–Asbestos air concentrations.

reconciliation work, almost to the point of being creative when the data is particularly sparse. However, we feel it is necessary in order not to miss large parts of the problem simply because the data is difficult to obtain. It gives us a plausible base from which to make an overall systems analysis and, at the same time, highlights areas where existing data may need to be refined. It also provides a first-order priority base for examining alternative controls.

In our analysis, we observe that although land disposal accounts for the great bulk of asbestos pollution, the largest source of air contamination is the 547 metric tons emitted from fabrication operations. We therefore have examined controls for asbestos fabricators. We also have examined the possibility of eliminating the second most significant airborne source: emissions from users of friction products (i.e., brake linings). Economic costs and operational effectiveness of control alternatives for these two pollution sources were examined in the next two steps, as shown in Figure 4. For asbestos manufacturing processes, we ascertained that fabric filters are the most effective method to control emissions.[8] They can eliminate about 96% of stack emissions. We estimated the total national cost for such a program would run about $2 million per year, plus another $1 million for monitoring and enforcement.

Substitution of other materials for asbestos brake linings is speculative since no satisfactory material has yet been found. But if one assumes that a material can be found for a 50% cost increase, the total extra cost would run to about $65 million per year.

These economic costs have to be balanced against the control program's reduction in public exposure and consequent hazard, which we also examined. Figure 5 shows the total areas now exposed in the U.S. to various concentration levels from industrial sources and from brake lining emissions, according to our simplified model of emission sources and air dispersion. Note that industrial sources are more concentrated over a smaller area than are brake-shoe sources. Total exposure to the population is about 80 mg/m^3 from each source.

The big hurdle in our analysis, as in most such analyses, came in trying to develop a dose-response function to evaluate the effects of these exposures. To do this, we looked at death rate estimates for the three most important causes of death from asbestos: mesothelioma, other cancers and non-cancer respiratory diseases.

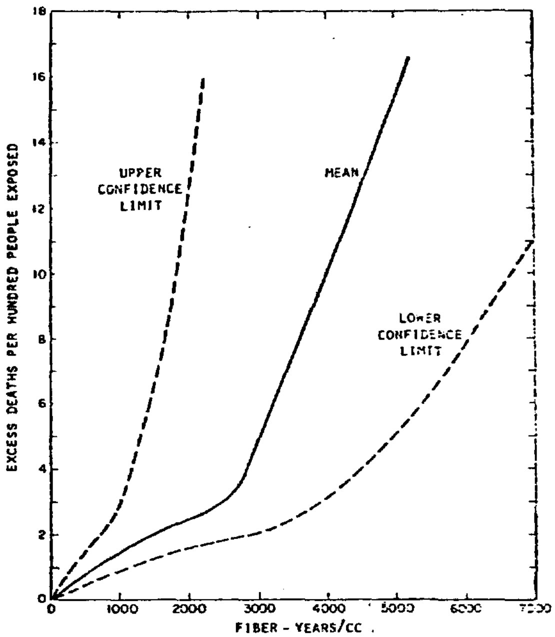

Figure 6–Asbestos dose-response: respiratory system disease.

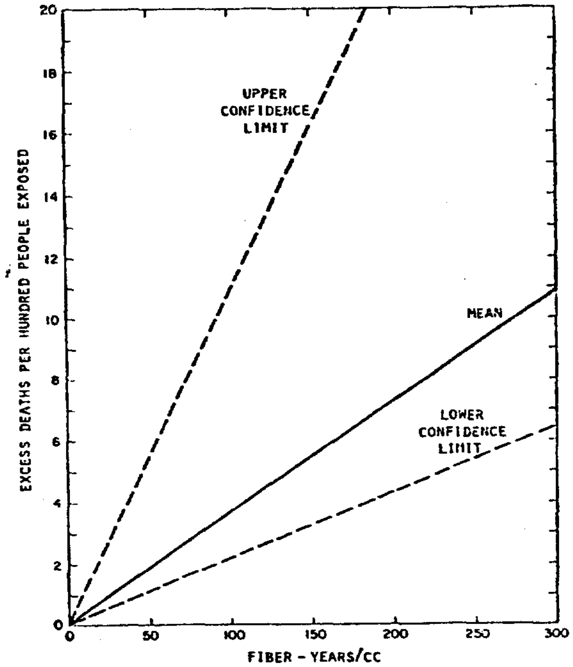

Figure 8–Asbestos dose response: mesothelioma.

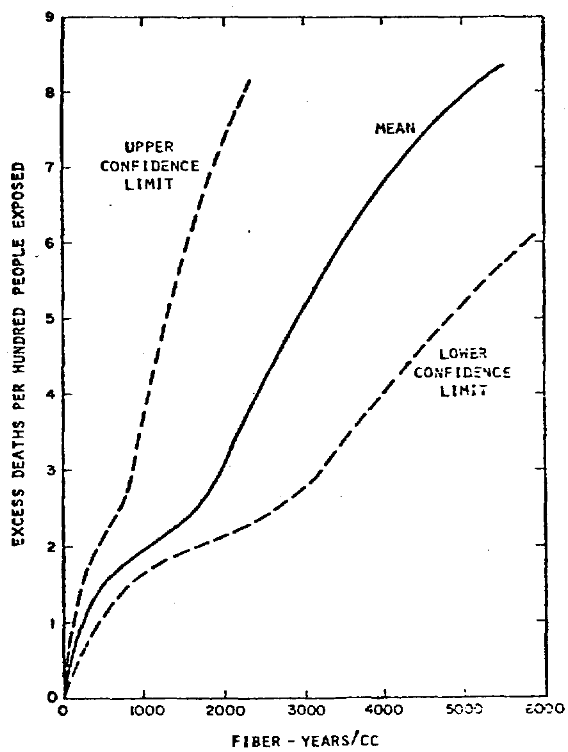

Figure 7–Asbestos dose-response: cancer (except mesothelioma).

Figure 6 shows excess deaths versus accumulated asbestos dosage for non-cancer respiratory diseases.[9] As with most of our data, we had some problems here in converting from one set of measures and dosage assumptions to another. For Figure 6, uncertainties in these conversion factors were the major uncertainties in determining the confidence limits that are shown.

Figure 7 illustrates excess death rates of people exposed to asbestos from all cancers except mesothelioma.[9] The Mae West shape is simply a matter of curve fitting and has no known physiological basis.

Excess deaths from mesothelioma only are shown in Figure 8. This diagram presents the widest uncertainty of all because its two references[10,11] both attributed their original data to a common source but differed by a factor of five in their resultant calculations.

By summing these three causes of excess death and combining their uncertainties as independent random variables, we arrived at the overall dose-response curves of Figure 9. We show these for analytical purposes as straight lines emanating from the zero intercept,

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although in fact we have no strong basis for assuming that the mean value is a straight line or that the uncertainties are fixed fractions of the dosage.

Mesothelioma appears to be the most significant contributor to the total excess death rate. Asbestosis produces a significant number of illnesses in addition to the excess deaths, but morbidity effects were not included in our analysis.

Hazards from ingestion of food and water were likewise not considered, since most studies of relative hazards indicate that the principal mode of er` ; of retained asbestos is via the lungs.[12-14]

Finally, we did not consider the effect of population mobility on the hazard, even though people with high exposures are statistically very unlikely to live next to an asbestos factory for their entire lives.

But these neglected effects are all relatively insignificant compared to the order-of-magnitude uncertainties and the other difficulties of reaching a tradeoff between risks and benefits. An overall method of evaluating and presenting risk/benefit tradeoffs is illustrated in Figure 10. Here, the two main parameters are measured in the separate dimension of the chart. The vertical scale shows risk in terms of lives saved by a control alternative relative to the existing "status quo" situation and the horizontal shows negative economic benefit (or cost) involved. Each alternative, surrounded by an ellipse representing the confidence limits, can be shown in terms of this tradeoff of lives versus non-health economic benefits. The dollar tradeoff between health and economic effects is not charted, but any particular valuation of human life can be represented by a diagonal line originating at the status quo position. Alternatives lying above this tradeoff line would be cost-effective in terms of that particular life valuation, whereas alternatives below the line would presumably not be.

Other constraints can also be shown on the chart; these act to restrict the feasible domain with which alternative solutions may be sought. At the top a "minimum reducible risk" line represents a limit in the number of lives that might be saved by any feasible alternative. The minimum reducible risk might be considered as a background level of contamination below which further reductions are extremely difficult. At the opposite side of the feasible domain, the "maximum acceptable social risk" represents a

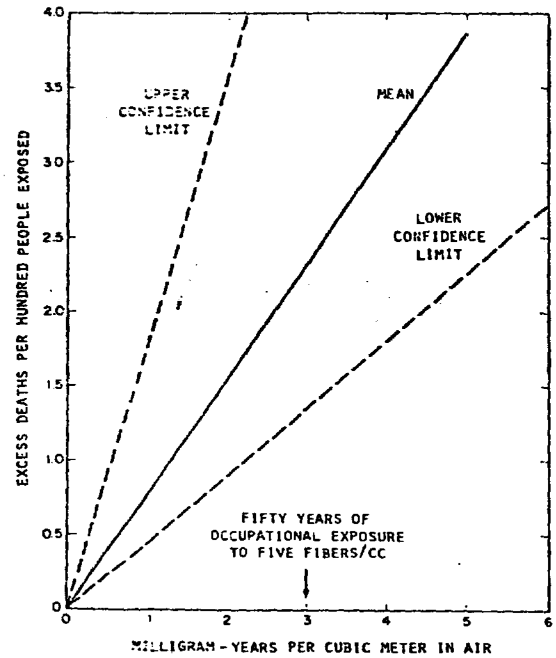

Figure 9–Asbestos dose-response: total.

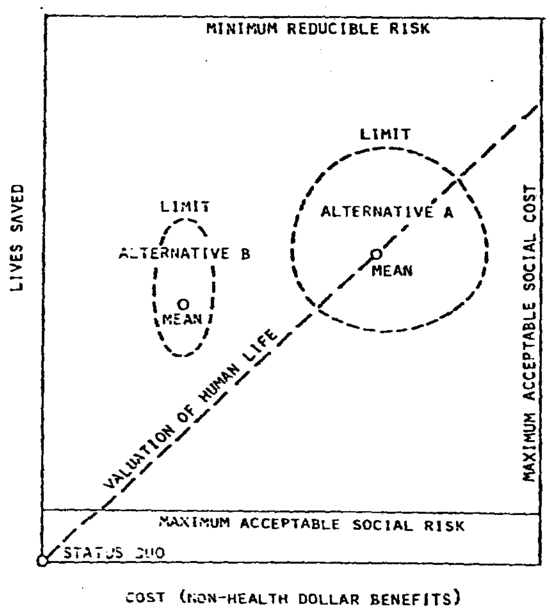

Figure 10–Multiple criteria comparison method.

