Development of a Mathematical Model for Predicting Concentrations of Small Asbestos Fibers

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The standard method of asbestos sample analysis by phase-contrast microscopy excludes fibers which are below the resolution limits of the light microscope. Electron microscopic studies revealed that fibers in these small size ranges comprise the majority of fibers in asbestos dust. This research was conducted to determine if the development of a mathematical model for predicting concentrations of small fibers (<5 μm length) based on phase-contrast concentrations was feasible. The model presented in this paper was evaluated for its practical utility and was determined to be of minimal value; however, it was felt that the development of a reasonably accurate model can be arrived at through continued research.

INTRODUCTION

The NIOSH recommended method of asbestos sample analysis through phase contrast microscopy excludes fibers below the resolution of the light microscope (Criteria for Recommended Standard: Occupational Exposure to Asbestos, 1972). Through electron microscopic examination, it has been found that these short fibers comprise the majority of fibers in asbestos dust (Zumwalde and Dement, 1977; Lynch et al, 1970; Gibbs and Hwang, 1975, 1980). Due to the possible carcinogenic potential of small fibers, they should not be ignored when analyzing air samples for asbestos (Dement et al. 1976).

However, electron microscopic analysis is often more expensive and time consuming, and is less generally available than phase-contrast methods. Thus the purpose of this pilot investigation was to determine the feasibility of developing a mathematical model capable of predicting concentrations of small fibers based upon phase-contrast microscopic counts. This was to be accomplished by determining the relationship between asbestos fiber size distributions obtained through phase contrast and scanning electron microscope (SEM) analyses. These data could then be used to develop a predictive formula for the concentration of fibers that would be observed using the SEM, by use of the geometric mean, geometric standard deviation, and concentration of fibers as determined by phase-contrast analysis.

Such a model would not be intended as a substitute for electron microscopy, since the model could never achieve the accuracy and precision of the electron microscope. The utility of the model would be more appropriate for estimating small fiber concentrations in future epidemiological studies where the only concentration information was phase-contrast counts of fibers >5 μm in length.

METHODS AND MATERIALS

It has been well established that the ratio between the fibers visible by optical microscopy and those visible by electron microscopy varies according to minerology and degree of processing (Gibbs and Hwang, 1980). Therefore this pilot research was limited to bulk chrysotile asbestos. Chrysotile was selected because it is the most common type of asbestos encountered in this country.

A Misto$_2$Gen aerosol generator filled with bulk chrysotile asbestos was placed inside a 1-m^3 chamber. Compressed air was used to generate the asbestos cloud inside the chamber. Samples were taken using sixteen 37-mm Nuclepore polycarbonate filters of 0.2-μm pore size, in cassettes on the four walls of the chamber.

A total of 30 filter samples were collected, and sections from each filter were examined using both phase-contrast and scanning electron microscopy. For the phase-contrast method, one-eighth of the filter was cut out and mounted in a drop of chloroform, then examined under phase contrast at 400×. A Porton graticule was used to measure fiber length. Truncated multiple traversing with an endpoint of 25 fibers per circle size was utilized (Silverman et al., 1971), including fibers down to 3.0 μm long.

For the SEM method, a 3 × 5-mm section of each filter was mounted on a strip of copper adhesive tape on a 14-mm aluminum stub. A sputter coater was used to coat the specimens with 400 Å of gold–palladium. A Hitachi Perkin–Elmer HHS-2R scanning electron microscope at 5000× was used for this analysis. Sizing was performed directly from the CRT, using a ruler corresponding to the Porton circle diameters. Truncated multiple traversing was used as described above, including only those fibers which lay completely within the borders of the CRT.

For each analysis, data including the concentration in fibers per cubic centimeter, total fibers for each circle size, and total number of traverses for each circle size were computerized. From these data, a scattergram of log size versus probits of cumulative frequency was obtained for each count, and the correlation coefficient, slope, y-intercept, geometric mean (GM), and geometric standard deviation (GSD) were calculated. Multiple regression analysis was also performed for each sample, omitting the last data point corresponding to a cumulative frequency of 100%.

