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Measurement of Asbestos Exposure

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THE SAMPLING STRATEGY DECISIONS made at the time of the basic epidemiologic study of an industrial dust hazard ultimately determine the methods that will be used to evaluate exposures in later regulatory or control situations. Threshold Limit Values (TLV) are based on a correlation between health effects and exposures as measured by a particular method. Since no method, with the possible exception of electron microscopy, measures all of the dust and no two methods measure exactly the same fraction, the correlation of exposures with health effects should not be expected to be the same where different methods of exposure measurement are used. Although it is possible to establish a transition from one method to another by means of simultaneous companion sampling, the number of samples required is large, making this approach difficult. Therefore, the methods used in the original study are important not only because of their contribution to the success of that study but also because succeeding industrial hygiene surveys will be largely committed to the use of those methods.

Threshold Limit Value for Asbestos

The present TLV for asbestos has its origin in a linear or "one time" epidemiologic study of the asbestos textile industry conducted by Dreesen et al.[1] in the Nineteen-Thirties. The then available impinger method was used to sample the dust; all particles, both grains and fibers, were counted since few fibers were seen. Dreesen et al. stated that, ". . . if the dust concentration in asbestos factories could be kept below 5 million particles per cubic foot (mppcf) new cases of asbestosis probably would not appear." Elsewhere, they described this suggested TLV as tentative. The reason for their hesitancy in recommending a definite exposure limit was that only four of the workers studied had been exposed to levels under 5 mppcf for over 10 years. This is not surprising when one considers the conditions of these mills at that time as compared with present conditions (Table I). The incidence of frank disease was so great that prior to the beginning of the study out of a total of less than 600 employees the plants discharged 150 workers suspected of having asbestosis.

Engineering controls have reduced dust concentrations by an order of magnitude over the past 30 years. The economics of dust control are such that the cost of further improvement, if necessary, may well equal the cost of all improvements made

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TABLE I

SURVEY OF OPERATION	Dust Concentrations — Asbestos Textile Surveys			
	PENNA. 1934	PHS 1938		PUBLIC HEALTH SERVICE 1964
		WITHOUT CONTROL	WITH CONTROL	
	Mean Concentration in mppcf			
Fiber Preparation	67.0	36.0	6.0	2.3
Cording	31.1	25.7	3.3	1.2
Spinning	16.2	7.1	—	1.2
Twisting	3.8	11.1	—	1.9
Weaving	19.8	14.0	2.1	0.8

to date. It is, therefore, necessary for the benefit of both the worker and the industry that precise knowledge of the health hazards of asbestos be obtained.

Present Epidemiologic Study

The present epidemiologic study of the asbestos products industry by the United States Public Health Service has been adequately described elsewhere,[2,3] and will only be summarized here. The reasons for the study are as follows.

1. The substantial changes in the size and technology of the industry have created new exposure situations in need of evaluation.

2. Over-all reductions in asbestos dust levels now make it possible to examine the relation of asbestos to asbestosis in workers with long-term lower level exposures.

3. The relationship between types and magnitudes of exposures and the occurrence of lung cancer needs to be defined.

The study is divided into the following segments.

(A). The present exposure of groups of workers will be measured by baseline surveys. Past exposures will be obtained from plant or regulatory agency records; and future exposures from periodic resurveys so as to yield a history of exposure spanning at least 20 years.

(B). Death certificates and, where available, autopsy records will be obtained for those members of the exposed group on whom social security death claims have been filed. From these data (age and cause) specific death rates will be constructed and related to exposure.

(C). More sensitive measures of health status will be obtained from medical examination of a selected sample of the study population.

(D). Techniques of future medical and environmental evaluation and hazard control will be developed.

This present paper is concerned with the first segment only, measurement of exposure.

Impinger Sampling and Counting

Impinger samples were collected routinely in both the baseline surveys and resurveys of the present epidemiologic study because only by this sampling method could dust levels be related to the present TLV, which is based on dust concentration measurement by impinger. Impinger samples collected simultaneously with other sample types are also used to establish relationships between methods to permit estimation of past exposures in terms of other fractions of the airborne dust. Since the confidence limits of a dust count improve as the number of particles counted increases and only a few fibers are seen in impinger samples the original investigators chose to count all particles and, thus, arrive at a measure of over-all dustiness. The success of this approach as applied to dust control in that era of massive exposures is evidenced in the improvement in the industry (Table I). However, in modern asbestos product plants, such as asbestos cement pipe plants, we find ourselves in the anomalous position of counting airborne dust known to consist mostly of cement against a TLV intended to apply only to asbestos dust.

The lack of fibers in the impinger samples was not due to the absence of fibers in the air. The impinger, an impaction device, has a collection efficiency related to the aerodynamic size of particles and is not efficient for particles with falling speeds less than that of one micron (μ), unit density spheres. Further, the 10X objective, light field, counting technique used does not resolve particles much smaller than one micron. Laboratory experiments showed that the impinger passed fibers and from field sampling it is estimated that only about one out of 100 fibers in the air as seen in electron micrographs was seen in the impinger samples.