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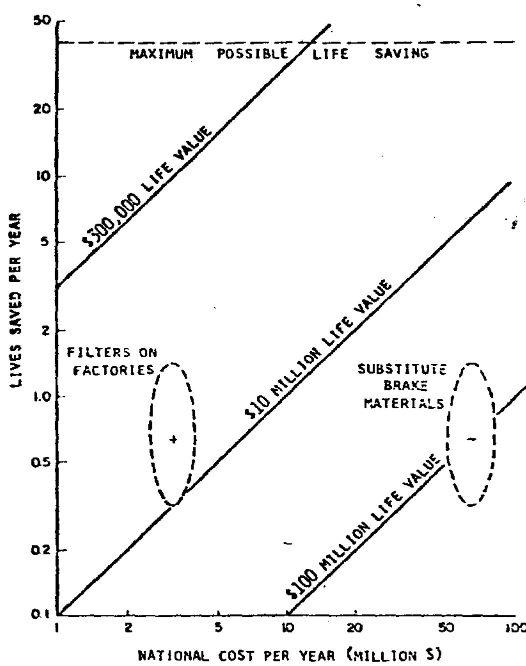

Figure 11 - Asbestos pollution control alternatives.

number of lives lost that will not be readily accepted by society. The maximum risk might be some vague social limit such as the prevailing rate of disease, or it may represent a "here and now" risk limit as defined by existing standards and regulations. Another constraint, not usually mentioned together with risk limits but nevertheless logically comparable, is that of "maximum acceptable social cost." This represents the maximum expenditure that society is willing to obligate at a particular time to solve a particular pollution problem. Equity considerations among the population are also now generally accepted as valid constraints. Equity considerations can be considered by making comparable charts for the analysis of each ethnic, income, geographic, generational, or other identifiable interest group. Together, the risk, benefit, and other constraints make up the "multiple criteria" problem.

When we apply this methodology to the asbestos control alternatives we obtain Figure 11, which has been derived specially for this paper. The first feature one notices in this logarithmic scaled chart is that lives saved by the two alternatives are about the same: namely, 0.6 person per year each, give or take confidence limits of about a factor of two in each direction. But implementation costs of the two alternatives differ by more than 20:1.

If one wishes to assign a value to saving lives, the chart shows that the factory filter alternative costs less than $10 million per life saved whereas brake substitution costs about $100 million per life. Neither alternative comes close to the $300,000 valuation that workers in hazardous occupations implicity give to their own lives[15,16] (see the upper diagonal line).

For this reason, both alternatives appear inefficient as measures for protecting the general public, if economic tradeoffs are considered. As always in such studies, however, we must qualify our conclusions. First, we have not considered potential effects of these measures on the health of industrial workers, which very likely would be more significant than those to the general public. Inhalation hazards to brake shoe installers, for example, would be completely eliminated by substitution of some other material for asbestos in brakes. Second, we have only examined two alternatives. Calculations based on our exposure model indicate that about 37 people per year could potentially be saved by eliminating asbestos from our ambient air (see top horizontal line in Figure 11). This potential life saving is 50 times as great as we get from either of the two alternatives considered, so additional protection possibilities certainly are worth investigating.

These and other factors that go beyond the assumptions of a particular analysis almost need to be considered by decision-makers in real life. Therefore, no single chart can give a complete answer. In addition to the formal trade-off charts of the type shown in Figures 10 and 11, a full presentation should include the listing of many supplementary criteria by which decision makers or other interested parties can derive their own values. Such a list is shown in Figure 12.[6]

Choices among the criteria presented can be made on the basis of many decision procedures, including those of expected value and ordinary old fashioned biases such as optimism, pessimism and probability. So many selection methods are available, in fact, that decision makers in some ways will have greater freedom

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	COMMENTS	ALTERNATIVES			
		NO REGULATION	BAN NOW	OPTION CONTROL A	OPTION CONTROL B
I. HAZARDS AVOIDED					
A. HEALTH					
B. ENVIRONMENTAL					
II. COSTS OF CONTROL					
A. DIRECT					
B. INDIRECT					
C. MARKET STRUCTURE					
III. BENEFITS LOST					
IV. DISTRIBUTION OF BENEFITS & COST					

Figure 12–Display of benefits and costs.

of action than they ever had before. The choice among alternatives may remain ambiguous. But at least decision makers will have explicit, quantitative means for weighing the practical tradeoffs that in the long run are going to have to be considered.

references

1. **Staff, C.**: Social Benefit Versus Technological Risk. *Sci. 165*:1232 (1969).
2. **Lave, L.B. and W.E. Wever**: A Benefit-Cost Analysis of Auto Safety Features. *Appl. Econ.* 2:1 (1970).
3. **Calibresi, G.**: *The Cost of Accidents.* Yale University Press, New Haven, Conn. (1970).
4. **Muehlhouse, C.O.**: *Risk-Benefit Analysis in Decision-making.* National Bureau of Standards, Washington, D.C., unpublished manuscript (1972).
5. **Moll, K.D., S. Baum, E. Capener, F.S. Dresch and R.M. Wright**: *Hazardous Wastes: A Risk-Benefit Framework Applied to Cadmium and Asbestos.* Stanford Research Institute for Environmental Protection Agency (September 1975).
6. Davies, J.C. ed: *Decision Making for Regulating Chemicals in the Environment.* Chapter 5 and Appendix H, National Academy of Sciences, Washington, D.C. (1975).
7. Background Information on the Development of National Emission Standards for Hazardous Air Pollutants: *Asbestos, Beryllium, and Mercury.* APTD-1503, Office of Air and Water Programs, U. S. Environmental Protection Agency, p. 34 (March 1973).
8. **Paddock, R.E.** *et al*: Comprehensive Study of Specified Air Pollution Sources to Assess the Economic Impact of Air Quality Standards, Vol. II, *Asbestos, Beryllium, Mercury.* PB-222 858, prepared for U.S. Environmental Protection Agency by Research Triangle Institute (August 1972).
9. **Enterline, P., P. DeCoufle and V. Henderson**: Mortality in Relation to Occupational Exposure in the Asbestos Industry. *J. Occup. Med. 14:897* (1972).
10. **Bruckman, L. and R.A. Rubino**: *Rationale Behind a Proposed Asbestos Air Quality Standard.* No. 74-222, presented at the 67th Annual Meeting of the Air Pollution Control Association, Denver, Colorado (9-13 June 1974).
11. **Selikoff, I.J.**: Asbestos Criteria Document Highlights. *ASSE J. (3)*:26 (1974).
12. A Study of the Problem of Asbestos in Water, by the American Water Works Association Research Foundation. AM. Water Works Assoc. Vol. 66, No. 9, Part 2, p. 1 (September 1974).
13. **Merliss, R.R.**: Talc-Treated Rice and Japanese Stomach Cancer. *Sci. 173*:1141 (1971).
14. **Masson, T.J., F.W. McKay and R.W Miller**: Asbestos-Like Fibers in Duluth Water Supply—Relation to Cancer Mortality *J. Am. Med. Assoc. 228*:1019 (1974).
15. **Thaler, R. and S. Rosen**: *The Value of Saving a Life:* Evidence from the Labor Market, paper presented 30 November 1973, published by University of Rochester.
16. **Melinek, S.J.**: *A Method of Evaluating Human Life for Economic Purposes.* Fire Research Note No. 950, Herts., England (November 1972).

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A method is described for calculating confidence intervals for particle or fiber concentration, and for dust collector penetration. The span of the interval depends upon the value of fiber concentration or collector penetration reported and upon the number of particles or fibres counted.

Uncertainty in particle counting and sizing procedures

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Introduction

The concentration of particles in a gas can be determined by passing a known gas volume through a filter and counting particles on representative filter portions. Particle concentrations are valuable to determine compliance with legal standards, as for asbestos fibers in workroom air, or to determine the particle size collection efficiency of a dust collection device by making counts of simultaneous upstream and downstream samples. For both applications, it is important to estimate the count reliability. Although enough particles must be counted to establish the validity of the result within acceptable limits, it is wasteful to insist upon excessive counting to obtain needlessly high reliability.

Particles for microscopic counting are conveniently collected on membrane filters[1,2] or electron miscroscope grids[1,3,4]. The "stratification" particle counting method[5-7] illustrated in Table I is often used to reduce counting time. An initial traverse is made by examining a representative number of fields under the microscope. All particles seen are segregated into convenient, continuous size categories. Subsequent traverses note entries for only those size ranges in which particles are present in relatively small numbers. The average number of particles in each size range per traverse, $\bar{x}$, is then calculated as shown in Table I. Stratified counting is a way to emphasize those particles whose concentrations are most difficult to assess with statistical reliability because of their relative rarity.