RESULTS

All of the distributions obtained by phase-contrast and SEM analyses were log normal, with correlation coefficients greater than 0.978 ($P < 0.001$). Mean values for GM, GSD, and concentration by the two counting methods are shown in Table 1. Fiber concentrations below the limits of resolution of phase-contrast microscopy were 6.8 times higher when counted by SEM. It should be noted that Gibbs and Hwang (1980) found ratios as high as 63 for chrysotile asbestos using transmission electron microscopy. However, Rendall and Skikne (1980) found a ratio of 4.3 which relates well to our ratio of 6.8.

Development of the predictive model required conditions be performed on the fiber distributions of both phase-contrast (PC) and SEM counts. A significant

TABLE 1

MEAN VALUES FOR GEOMETRIC MEAN (GM), GEOMETRIC STANDARD DEVIATION (GSD), AND
CONCENTRATION OBTAINED BY PHASE-CONTRAST (PC) AND SCANNING ELECTRON MICROSCOPY (SEM)
SIZE COUNTS OF ASBESTOS ON THE SAME FILTERS

	PC	SEM
GM*	5.43 μm	2.05 μm
GSD*	2.66	2.99
Concentration	4250 fibers/cm^3	28700 fibers/cm^3

* $P < 0.0005$, by paired t test.

correlation ($P < 0.005$) was noted between the $\log_e$ of the SEM concentration.
This allowed for the development of the following regression equation:

$$\log_e \text{ SEM concentration} = 5.15 + 0.600 \log_e \text{ PC concentration.}$$

This model was used to predict SEM concentrations from phase-contrast con-
centrations. The mean percentage error was $\pm 41.5\%$. The 95% confidence band
for the fitted line obtained by use of this model is found through the formula

$$(a + b_x) \pm 1.046 \left[\frac{1}{30} + \frac{(x - \bar{x})^2}{(n - 1) s_x^2} \right]^{1/2} ,$$

where $x = $ log phase-contrast concentration value.
    For a given phase-contrast concentration, the SEM concentration can be pre-
dicted from Fig. 1. The prediction band, or 95% confidence band, for a future
value of y ($\log_e$ SEM concentration) at x ($\log_e$ phase-contrast concentration) is
given by

$$(a + b_x) \pm 1.046 \left[1 + \frac{1}{30} + \frac{(x_0 - \bar{x})^2}{(n - 1) s_x^2} \right] ,$$

where $x_0 = $ given value of $\log_e$ phase-contrast concentration.
    For example, if an asbestos filter sample was found by phase-contrast micros-
copy to have a fiber concentration of 4910 fibers/cm^3 with a $\log_e$ concentration
of 8.5, the SEM concentration would have a $\log_e$ value between 9.15 and 11.4.
When these values are converted into actual numbers of fibers per cubic centi-
meter, the SEM concentration would lie within the interval 9410 to 85,000 fibers/
cm^3 with a confidence level of 95%. Obviously, this relationship has limited prac-
tical value due to the wide range within the prediction interval.

CONCLUSIONS

From the results of this study, it appears that the use of this predictive model
to estimate SEM concentration from phase-contrast concentration is not a viable
approach at this time. However, by generation of a cloud of a known quantity of
asbestos into the chamber, which would result in a lower concentration (e.g., <1
mg/m^3), and should reduce the asbestos concentration variability and provide
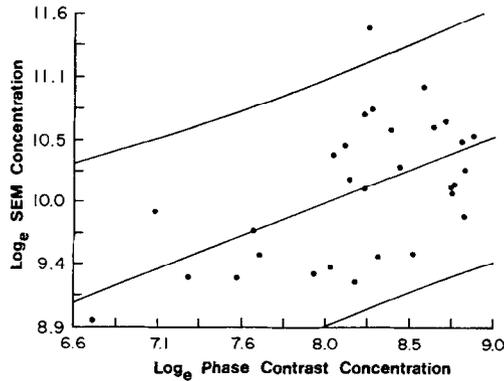
FIG. 1. The prediction band based on the line obtained by the use of the model.

better correlation between the SEM and phase-contrast counts. Improvements in this correlation would lead to a narrowing of the confidence and prediction bands, thus producing smaller, more practically useful prediction intervals. Since concentrations below the limits of resolution for phase-contrast microscopy were 6.8 times greater by SEM determination, small fibers should not be ignored.

ACKNOWLEDGMENT

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