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Fiber Counts on Membrane Filters

It is evident from the preceding that another method is needed if we are to obtain a statistically useful index of airborne fiber concentration. Interest in fibers stems from the need to measure that factor in the environment that is most relevant to the disease-causing mechanism and will, therefore, yield a significant correlation between health and exposure. Fibers have long been implicated as the causative agent in asbestosis and may be significant in cancer. Timbrell's[4] work showed that because of the peculiar aerodynamic properties of fibers (i.e. that their falling speed is dependent on diameter only when aspect ratios are greater than 10) it is possible for much larger objects (longer and heavier) to penetrate deep into the lung in the shape of fibers than in the shape of grains. This appears to be a most significant biologic property considering that the parent minerals involved (amphibole and serpentine) are not considered biologically active.

Based on methods developed in Great Britain,[5] a method of collecting and counting fibers on membrane filters was developed.[6] These fibers have pore sizes of 0.8 μ but are almost 100% efficient down to several hundredths of a micron because of surface effects. They are rendered transparent with a 1-to-1 mixture of diethyl oxalate and dimethyl phthlate and counted with a 4 mm. objective (430X) under phase contrast illumination. By examining a suitable number of fields, it is possible to count enough fibers to make a statistically useful estimate of fibrous dust concentration. In addition, longer duration personal-type samples which are not possible with the impinger method may now be used.

Some comments on the relationship between the impinger and the membrane filter with respect to the question of sensitivity will reveal a further limitation of the impinger method. From large numbers of companion impinger/filter pairs collected in asbestos textile mills an equivalence between the two sampling methods has been obtained.[7] Thus, when impinger samples yield, on the average, a concentration near the TLV of 5 mppcf, the fiber concentrations as measured by membrane filter samples would be expected to be as shown in Table II

Although there is no formal TLV applicable to English asbestos textile mills, a goal of 4 fibers longer than 5 μ per cc. has been mentioned.[8] If the above equivalence is approximately valid, this indicates that the TLV by impinger would be on the order of 1 mpccf. If the safe level of exposure should fall in this lower range, dust concentrations would be so near the lower practical limit of sensitivity for the impinger that accurate measurements would be impossible. Consequently, the shift in emphasis in the present study from the impinger to the membrane filter method is based not only on increased relevance, but also on the greater sensitivity of the latter method.

TABLE II

TYPE COUNT	CONCENTRATION FIBERS/CC
Total fibers	50
Fibers longer than 5 μ	30
Fibers longer than 10 μ	15

Weight Methods for Asbestos

Even though the greater precision of gravimetric methods over count methods is unquestioned, the ability to capitalize on this lessened variability is limited by the natural variability of the environment. When used as an index of asbestos exposure a measurement of the gross weight of airborne dust suffers from the same problem as impinger counts. If the relevant factor is the airborne concentration of respirable fibers, a gross mass measurement yields only an index of over-all dustiness, which includes much dust of lower biologic significance, especially in mixed-dust environments. Size-selective presampling devices suitable for long-period respirable mass sampling have been developed. However, airborne dust, even in the respirable fraction, contains mostly grains, both in number and in weight. Some of these grains are particles of the parent rock adjacent to the asbestos vein, chemically and crystallographically indistinguishable from fibrous asbestos. Other particles are grains of process materials and of ambient dust. With the non-respirable dust excluded by a presampling device, the asbestos and parent rock fraction can be determined by x-ray diffraction or, in the case of chrysotile, by magnesium analysis. No analytical method has been developed for measuring only fibrous asbestos in the presence of particles of associated rocks.

Airborne Carcinogens

All of the foregoing has been concerned with exposure measurement for the prevention of asbestosis. Although the mechanism of cancer among asbestos workers is not clear, apparently airborne asbestos fibers are a factor. Thus, the methods of fiber concentration measurement serve to measure this fiber factor with respect to cancer as well. Other asbestos contaminants of interest are polynuclear aromatic hydrocarbons and cer-

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tain trace metals, especially nickel, chromium, cobalt and manganese. In all of the early plants surveyed in this study, high volume (30 to 50 cfm) samples on glass fiber filters were collected for airborne polynuclear aromatic hydocarbon measurement. Levels in the work places were not significantly above ambient air pollution levels. However, trace metal analyses, of similar high volume samples collected on glass fiber and, more recently, membrane filters, do show significant amounts of nickel, chromium, cobalt and manganese and it can be presumed that past levels were higher.[9] Since these data are collected without exact information on the specific factor to measure for cancer-risk correlation no conclusions can be drawn at this time.

Selection of a Standard Method

As an outcome of an epidemiologic study, a safe level of exposure should be set in terms of a method of exposure measurement which meets the following criteria in the order given:

1. The environmental factor measured should be sufficiently relevant to the disease mechanism to correlate with health status even in environments where exposures to mixed dust occur.

2. The sensitivity of the method should be such as to measure levels well below the TLV.

3. The method should lend itself to an appropriate sampling strategy; e.g., long-period personal samples in the case of asbestos.

4. The expense of conversion from existing methods should be reasonable.

The impinger method of measuring asbestos exposure does not meet any of the criteria well with the exception of expense. Weight methods would be preferred if there were an analytical breakthrough. At present fiber counts on membrane filters are the best method of estimating exposure as related to the risk of asbestosis and the airborne fiber concentration as a factor in the risk of lung cancer.

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