Nomenclature

A — inverse of the fraction of total filter area examined per traverse
G — inverse of the total volume of gas passed through a filter
m — number of an equal area, counting outward from filter center
M — total number of equal areas into which a filter is divided

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TABLE I

Data Tabulation for Particle Sizing by Stratified Counting[5]

TRAVERSE	PARTICLE SIZE RANGE, MICROMETERS < 0.44	0.45-0.62	0.63-0.88	0.89-1.29	1.30-1.79	1.80-2.49	2.50-3.49	3.50-4.99	5.00-7.09	7.10-10.00	TOTAL PER TRAVERSE
1	57	87	54	36	21	24	6	12	0	3	300
2							12	6	3	0	21
3									3	0	3
4									2	1	3
5									2	1	3
6									1	2	3
Total, N	57	87	54	36	21	24	18	18	11	7	333
Mean Count per Traverse, $\bar{x}$	57	87	54	36	21	24	9	9	1.8	1.2	300
Std. Deviation of Mean, $\sigma_{\bar{x}}$	7.55	9.33	7.35	6.00	4.58	4.90	2.12	2.12	0.55	0.45	
95% Confidence Interval	72 to 42	105 to 69	68 to 40	48 to 24	30 to 12	34 to 15	13 to 4.8	13 to 4.8	2.9 to 0.7	2.1 to 0.3	

n — number of traverses performed in a stratified counting procedure

N — total number of particles of a certain size counted through all traverses

N_{down} — N for filter downstream of a particle collector

N_{up} — N for filter upstream of a particle collector

P — number of particles per volume of gas

P_{down} — P for gas downstream of a particle collector

P_{up} — P for gas upstream of a particle collector

Pt — dust collector penetration (1 − efficiency), P_{down}/P_{up}

r_m — distance from center of filter to point where microscope is to be focused for equal area m

r_f — radius of filter

x — number of particles in a certain size range present in one traverse

$\bar{x}$ — mean number of particles in a certain size range found per traverse

σ — standard deviation of x

$\sigma_{\bar{x}}$ — standard deviation of $\bar{x}$

σ_{Pt} — standard deviation of Pt

Microscopic field selection

When a filter holder has a small diameter inlet relative to the filter diameter, the largest particles may concentrate on that part of the filter directly downstream of the gas inlet. Dennis and co-workers[8] found that such radial concentration gradients did not occur for particles smaller than 20 micrometers diameter when filter holders were used which had a ten degree included angle between gas inlet and filter surface. However, filter holders of this design are not always practical because of their large size.

To avoid bias when using a conventional holder with small inlet, fields are usually selected at random from a pie shaped piece of the circular filter paper. About twenty fields must be examined[2] to complete one unbiased estimate of the particle size distribution. Totally random field selection gives an unbiased estimate of particle concentration when a sufficiently large number of fields is examined. However, the same result can be obtained with fewer fields by an ordered approach. Because the pressure drop across a membrane filter is sufficient to assure uniform gas velocity normal to the filter surface, the volume of gas flowing through each equal, concentric area on the filter will be the same, unless the central areas become plugged because of excessive particle deposition there. The overall dust concentration for the gas sampled will be the average of the concentrations found in the gas passing through each of the equal areas. To utilize an ordered approach, the microscope should be focused at the center of each equal area ring present in the sector, and a single field examined. After one field in each equal area has been inspected, all data can be combined to make an entry for one traverse, as shown in Table I.

Additional traverses are made along different radii of the filter sector.

This equal area traverse method for locating counting fields is analogous to the method used for positioning a pilot-static tube when determining the average gas velocity in a round duct. Average gas velocity could be determined by measuring the velocity at many random points within the duct cross section and averaging the results found. However, the number of measurements needed to reach the same statistical reliability using this approach is greater than for the equal area method, and the random approach is not used. By analogy, it is as logical to use an ordered approach for locating counting fields on a membrane filter as it is to use it for locating pitot-static measuring points in a duct.

The distance, r_m, from the center of a filter of radius r_f to the midpoint of each of M equal areas can be found from

$$\frac{r_m}{r_f} = \sqrt{\frac{2m - 1}{2M}} \tag{1}$$

Here, m is the number assigned to an equal area, starting from the filter center and counting outwards. Alternatively, values can be found in a reference giving the relative distance from the wall at which a pitot probe should be placed in order to have an unbiased estimate of average gas velocity in a circular duct.[9,10]

95% confidence intervals

After stratified counting procedures have been employed and mean concentrations for particles in each size range calculated, it is important to determine confidence intervals for these values. Systematic sources of error such as anisokinetic sampling, inaccuracies of flow measuring devices, improper microscope calibration and the like can be minimized through careful experimental technique.[11] Assignment of particles to improper size categories is not a significant problem when trained observers use a standard Porton graticule for determining particle diameter.[12]

A source of non-systematic sampling error that cannot be eliminated by control of experimental procedures is associated with random variations in the number, x, of particles in a certain size range which are present in each traverse of a stratified counting procedure comprising in traverses. A Poisson distribution describes the variation in these x values [12-14]. The standard deviation of these values, σ, therefore equals the square root of the mean number of particles in that size range per traverse, $\bar{x}$, i.e.

$$\sigma = \sqrt{\bar{x}} \tag{2}$$

The standard deviation of the mean, $\sigma_{\bar{x}}$, is the standard deviation, σ, divided by the square root of n, the number of traverses.

$$\sigma_{\bar{x}} = \sqrt{\frac{\sigma^2}{n}} = \sqrt{\frac{\bar{x}}{n}} \tag{3}$$

From Equations 2 and 3,

$$\frac{\sigma_{\bar{x}}}{\bar{x}} = \sqrt{\frac{1}{n\bar{x}}} = \sqrt{\frac{1}{N}} \tag{4}$$

where N is the total sum of all particles in a certain size range counted through all traverses. Equation 4 is an application to stratified counting of the expression given by Chapman and Ruhf for the relative error associated with repeated counts of particles in liquid suspension.[15] Appropriate values for the standard deviation of the mean, $\sigma_{\bar{x}}$, are given for the data shown in Table I. The number concentration of particles in a certain size range, P, is proportional to x, the mean number of particles of this size per traverse, to the inverse, A, of the fraction of total filter area examined per traverse, and to the inverse, G, of the total gas volume passed through the filter.

$$P = \bar{x}\,A\,G \tag{5}$$

The standard deviation of a product can be found from[16]

$$\left(\frac{\sigma_{\bar{x}AG}}{\bar{x}\,A\,G}\right)^2 = \left(\frac{\sigma_P}{P}\right)^2 = \left(\frac{\sigma_{\bar{x}}}{\bar{x}}\right)^2 + \left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_G}{G}\right)^2 \tag{6}$$

With careful technique, the standard error associated with A and G can be made small compared to that for x. The substitution of Equation 4 into Equation 6 gives the relative standard error associated with a measurement of concentration, P.

$$\frac{\sigma_P}{P} = \sqrt{\frac{1}{N}} \tag{7}$$

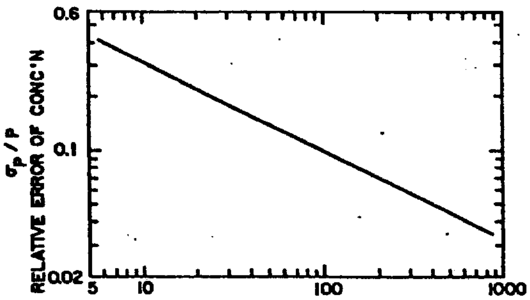

Figure 1 – Number of particles counted versus relative error of particle concentration.

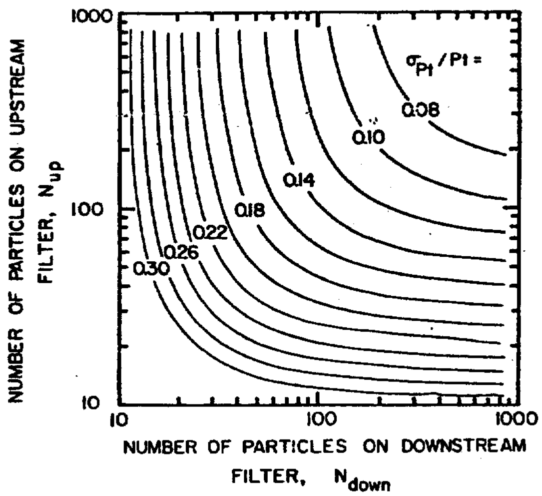

Figure 2 – Number of particles of one size counted on downstream filter versus number of particles of that size counted on upstream filter, with relative error of penetration as parameter.

A 95% confidence interval about P will extend plus and minus 1.96 times the standard deviation for P.

$$P \pm 1.96\, P \sqrt{1/N} \tag{8}$$

Figure 1 is a plot of the relative standard error of particle concentration, σ_P/P, against the number of particles counted, N.

Applications

When asbestos fibers are counted to determine compliance with an applicable standard, it is prudent to determine periodically the mean fiber concentration and associated confidence interval. The count should be continued only until the standard is no longer contained within the confidence interval, as one can then state with 95% certainty whether or not the standard has been met. When the fiber concentration is close to the standard, it will be necessary to count a larger number of particles to establish with 95% confidence whether or not the standard is met, than when the concentration is clearly well above or below the standard.

For example, after counting 50 asbestos fibers on a membrane filter, one might find that the mean concentration in the air passed through the filter was 1.5 fibers/cc. Equation 8 and Figure 1 show that one can state with 95% confidence that the true fiber concentration was $1.5 \pm 1.96 \times 1.5 \times (1/50)^{1/2}$, or from 1.08 to 1.92 fibers/cc. The upper bound of the confidence interval for this example is below the 1976 OSHA standard of 2.0 fibers/cc. Counting additional fibers would make the 95% confidence interval smaller, but would be unnecessary if 95% confidence that the standard is met is sufficient.

Equation 4 can also be used to determine confidence intervals about an experimentally determined value for dust collector penetration or efficiency. Penetration for particles of a certain size is the ratio of particle concentration in the downstream gas to the analogous concentration in the upstream gas.

$$Pt = \frac{P_{down}}{P_{up}} \tag{9}$$

The standard deviation of this quotient is[16]

$$\left(\frac{\sigma P_{down}/P_{up}}{P_{down}/P_{up}}\right)^2 = \left(\frac{\sigma_{Pt}}{Pt}\right)^2 = \left(\frac{\sigma P_{up}}{P_{up}}\right)^2 + \left(\frac{\sigma P_{down}}{P_{down}}\right)^2 \tag{10}$$

The substitution of Equation 7 into Equation 10 yields

$$\frac{\sigma_{Pt}}{Pt} = \sqrt{\frac{1}{N_{up}} + \frac{1}{N_{down}}} \tag{11}$$

Therefore, a 95% confidence interval about Pt will extend plus and minus 1.96 times the standard deviation of Pt, as shown in Equation 12.

$$Pt \pm 1.96\, Pt \sqrt{1/N_{up} + 1/N_{down}} \tag{12}$$

Equation 11 indicates that the relative error in penetration for particles of a certain size is only a function of the total number of particles of that size counted upstream, N_{up}, and downstream, N_{down}, of the collector. This relationship is plotted in Figure 2.

Equation 11 and Figure 2 show, for example, that to be 95% confident that pentration of particles in a certain size range is between 40 and 60% ($1.96\ \sigma_{Pt} = 10\%$ with mean penetration of 50%) it will be necessary to count 200 particles in this size range on the upstream filter and 200 particles in the same size range on the downstream filter. Alternatively, 500 particles counted upstream and 125 downstream would give the same result. However, the fewest total particles that must be counted to achieve a given relative error in penetration will always be found when the number of particles counted on the upstream and downstream filters is equal. This can be proven by differentiating Equation 11 with respect to N_{up}, setting the derivative equal to zero, and proceeding in the usual manner. When the particle deposit is less dense on the downstream filter, it becomes necessary to make more traverses for that filter in order to count about the same number of particles as are counted on the upstream. Or, a larger field size could be used for the less dense filter. When the particles observed on a filter are separated into many size categories to determine collector particle size efficiency, it is necessary to observe a large total number of particles to generate adequate confidence in the penetration or efficiency results for each size range considered.

When it is desirable to maintain a 95% confidence interval of constant size, i.e. a constant value of σ_{Pt} for all size ranges, Equation 12 shows that fewer particles need be counted in each size range as penetration decreases. The stratified counting technique can be used with good effect to concentrate the microscopist's efforts on the size ranges where penetration is high. Therefore, it is worthwhile to identify these size ranges as soon as possible by making a preliminary estimate of penetration based on an initial traverse of the upstream and downstream filters.

This method of calculating confidence intervals applies whenever concentrations are determined by counting. The techniques outlined above can be used for data from automatic counting devices such as optical instruments working on light scattering principles, as well as for data from other automatic counting devices.

Summary

An equal area traverse method is described for selecting microscopic fields when counting particles or fibers on a membrane filter. This method is analogous to that used to position a pitot-static tube in a duct when determining average gas velocity. The equal area traverse approach is an aid in avoiding inadvertent counting bias due to nonrandom field selection.

Although confidence intervals are important to establish the significance of particle concentration or collector efficiency data, they are seldom calculated or reported. When particle size data are generated by a stratified counting procedure, the method described can be used to establish with 95% confidence whether or not mean concentrations are below or above a fixed value.

Confidence intervals about values of penetration or efficiency can be calculated in a similar manner. The stratified counting approach allows the microscopist's efforts to be concentrated onto those particle size ranges where small confidence intervals for penetration are the most difficult to achieve. Charts have been prepared that make it possible to determine easily the number of particles or fibers which must be counted to assure desired confidence intervals.

References

1. SILVERMAN, L., C. E. BILLINGS and M. W. FIRST: *Particle Size Analysis in Industrial Hygiene.* Academic Press, New York (1971).
2. EDWARDS, G. H. and J. R. LYNCH: The Method Used by the U. S. Public Health Service for Enumeration of Asbestos Dust on Membrane Filters. *Ann. Occup. Hyg. 11:*1 (1968).
3. MORROW, P. E. and T. T. MERCER: A Point to Plane Electrostatic Precipitator for Particle Size Sampling. *Am. Ind. Hyg. Assoc. J. 25:*8 (1964).
4. BILLINGS, C. E. and L. SILVERMAN: Aerosol Sampling for Electron Microscopy. *J. Air Pollut. Control Assoc. 12:*586 (1962).

5. SICHEL, H. S.: On the Size Distribution of Airborne Mine Dust. *J. S. Afr. Inst. Min. Met. 58*:171 (1957).

6. HOEL, P. G.: *Introduction to Mathematical Statistics*. Wiley, New York (1949).

7. WHITBY, K. T.: *Determination of Particle Size Distribution—Apparatus and Techniques for Flour Mill Dust*. Univ. of Minn. Eng. Expt. Station Bull. No. 32 (January, 1950).

8. DENNIS, R., L. SILVERMAN, C. E. BILLINGS, E. KRISTAL, D. M. ANDERSON AND P. DRINKER: *Air Cleaning Studies Progress Report for July 1, 1955 to June 30, 1956*. A. E. C. Contract No. AT(30-1)841 (March 16, 1959).

9. American Conference of Governmental Industrial Hygenists: *Industrial Ventilation*. 13th ed. P. O. Box 453, Lansing, Michigan (1974).

10. HEMEON, W. C.: *Plant and Process Ventilation*. 2nd ed. Industrial Press, New York (1963).

11. HAWKSLEY, P. G. W., S. BADZIOCH and J. H. BLACKETT: *Measurement of Solids in Flue Gases*. British Coal Utilization Research Assn., Leatherhead, Surrey, England (1961).

12. FAIRS, G. L.: XII—Developments in the Technique of Particle-size Analysis by Microscopical Examination. *J. Roy. Microscop. Soc. 71*:209 (1951).

13. CORN, M.: Statistical Reliability of Particle Size Distributions Determined by Microscopic Techniques. *Am. Ind. Hyg. Assoc. J. 26*:8 (1965).

14. HERDAN, G.: *Small Particle Statistics*. 2nd ed. Academic Press, New York (1960).

15. CHAPMAN, H. M. and R. C. RUHF: Dust Counting Reliability. *Am. Ind. Hyg. Assoc. Quart. 16*:201 (1955).

16. ARKIN, H. and R. R. COLTON: *Statistical Methods*. 5th ed. Barnes and Noble, New York (1970).

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Counting Asbestos Fibers by the Most Probable Number Method

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A procedure for evaluating asbestos fiber counts is described which uses the most probable number method of bacteria counting. This technique is faster than conventional counting methods, with approximately comparable accuracies, although it suffers from a lack of rigor and requires the observer to estimate fiber concentrations to within an order of magnitude before counting. For the routine assessment of a large number of asbestos samples this procedure would seem to be more desirable than conventional counting because of the economy of time as well as being easier on the observer.

Introduction

RECENT FINDINGS ON THE TOXICITY of asbestos have led to increased interest in sampling and analytical procedures for determining the concentration of asbestos fibers in air. The Occupational Safety and Health Administration has established an interim eight-hour time weighed average airborne allowable concentration of five asbestos fibers greater than 5 microns length per cubic centimeter of air, and this standard will be lowered to 2 fibers/cm^3 on July 1, 1976.

Evaluation of asbestos fiber concentrations in air is carried out using samples collected on membrane filters and viewed with phase contrast illumination at 400X-450X.[1,2] This method is the standard field sampling method adopted by the Public Health Service.

Fibers are assumed to be distributed randomly over the filter surface and at least 20 but no more than 100 fields are to be viewed. At least 100 fibers are counted which gives a 95% confidence limit of ± 20%. Because of the relatively small amount of sample collected, more than 100 fields would have to be viewed if one were to find 100 fibers on a 10 minute sample collected at a rate of 2 liters per minute from air containing 5 fibers (5 microns length) per milliliter, and if the concentration were only 2 fibers per milliter, 435 fields would have to be assessed.[3] Of course, the number of fields necessary could be decreased by increasing the sampling time—in the latter case a 90 minute sample would yield 100 fibers in 50 fields—but the flexibility of short-term samples is then lost.

Counting fibers is a tedious and time-consuming business fraught with a number of subjective decisions for the microscopist to make. For example, in the case of two fibers lying side by side he must decide when a fiber is a fiber or when it is only a large particle. (It is considered that any particle having an aspect ratio of three or greater is a fiber).

If the sample is relatively light, a great deal of information is lost which actually can be used to determine fiber density. Besides actually counting the number of fibers, there is another quite distinct statistical method which could be used for estimating the number of fibers randomly distributed over a surface, the so-called most probable number method. In this paper the method will be applied to asbestos fiber counting and the advantages and limitations of its use will be discussed.

Theory

The concept of the most probable number method for esitmating randomly distributed number densities was first described by McCrady[4] and more recently by Cochran[5] and principally was applied to the problem of estimating bacterial densities. Chapman[6] applied the method to dust counting but it was not received with much enthusiasm for reasons which will be discussed later. Most recently the technique has fallen into disfavor even for estimating bacterial concentrations in milk and water samples, mainly because of the advent of more direct membrane filter techniques. For fiber counting however, the method appears promising because it eliminates the need to resolve individual fibers and with the low densities normally found, gives the same counting accuracy in a much shorter period of time and with much less eyestrain.

Consider a filter of area A which is broken up into a fields. If there are m fibers distributed randomly over the filter surface, then the average number of fibers per field, f, is

$$f = \frac{m}{a} \qquad (1)$$

The probability, P, than n fibers lie in a certain field can be expressed using the Poisson relationship

$$P(n) = \frac{f^n}{n!}e^{-f} \qquad (2)$$

provided that a is a large number. The probability of a field being void of fibers is, from above

$$P(o) = e^{-f} \qquad (3)$$

If the void fields are distributed randomly across the filter and L fields are sampled, the probability that exactly l of these fields will be void is

$$P_l(o) = \frac{L!}{l!\,(L - l)!}[P(o)]^l\,[1 - P(o)]^{(L-l)} \qquad (4)$$

Equation 4 gives a distribution of probabilities which is very small for small l and rises

TABLE I
95% Confidence Interval for a Given Average Number of Particles Per Field

Particles/Field True Average	95% Confidence Interval Expressed as a Percentage of the True Average (left column, minus; right column, plus) L = 25	L = 50	L = 100	L = 200
0.1	100 — 229.1	75.8 — 138	56.7 — 84.9	43.3 — 51.1
0.2	76.6 — 156	58 — 79.7	41.3 — 51.7	29.8 — 35
0.3	69.6 — 111.3	49.9 — 58.8	34.1 — 43.1	25.9 — 28.1
0.4	54.8 — 90.3	42.1 — 59.8	31.5 — 36	23.1 — 25.5
0.5	56.3 — 79.4	41.1 — 52	27.8 — 36.2	21.8 — 22.6
0.6	52.7 — 76.2	37.4 — 40.8	27.9 — 33.6	18.7 — 22.8
0.7	47.5 — 55.2	35.6 — 47.4	23.9 — 32.2	18.8 — 21.7
0.8	45.6 — 73.8	33.6 — 38.8	25.1 — 31.5	18.1 — 21.2
0.9	44.3 — 75.6	32.8 — 38.9	22.3 — 31.4	17.6 — 19.4
1	43.2 — 57.5	32.2 — 39.7	21.9 — 31.7	17.4 — 19.5
1.1			23.9 — 28.7	17.4 — 18.1
1.2			21.8 — 29.6	16.3 — 18.5
1.3			22 — 26.8	16.5 — 19.2
1.4			23.3 — 28.4	15.6 — 18.1
1.5			22.6 — 29.9	15.9 — 19
1.6			20.9 — 26.8	16.3 — 17.9
1.7			21.4 — 28.7	16.8 — 19
1.8			22.1 — 25.6	16 — 20
1.9			20.2 — 33.1	15.2 — 21.4
2			23.5 — 30.3	15.7 — 20.2

to some maximum value before becoming small again. The most likely probability, that having the largest value, occurs at

$$l = Le^{-f} \quad (5)$$

Turning this around, the most probable fiber concentration is thus

$$f = ln\ (\frac{L}{l}) \quad (6)$$

The above development results in a simple procedure for assessing fiber concentration. A number of fields are scanned to determine only whether fibers are or are not present in any given field. Then by taking the natural log of the ratio of the number of fields scanned divided by the number of fields containing no fibers (Equation 6) the most probable number of fibers per field can be estimated.

As the number of fields scanned is increased, the accuracy of the estimate increases. Table I shows the 95% probability range for scans of 20, 50, 100 and 200 fields at various fiber densities, as calculated from Equation 6. Thus, for example, assaying 100 fields will yield results within about ± 30% of the true value 95% of the time, regardless of the total number of fibers seen, provided, of course, that the average fiber density is somewhere around two fibers per field or less. Assaying 200 fields will increase the accuracy of the 95% confidence interval to something less than 20% of the true count.

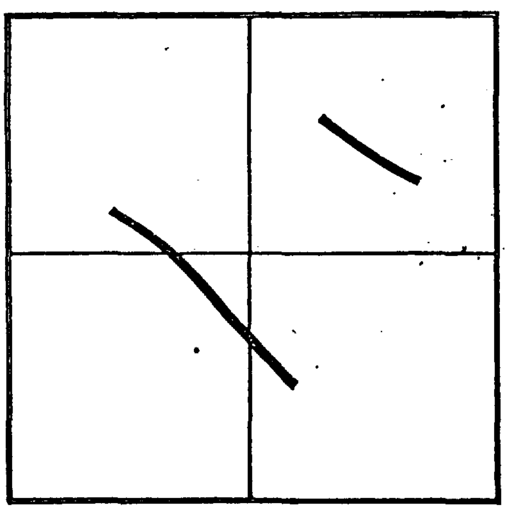

Figure 1. Various orientations of fibers in the microscope field.

For the case of $L = 200$, the accuracy appears to increase with an increasing average number of particles per field. This will continue until the point is reached where there is a good chance that every field contains at least one fiber. This occurs when the average number of fibers per field is slightly in excess of three. Thus for this method it is necessary to estimate ahead of time the fiber concentration to within one order of magnitude so that there will be about 0.2 to 2 fibers per field, or, if there appear to be plenty of fibers in evidence, to then use the direct count method. Of course, the number of fibers per field can be easily varied by changing the field size.

Definition of a Field Containing a Fiber

Thus far, for the purpose of development of the theory, fibers have been considered as if they were particles. But they are not. A fiber has length and as such may start in one field, extend through another or several others and finally terminate in yet another field. Figure 1 illustrates such a situation. The fiber originates in the upper left hand corner, continues through the lower left hand corner and then ends in the lower right hand corner. The fiber in the upper right corner represents no problem.

There are several ways in which the fiber that passes through several fields can be treated. First, only the lower (or upper) end of the fiber can be considered, and the field that it lies in then is a field not devoid of fibers. In the rare case where the fiber is perfectly horizontal, some convention, such as choosing the left hand side of the fiber would be appropriate. A field would be considered blank if the lower end of a fiber were not in it. Thus, in Figure 1, only the fields on the upper right hand side and lower right hand side would be considered to contain fibers. Since each fiber is asso-

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ciated with one "lower" end, the estimated number ends would equal the estimated number of fibers.

A second approach would be to call a field void only if it contained no fiber ends at all. In Figure 1 only the lower left hand field would be considered to be void. The most probable number of ends would then be estimated and since each fiber has two ends, the most probable number of fibers would be the estimated number of ends divided by two. An obvious disadvantage of this approach is that the upper limit of density which could be used is half of what otherwise would be used.

The most reasonable approach is to assess only one end of the fiber. If the fiber is a bundle with a rough end lying on the edge of a field so that there is some question as to whether it is in or outside of the field, then the same rules as those used in particle counting could be applied to determine whether the fiber is in the field or not.

Experimental

In order to determine the efficacy of the proposed counting procedure a number of asbestos samples were counted using a direct counting method and a record was kept of the number of void fields observed. Most probable number data as determined from

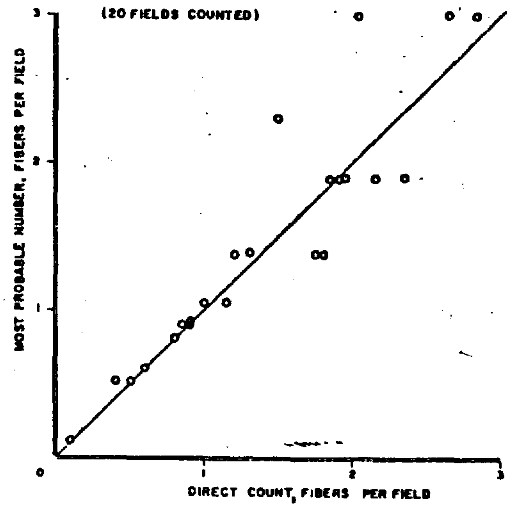

Figure 3. Plot of most probable number versus direct count for data from computer simulation for 20 fields.

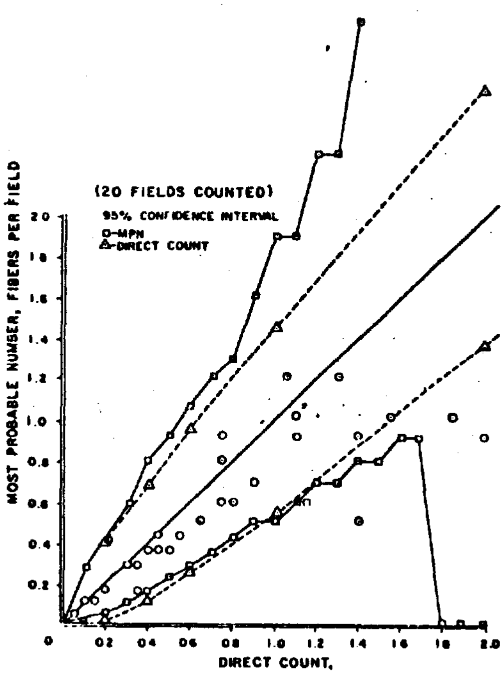

Figure 2. Most probable number data as determined from Equation 6 versus direct count.

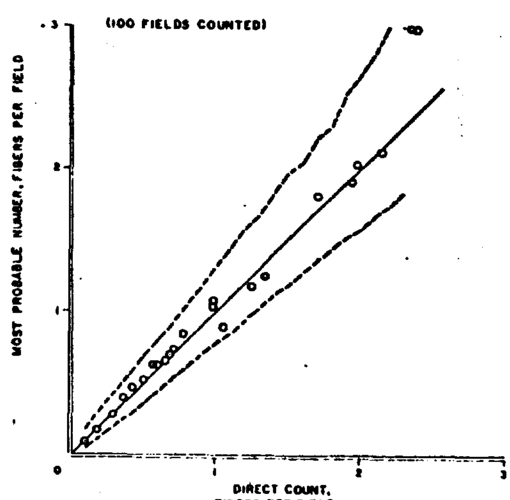

Figure 4. Plot of most probable number versus direct count for data from computer simulation for 100 fields.

Equation 6 are plotted as a function of the direct count which was observed for the samples and the results are shown on Figure 2. Also shown on this figure are the 95% confidence limits for both the MPN method and direct counting. Although there is some spread in the data, the general reproducibility is apparent. However, it appears that the most probable number method consistently gives results which are lower than those determined by direct count. This observation is consistent with a similar one of Chapman's who surmised that the difference could be due to failure to see a single particle in an otherwise void field.

For more extensive work a computer simulation was developed in which fields of 10,000 bits were assigned particles randomly corresponding to some preset particle density. Then fields of various sizes were randomly chosen and the average number of particles per field determined using the two methods. In addition, the absolute number of particles per field was determined. From this simulation it was possible to carry out non-biased counts using both conventional counting and the most probable number method for samples of 20, 100 and 200

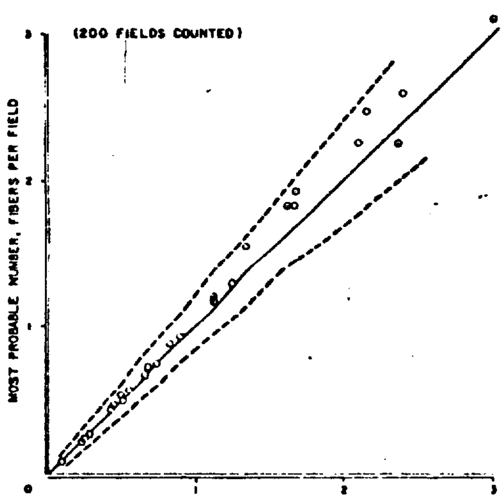

Figure 5. Plot of most probable number versus direct count for data from computer simulation for 200 fields.

fields. These data are shown in Figures 3, 4 and 5. Unlike the actual experimental data, however, there appears to be no bias toward the direct count information, indicating that the higher count averages noted on the actual direct counts results from a bias introduced by the observer rather than by the technique. Similar to Figure 2, error limits for the 95% confidence interval are shown as dotted lines.

Advantages and Disadvantages

The advantages of the most probable number method are threefold. Sampling times are shorter, lighter samples with less chance of overlap can be used, and counting times are shorter. Using fairly light samples for asbestos concentration assessment means that shorter sampling times are needed in the field, often an advantage to the industrial hygienist. For a given number of fibers observed, the MPN method implies greater accuracy if this total number is relatively small. There is less eyestrain for the microscopist since he only has to determine whether there is or is not something there, and not resolve a specific number of fibers. If problems of fiber clumping have occurred they will be more evident because of the lighter sample density. Finally, since fields are being counted instead of particles, the counting should proceed at a faster pace. For example, in discussing particle counting by the most probable number method, Chapman pointed out that one observer could determine particle concentrations about twice as fast using the most probable number method compared to standard counting methods while another observer was three times as fast using the MPN method. We have not studied counting times objectively, but subjectively the people in this laboratory who have compared the two methods for counting asbestos fibers also feel that the most probable number method is much faster.

The principal disadvantage of the most probable number method is that it is not

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rigorous. An observer could, in theory, accurately count the total number of fibers deposited on a filter whereas using the most probable number method, even if the whole filter were assessed, the observer would in the end still only have an estimate of the number of fibers present. In addition, for a given number of particles per field, the 95% confidence intervals for the direct counting method are slightly narrower than for the most probable number method, the effect becoming increasingly pronounced when the average number of fibers per field exceeds two. The accuracy is sufficient, however, for routine asbestos counting.

Summary

A procedure for evaluating asbestos fiber counts is described which uses the most probable number method of bacteria counting. This technique is faster than conventional counting methods, with approximately comparible accuracies, although it suffers from a lack of rigor and requires the observer to estimate fibers to within an order of magnitude before counting. However, for the routine assessment of a large number of asbestos samples this procedure would seem to be more desirable because of the economy of time as well as being easier on the observer.

References

1. Edwards G. H., and J. R. Lynch: The Method Used by the Public Health Service for Enumeration of Asbestos Dust on Membrane Filters. *Ann. Occup. Hyg. 11:* (1968).
2. Joint AIHA-ACGIH Aerosol Hazards Evaluation Committee: Recommended Procedures for Sampling and Counting Fibers. *Amer. Ind. Hyg. Assoc. J. 36:*83 (1975).
3. *Annon.: Occupational Exposure to Asbestos,* p. viii-5, HSM 72-10267, U.S. Dept. H.E.W., NIOSH, Washington (1972).
4. McCrady, M. H.: The Numerical Interpretation of Fermentation Tube Results. *J. Infec. Dis. 17:*183 (1915).
5. Cochran, W. G.: Estimation of Bacterial Densities by Means of the Most Probable Number. *Biometrics 6:*105 (1950).
6. Chapman, H. M.: Dust Counting by the Most Probable Number Method. *A.M.A. Arch. Industr. Hyg. 8:*234 (1953).

JOURNAL OF PAINT TECHNOLOGY

Handling Asbestos

Chrysotile Asbestos in Plastics

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Asbestos has received a great deal of attention and publicity in recent years, especially after it was designated a "target health hazard" by OSHA and a "hazardous air pollutant" by the EPA. Many of the articles on asbestos by the press have been emotionally oriented or distorted and, in some cases, stories have been sensationalized, based on obvious misinterpretation of facts. The use of half-truths or unsubstantiated statements has led to general confusion and the unfair castigation of asbestos and products containing asbestos. The purpose of this paper is to put the matter of asbestos use and asbestos hazards into a logical and practical perspective. In this paper, the different types of asbestos and their many uses are discussed, along with government regulations controlling the use of asbestos. The health hazards associated with asbestos, both occupational and environmental, and some industrial experience with air sampling and dust control measures are also covered.

KEY WORDS: Asbestos; Plastics; Air pollution; Toxicology.

What is Asbestos?

Asbestos is a commercial or generic term used to describe six naturally occurring "asbestiform" minerals that are fibrous, hydrated metal silicates. The six varieties are divided into two classes—serpentine and amphibole—based on their crystal structure. Chrysotile is the only member of the serpentine class, while the amphiboles include crocidolite, amosite, anthophyllite, tremolite, and actinolite. Chrysotile is by far the most-used variety and accounts for over 95% of U.S. consumption, as noted in *Table* 1.

Crocidolite, also known as blue asbestos, is imported from South Africa. Because of its high mechanical strength and good resistance to acids and alkalis, it is used to reinforce a limited variety of plastics where its pronounced color is not objectionable. Amosite, also imported from South Africa, is used primarily in thermal insulation. Although there are some deposits of anthophyllite in the U.S., most of it is imported from Finland. It is used primarily as a filler for polypropylene and in insulating materials. A comparison of the four varieties of asbestos which are of commercial importance is presented in *Table* 2. It should be noted that there are significant differences between chrysotile and amphiboles with regard to chemical composition and certain physical properties.

Where is Asbestos Used and Why?

Asbestos has served mankind for more than 100 years in a broad variety of applications. The general areas in which asbestos is used in the U.S. are shown in *Table* 3. Based on information from asbestos producers and consumption surveys, it is estimated that the plastics industry uses about 33% of the 800,000 tons consumed annually, which makes it the largest single user of asbestos fiber.

The largest uses of asbestos by the plastics industry are in vinyl-asbestos floor tile and in phenolic molding compounds. It is also used in other plastics such as polypropylene, polyester, nylon, melamine, epoxy, silicone, and vinyl. Asbestos provides a valuable function in such products as brake linings, clutch facings, electrical components, automotive parts, furniture, boats, sealants, coatings, adhesives and mastics. The most important functions of asbestos in plastics are reinforcement, dimensional stability, heat resistance, flow control, and general-purpose filling. Most of the functions are supplied by short-fiber chrysotile asbestos fiber, although longer chrysotile fibers and other asbestos varieties are sometimes required for particular properties.

Why Use Chrysotile?

Among the several advantages of chrysotile, which set it apart from the amphibole minerals and account for its widespread and increasing usage, are world-wide availability, mechanical strength, flexibility, positive surface charge, low iron content, softness, and low refractive index. It is conservatively estimated that chrysotile asbestos is used in over 3,000 applications and, in most of these applications, it is an essential ingredient for which no replacement is readily available.

The information in *Table* 1 shows that the use of chrysotile asbestos and its share of the total market are steadily increasing. This is due partly to technical advances permitting the broader use of chrysotile in plastics and the general decline in the use of asbestos in certain fireproofing and insulating materials. In addition, there is increasing evidence that crocidolite and amosite are more hazardous to

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Table 1—Apparent U.S. Consumption of Asbestos, Tons[a]

Year	Total	Chrysotile	Amosite	Crocidolite
1967	720,583	686,044 (95)[b]	12,558 (1.7)	14,917 (2.1)
1968	817,363	775,711 (95)	20,467 (2.5)	13,965 (1.7)
1969	784,321	749,708 (96)	14,618 (1.9)	10,558 (1.3)
1970	728,131	695,770 (96)	14,261 (2.0)	8,936 (1.2)
1971	758,571	729,272 (96)	14,580 (1.9)	6,953 (0.9)
1972	808,554	791,020 (98)	7,125 (0.9)	5,374 (0.7)

(a) Information based on import and production data from U. S. Bureau of Mines' Minerals Yearbooks.
(b) Percent of total shown in parentheses.

Table 3—Apparent U.S. Consumption of Asbestos By General Use Areas

Area of Use	Percent of Consumption
Construction	40
Floor tile	15
Felt paper	15
Friction and packing	14
Insulation	3
Textiles	2
Other	11

human health than chrysotile.[3] Since 1970, the use of crocidolite in Britain has been restricted after a panel of experts "concluded there was sufficient evidence to suggest other types of fibre should be substituted for crocidolite wherever possible."[3]

What is the Asbestos Hazard?

It is readily accepted that asbestos, like many other foreign bodies, can cause disabling lung damage (pulmonary fibrosis), commonly referred to as asbestosis. This disease and bronchogenic carcinoma (lung cancer) are the two most common asbestos-related diseases. It is important to note that, based on epidemiological data, these diseases have occurred primarily in workers with high, long-term exposures to asbestos dust. It is of further interest that one noted researcher has reported that neither of these diseases is peculiarly related to or caused solely by the inhalation of asbestos fiber.[3] Another important consideration is the relation between cigarette smoking and lung cancer, as reported by Dr. E. C. Hammond and Dr. I. J. Selikoff.[4] In this study, they reported that: "It seems clear, then, that lung cancer is uncommon among asbestos insulation workers who have no history of cigarette smoking and that if the risk is increased, such increase is not great."

A third disease, mesothelioma, has more recently been associated with persons exposed to asbestos. Mesothelioma is an extremely rare cancer of the lining of the chest (pleura) or the abdominal cavity (peritoneum). In contrast to the lung diseases, there is some evidence that mesothelioma can occur after brief exposures to relatively high fiber levels.

According to the 33-member Advisory Committee on Asbestos Cancers of the International Agency for Research on Cancer (a division of the World Health Organization): "There is evidence of an association of mesothelial tumors with air pollution in the neighborhood of crocidolite mines and of factories using mixtures of asbestos fiber types. The evidence relates to conditions of many years ago. There is evidence of no excess risk of mesotheliomas from asbestos air pollution which has existed in the neighborhood of chrysotile and amosite mines. There are reported differences on incidence of mesothelioma between urban and rural areas, the causes of which have not been established. There is no evidence of a risk to the general public at present."[5]

The same body quoted above has also concluded that there is, at present, no evidence of lung damage by asbestos to the general public; and such evidence as there is does not indicate any risk of cancer resulting from asbestos fibers present in water, beverages, food, or in the fluids used for the administration of drugs.[5]

While there seems to be general agreement that the public is not in any present danger from asbestos, it is also recognized that excessive, long-term occupational exposure can cause serious health problems. Also, if man-made emissions are not controlled, then environmental contamination could could approach harmful levels. During the past two years, significant legislation has been enacted by the Federal government to reduce and control occupational exposure to asbestos fibers and to minimize fiber emissions to the environment. Additional standards or regulations have been proposed or enacted by many states and local governments.

Table 2—Comparative Data for Asbestos Minerals[a]

Formula	Chrysotile $3MgO2SiO_2 \cdot 2H_2O$	Crocidolite $Na_2O \cdot Fe_2O_3 \cdot 8SiO_2 \cdot H_2O$	Amosite $1.5MgO \cdot 5.5FeO \cdot 8SiO_2 \cdot H_2O$	Anthophyllite $7MgO \cdot 8SiO_2 \cdot H_2O$
Composition, %				
SiO_2	37—44	49—53	49—53	56—58
MgO	39—44	0—3	1—7	28—34
FeO	0—6	13—20	34—44	3—12
Fe_2O_3	0—5	17—20	—	—
Al_2O_3	0—2	—	2—9	0—2
H_2O	12—15	2—5	2—5	1—6
CaO	0—5	—	—	—
Na_2O	—	4—8	—	—
$CaO+Na_2O$	—	—	0—3	—
Crystals	Fine fibers	Brittle fibers	Prismatic	Prismatic
Color	Gray green	Blue	Gray/brown	Gray
Texture	Soft silky	Harsh	Harsh	Harsh
Flexibility	Very good	Good	Good	Poor
Hardness, mohs	2.5-4	4	5.5-6	5.5-6
Fiber diameter, A	180-300	600-900	600-900	600-900
Tensile, mpsi	800	600	200	<4
Surface charge	Positive	Negative	Negative	Negative
Resistance to acid	Poor	Good	Good	Very good
Resistance to alkali	Good	Good	Fair	Good

(a) Sources: Modern Plastics Encyclopedia (1973), and Encyclopedia of Chem. Tech., Vol. 2.

Summary of OSHA Regulations

The William-Steiger Occupational Safety and Health Act of 1970 became effective on April 28, 1971, with the following Congressional purpose: "To assure so far as possible every working man and woman in the nation safe and healthful working conditions and to preserve our human resources." The Act established the Occupational Safety and Health Administration (OSHA) within the Department of Labor, which has responsibility for administration and enforcement. Research and related functions are handled by the Department of Health, Education and Welfare (HEW) through the National Institute of Occupational Safety and Health (NIOSH). Five million employers and 60 million of the nation's 80 million workers are covered by OSHA. Specifically excluded from coverage are government employees and operations which are protected under other federal health and safety laws. In a news release issued January 4, 1972, OSHA announced a Target Health Hazards Program aimed at improving health factors associated with working conditions. The following five substances were designated to be the focus of initial and concerted efforts by OSHA and NIOSH: asbestos, cotton dust, silica, lead, and carbon monoxide.

At the present time, new standards have been established only for asbestos, although, of the 8,000 toxic substances on the NIOSH list, only 500 are covered by standards and many of those need updating. The new Standard for Exposure to Asbestos Dust was published in the *Federal Register*, Vol. 37, No. 110, on June 7, 1972. The basic exposure standard is an 8-hr time weighted average (TWA) of five fibers, longer than 5 micrometers, per cubic centimeter of air. The TWA limit is to be reduced to two fibers per cubic centimeter on July 1, 1976. A peak concentration of 10 fibers per cubic centimeter is not to be exceeded at any time. All of the fiber concentrations are those to which an employee may be exposed without protective clothing and equipment. The first basic requirement of the new standard is monitoring to determine whether or not fiber concentrations are in excess of the exposure limits. Some asbestos suppliers provide a monitoring service to customers, and a similar service may be obtained from state health department officials, insurance carriers, or private consultants. The law requires that monitoring be repeated as necessary to ensure that employees are not exposed to levels in excess of the exposure limits.

Improper interpretation of the regulations has created many misconceptions about equipment and procedures needed to properly use asbestos. If exposure limits are not exceeded, there are no further compliance requirements except for medical examinations. Medical examinations are required for all employees in any occupation exposed to airborne concentrations of asbestos fibers. The examinations are relatively simple and should cost no more than $50 per year, per employee.

Respirators and special clothing are required in the construction trade for the spray application of insulation and fireproofing materials, and for the removal of such materials. This special protection is not required for any other use of asbestos unless exposure limits are exceeded. This is also true for other items such as specially equipped tools, change rooms, clothes laundering, and waste disposal. Respirators are not a substitute for engineering controls, but the law allows their use while controls are being implemented, in special situations where controls are not feasible or adequate, in emergencies, and for infrequent short-term job assignments. Caution labels are required on products containing asbestos except where the fibers have been modified by a bonding agent or other material to prevent dusting during any normal subsequent use or handling. Besides raw asbestos fiber, products which require package labeling could include: dry acoustical spray products and joint cements, unsaturated roofing felt and textiles, and some insulating products made without adequate binders. The labeling of a product does not prohibit its use. It should be noted here that in at least 90% of the products containing asbestos, the fibers are solidly locked into the product thereby presenting little danger of dust generation during normal use and handling of the product.

EPA Standards

Whereas OSHA is responsible for the protection of the worker, the Environmental Protection Agency (EPA) is charged with improving the environment to which the general public is exposed. On March 31, 1971, asbestos, along with beryllium and mercury, was identified as a "hazardous air pollutant" by the Administrator of the EPA. National Emission Standards for asbestos were then published by EPA in the *Federal Register*, Vol. 38, No. 66, April 6, 1973. Although no numerical emission standards were established, operating criteria are prescribed to prevent or limit asbestos emissions to the outside air from asbestos mills, roadways, certain manufacturing operations, building demolition, and the spray-on application of materials used to insulate or fireproof equipment and machinery. The law further requires that spray-on materials used to insulate or fireproof buildings, structures, pipes, and conduits shall contain less than 1% asbestos on a dry-weight basis. This should significantly reduce emissions to which the general public may be exposed, especially in large urban areas.

". . . the Administrator (of EPA) has determined that, in order to provide an ample margin of safety to protect the public health from asbestos, it is necessary to control emissions from major man-made sources of asbestos emissions into the atmosphere, but that it is not necessary to prohibit all emissions.

"In this determination, the Administrator has relied on the National Academy of Sciences' report on asbestos, which concludes: "Asbestos is too important in our technology and economy for its essential use to be stopped. But, because of the known serious effects of uncontrolled inhalation of asbestos minerals in industry, and uncertainty as to the shape and character of the dose-response curve in man, it would be highly im-

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prudent to permit additional contamination of the public environment with asbestos. Continued use at minimal risk to the public requires that the major sources of man-made asbestos emission into the atmosphere be defined and controlled.'"[7]

What is Industry Doing?

The Asbestos Information Association/North America reports that, during the past 30 years, the asbestos industry has spent millions of dollars to improve mining, milling, and manufacturing methods.[8] The establishment of safer working conditions has been a prime target and this work continues unabated and in close association with government agencies and independent medical researchers.[9]

The ultimate goals of the asbestos industry are: Reduction of work-area dust to minimum levels; Protection of workers from asbestos-related diseases; Maintenance of environmental emissions at levels low enough to preclude public endangerment.

Air Sampling

In order to comply with OSHA standards and to determine the need for dust control measures, air monitoring should be conducted in areas where asbestos is regularly handled or used. OSHA standards require that "all determinations of airborne concentrations of asbestos fibers shall be made by the membrane filter method at 400-450X (magnification) (4 millimeter objective) with phase contrast illumination."[10] The equipment for collecting air samples costs less than $400 and is readily available. A phase contrast microscope can be obtained for as little as $600, or an existing microscope can be modified for "counting" the asbestos fibers in compliance with NIOSH criteria.[11]

Air samples have been collected and analyzed on a regular basis by the asbestos industry for years. Except for a few applications where dust control is an engineering problem, industry is finding that dust levels are already within acceptable standards or that minimum changes are necessary to achieve compliance. Although data on many asbestos/plastic applications are not available, the summary in *Table* 4 is typical of our measurements of dust levels during asbestos handling in various types of plants and operations. The dust levels reported are ceiling concentrations, and it should be noted that the allowable OSHA level is 10 fibers/cc. In most cases, the TWA exposure level would be well below OSHA standards. Most of the data were collected before the installation of any special dust-control measures. Monitoring often shows that obviously dusty conditions are caused by materials other than asbestos. This does not preclude the need for controls, but it could change their scope and facilitate compliance with government regulations. Because of "bad press," asbestos is frequently ordered out of use without regard to whether or not a hazard actually exists due to air contamination. If acceptable dust levels are feasible, there is no need to replace asbestos at the expense of product quality or economic penalty. Gordon Everett of EPA points out that information on the biological effects of asbestos is very limited and that the effects of many substitutes have not been investigated at all. Before asbestos is replaced, it should be certain that a safer alternative is available.[12]

Table 4—Typical Air Sampling Results[a]

Type Plant Or Operation	Ceiling Concentration, Asbestos Fibers/cc
Floor tile	1-3
Polyester	1-3
Phenolic compounding	2-5
Handling phenolic	3-14
Caulks and sealants	0-8
Gypsum compounds	2-9

(a) Source: Union Carbide Corp., from air monitoring reports.

Obviously there are more people exposed to products containing asbestos than there are to raw asbestos fibers. As noted previously, more than 90% of the asbestos used in this country is in products in which the asbestos is "locked in" or bound with cement, plastics, or other binders, so that there is no release, or at least no significant release, of fibers in work areas or to the environment. Materials or products with locked-in fibers would include: floor tile, polyester resins, phenolics, sealants, coatings, brake linings, friction materials, rubber, roofing compounds, and reinforced plastics. Since an abrading action on some of these products could release asbestos fibers, appropriate monitoring and/or control measures should be instituted if it is thought that such action would release fibers.

Dust-Control Measures

Asbestos producers and users are spending a considerable amount of time and money on various dust-control measures. Conventional means to achieve minimum dust levels include: filtered ventilation systems on process equipment, local ventilation for saws and similar tools, conversion to a "wetted" operation, leak-proof packaging, vacuum clean-up, more care in bag disposal and other asbestos waste handling, and automatic bag openers. Unusual innovations include: pelletized asbestos, special packaging, and treated products.

Only short-fiber chrysotile is available as pellets, but this product serves a fair portion of the asbestos market. Pellets not only reduce dust during conventional handling but they are also available in bulk hopper cars and can be transferred and used in totally enclosed systems. Barring leaks in the system, dust in work areas is virtually eliminated. Used in bulk, asbestos pellets also reduce shipping costs, eliminate warehouse storage and handling, facilitate automation, reduce clean-up, and eliminate bag handling and disposal. The pellets contain no binder and are friable enough to be dispersed in dry form or in aqueous or resinous systems with conventional high-shear grinding equipment.[13]

Several types of special packaging are currently available, and suppliers consider customer requests for unusual requirements. The floor tile industry can obtain asbestos in plastic bags which can be added directly to the compounding operation. Asbestos in bleached paper bags assembled with water-soluble glue and printed with water-dispersible ink can be added directly to paper-making finishes or acoustical tile formulations.

Although "wetted" asbestos is not generally available, most suppliers are working with customers to provide "dustless" products. When justified by market demand, asbestos can be treated with water, mineral spirits, glycol, or other materials compatible with the application or system.

Conclusion

Asbestos is one of industry's many raw materials which involves a potential hazard when not used with reasonable respect and care. Although all forms of asbestos are recognized as hazardous to health when inhaled excessively, there is growing evidence that crocidolite and amosite are more hazardous than chrysotile. Fortunate-

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ly, the plastics industry uses primarily chrysotile asbestos and, in most products, the fibers are locked-in to prevent airborne contamination. Although asbestos dust levels are generally lower than expected, industry continues to expend large amounts of time and money to further improve the quality of the workplace. Although the general public is not currently in danger, occupational controls are required to prevent future environmental contamination.

Chrysotile asbestos is an important and necessary raw material, vital to the nation's safety and economy; and, with proper control, it can be used safely and in compliance with government regulations. Medical, scientific, government, and industrial personnel must continue to work closely together to establish reasonable exposure limits, provide safe work areas, and eliminate any possibility of public endangerment. □

References

(1) Enterline, P. E. and Henderson, V., *Arch. Environ. Health, 27,* 312 (Nov. 1973).

(2) Wagner, J. C., *Ann. Occup. Hyg., 15,* 61 (1972).

(3) Wright, G. W., statement before U.S. Dept. of Labor, Occupational Safety and Health hearing on proposed occupational asbestos standard, March 16, 1972, p. 3.

(4) Hammond E. C. and Selikoff, I. J., "Relation Of Cigarette Smoking To Risk of Death of Asbestos-Associated Disease among Insulation Workers in the U.S.A.," presented at meeting of the Working Group to Assess Biological Effects of Asbestos, International Agency for Research on Cancer. Lyon, France (Oct. 4, 1972).

(5) 'Report of the Advisory Committee on Asbestos Cancers," *Brit. J. Industr. Med., 30,* 180 (1973).

(6) "Asbestos," *National Safety News* (Oct. 9, 1973).

(7) "National Emission Standards for Hazardous Air Pollutants," *Federal Register, 38,* No. 66, 8820 (April 6, 1973).

(8) "Protecting the Asbestos Worker," Booklet No. 101D37, The Asbestos Information Association/North America, p 5.

(9) Selikoff, I. J., *Industr. Medicine, 39,* No. 4, 21 (April 1970).

(10) "Standard for Exposure to Asbestos Dust," *Federal Register, 37,* No. 110, 11320 (June 7, 1972).

(11) Bayer, S. G., et al, "Equipment and Procedures for Mounting Millipore Filters and Counting Asbestos Fibres by Phase-Contrast Microscopy," Bureau of Occup. Safety and Health, U.S. Dept. of Health, Education, & Welfare (Feb. 1969).

(12) "Asbestos Health Question Perplexes Experts," *Chem. Eng. News,* 18 (Dec. 10, 1973).

(13) Myers, J. L., "Calidria Asbestos Pellets," *ASBESTOS* (Oct. 1971).

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 mesotheliomas 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 I). 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-

2-20 (8)

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	0.347–9.81	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 variour 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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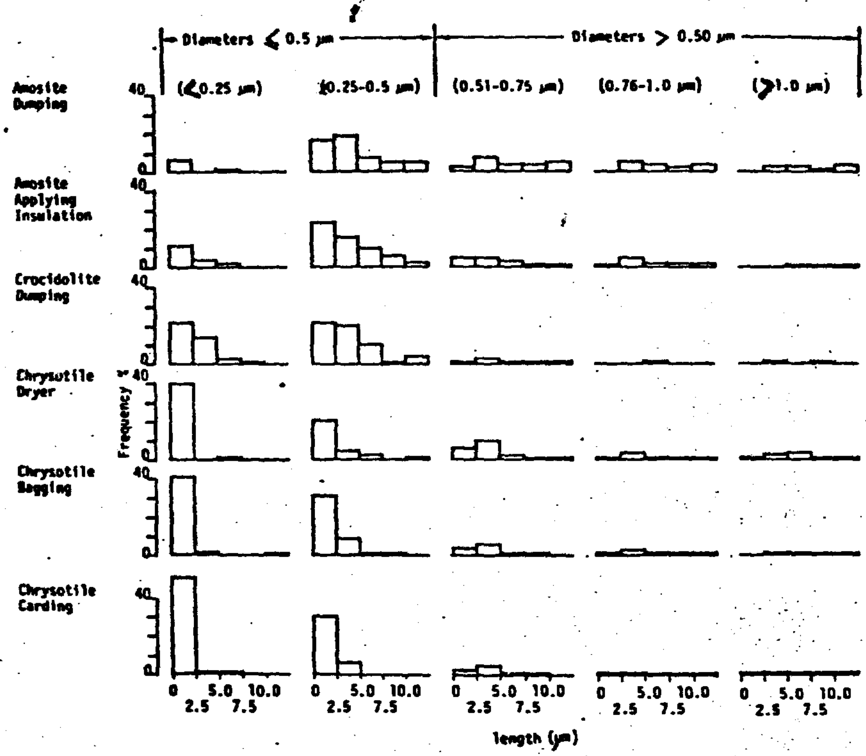

Figure 1. Length and diameter distributions of fibres collected during various asbestos processes.

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

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.[15] 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 various 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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References

1. Wagner, J. C., G. Berry, V. Timbrell: Mesotheliomas in Rats. In *Pneumoconiosis, Proceedings of the International Conference Johannesburg, 1969* (H. A. Shapiro, Ed.), p. 216, Oxford University Press, Capetown (1970).
2. Selikoff, I. J., E. C. Hammond, J. Churg: Mortality Experiences of Asbestos Insulation Workers 1943-1968. In *Pneumoconiosis, Proceedings of the International Conference Johannesburg, 1969* (H. A. Shapiro, Ed.), p. 180, Oxford University Press, Capetown (1970).
3. McDonald, J. C., A. D. McDonald, G. W. Gibbs, J. Siemiatycki, C. E. Rossiter: Mortality in the Chrysotile Asbestos Mines and Mills of Quebec. *Arch. Env. Health 22*:677 (1971).
4. Meurman, L. O., R. Kiviluoto, M. Hakama: Mortality and Morbidity of Employees of Anthophyllite Asbestos Mines in Finland. In *Biological Effects of Asbestos*, (P. Bogovski, J. C. Gilson, V. Timbrell, J. C. Wagner, Ed.), p. 199, International Agency for Research on Cancer, Switzerland (1973).
5. Newhouse, M. L.; The Mortality of Asbestos Factory Workers. In *Pneumoconiosis, Proceedings of the International Conference Johannesburg, 1969* (H. A. Shapiro, Ed.), p. 158, Oxford University Press, Capetown (1970).
6. Webster, I.: Malignancy in Relation to Crocidolite and Amosite. In *Biological Effects of Asbestos*, (P. Bogovski, J. C. Gilson, V. Timbrell, J. C. Wagner, Ed.), p. 195, International Agency for Research on Cancer, Switzerland (1973).
7. Selikoff, I. J., C. E. Hammond, J. Churg: Carcinogenicity of Amosite Asbestos. *Arch. Environ. Health 25*:183 (1972).
8. Selikoff, I. J., J. Churg, E. C. Hammond: The Occurrence of Asbestosis among Insulation Workers in the United States. *Ann. N.Y. Acad. Sci. 132*:139 (1965).
9. Rossiter, C. E., L. J. Bristol, P. H. Cartier, J. C. Gilson, T. R. Grainger, J. C. McDonald: Radiographic Changes in Chrysotile Asbestos Mine and Mill Workers of Quebec. *Arch. Environ. Health 24*:388 (1972).

10. Harries, P. G., F. A. F. Mackenzie, G. Sheers, J. H. Kemp, J. T. Morgan, T. P. Oliver: A Radiological Survey of Men Exposed to Asbestos in Naval Dockyards. *Brit. J. Indust. Med. 29*:274 (1972).

11. Enterline, P. E., H. Weill: Asbestosis in Asbestos Cement Workers. In *Biological Effects of Asbestos*, (P. Bogovski, J. C. Gilson, V. Timbrell, J. C. Wagner, Ed.), p. 179. International Agency for Research on Cancer, Switzerland (1973).

12. Newhouse, M. L.: Cancer among Workers in the Asbestos Textile Industry. In *Biological Effects of Asbestos*, (P. Bogovski, J. C. Gilson, V. Timbrell, J. C. Wagner, Ed.), p. 203. International Agency for Research on Cancer, Switzerland (1973).

13. Timbrell, V.: The Inhalation of Fibrous Dusts. *Ann. N.Y. Acad. Sci. 132*:255 (1965).

14. Timbrell, V., J. W. Skidmore: The Effect of Shape on Particle Penetration and Retention in Animal Lungs. In *Inhaled Particles III* (W. H. Walton, Ed.), Unwin Bros. Ltd. Surrey, England 1:49 (1971).

15. Wagner, J. C., G. Berry, and V. Timbrell: Mesotheliomata in Rats after Inoculation with Asbestos and Other Materials. *Br. J. Cancer 28*:173 (1973).

16. Stanton, M. F. and C. Wrench: Mechanisms of Mesothelioma Induction with Asbestos and Fibrous Glass. *J. Natl. Cancer Inst. 48*:797 (1972).

17. Timbrell, V.: personal communication

18. Timbrell, V., F. Pooley, and J. C. Wagner: Characteristics of Respirable Asbestos Fibres. In *Pneumoconiosis, Proceedings of the International Conference Johannesburg, 1969* (H. A. Shapiro, Ed.), p. 120. Oxford University Press, Capetown (1970).

19. Skidmore, J. W.: personal communication

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.

Tentative course offerings include elementary and intermediate biostatistics, actuarial statistics, demography, sampling methods, research design, design of experiments, Bayesian inference, categorical data, and health facility statistics. Several of these subjects will be intensive three-week courses. Instructors for the session will include Helen Abbey, Chin Long Chiang, Jerome Cornfield, Wanzer Drane, Margaret Drolette, and Norman Johnson.

These courses, at a wide range of academic and experience levels, are designed to benefit statisticians, epidemiologists, and health science personnel, as well as administrators, health planners, and other health workers who utilize quantitative data in decision making and problem solving. Graduate students, medical students, and teachers in statistics and in the health, medical, and biological sciences will also be interested in the program. The Summer Session is supported by funds from the U.S. Public Health Service.

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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