APPENDIX B
SUMMARY OF TEM PARTICLE SIZE DISTRIBUTION DATASETS

OVERVIEW

As discussed in the main text (see Section 5.3.2), calculation of the concentration of asbestos fibers in each of the bins of potential interest requires particle size distribution data derived using transmission electron microscopy (TEM). Unfortunately, there are at present no epidemiological studies in which TEM was used to characterize asbestos type and size distributions in workplace air. Therefore, particle size distribution data must be extrapolated from other reports. For this effort, published literature was reviewed to identify reports containing bivariate (length, width) TEM fiber size distributions for various asbestos types and industry settings. These studies are summarized below.

STUDY DESCRIPTIONS

Dement and Harris (1979) report bivariate particle size data for asbestos, mineral wool, and fiber glass at various workplaces for multiple industries. Between 1971 and 1977, fiber samples were collected using personal air monitors as part of numerous NIOSH field investigations. These samples were collected using Millipore Type AA membrane filters (37 mm diameter) at flow rates ranging from 1.7 to 2.0 L/min. Sampling times varied depending on relative dust levels. Fiber counts for those longer than 5 um were conducted using phase contrast, optical microscopy. Fibers were defined as particles with an aspect ratio of 3-to-1 or greater. For determination of length and width distributions for asbestos fibers, TEM was the principle method used with magnifications ranging from 10,000 to 17,000 X. Fiber diameter was defined as the maximum transverse dimension of the particle while length was defined to be the maximum chord of a circle containing the fiber. Samples were prepared according to the direct mounting method as described in Zumwalde and Dement (1977). The numbers of samples analyzed varied across industry, ranging from 2 samples (amosite pipe insulation) to 27 samples (anthophyllite and tremolite talc production). For the chrysotile samples, thousands of fibers were sized for each operation from which samples were obtained. Conversely, only several hundred fibers were sized from the amphibole samples collected. Appendix C of Dement and Harris (1979) present fiber size determinations for each fiber type, industry and operation studied. There are 16 bivariate data sets for asbestos including those for chrysotile, amosite, anthophyllite, and tremolite in industries including the manufacturing of textiles, friction products, cement pipe, insulation, and talc. The midpoints of the bins are reported and the largest width and length bins are unbounded.

Gibbs and Hwang (1980) report fiber size distributions for samples of airborne dust collected in working areas of mines and mills in South Africa and Canada. Samples were collected on Nucleopore and Millipore membrane filters, although the size and diameters of the filters were not reported. Samples collected on Nucleopore filters were evaluated using SEM analysis and those collected on Millipore filters were analyzed using TEM and light optical microscopy. As shown in Gibbs and Hwang (Table 1), combining the results from PCM and TEM allows for a somewhat improved characterization of the frequency of long fibers. Gibbs and Hwang (1980) do not report any further information on sample preparation or analytical methodology. Fibers were defined as particles having an aspect ratio of 3:1 or greater. Fiber dimensions were measured using photographs of random fields and true diameter, true length, coil diameter, and coil length were estimated. True diameter was measured as the average width of the central portion of the fiber appearing in the photograph. True length was measured along the center line of the fiber. Coil diameter and coil length were measured as the inside diameter and length of an imaginary cylinder.

In this study, width data were reported as > 0.3 um, which complicates assessments in which a thickness cutoff of 0.4 um is used. Log-probability plotting indicates the thickness distribution is approximately lognormal, which allows calculation of the fraction between 0.3 and 0.4 um, and > 0.4 um based on the parameters of the fitted lognormal. Also, length data were truncated at 20 um, which results in an underestimation of the fraction of fibers > 10 um. Data from Gibbs and Hwang 1980 (Table 1) indicate that this error is small (0.01 to 1.3%), but for completeness, the data were adjusted before use to include the fraction of fibers > 20 um.

Hwang and Gibbs (1981) collected samples of airborne dust at an underground crocidolite mine and two mills, and a pipe manufacturing plant using both chrysotile and crocidolite in South Africa. A total of 52 samples were collected side by side at the same locations on 26 Millipore membrane filters (type AA; 0.8 um pore size, 37 mm diameter), and 26 Nucleopore filter (0.4 um pore size, 25 mm diameter). During sample collection, sampling rates were of 1 to 2 L/min and sampling times ranged from 2 to 153 minutes depending on environmental conditions. Light optical microscopy and TEM were used to analyze the Millipore filters, and SEM was used to analyze the Nucleopore filters. Samples were prepared for TEM analysis based on a modified version of the method described by Ortiz and Isom (1974). Electron micrographs of fibers were captured using a 35-mm camera at a magnification of 7000X. Within a selected grid opening, 4 to 9 fields were chosen to avoid overlap. Magnification was reduced in cases where a fiber length was curtailed by field edges to permit measurement of the total length of the fiber. For filters analyzed by SEM, electron photomicrographs were taken of approximately 60 fields at a magnification of 6000X. Only fibers with an aspect ratio of 3-to-1 or greater were measured. Measuring lengths greater than 65 um was not possible using TEM as its ends would be lost to view by the grid material. Measurements for fibers with lengths greater than 5 um were obtained by combining the light optical and TEM observations. The largest length bin is reported as a lower bound of 20 um, and the maximum length observable as mentioned above was 65 um. The largest width bin is unbounded at > 0.5 um, and the authors report that less than 1.5% of fibers measured had a diameter greater than 0.4 um.

Sebastien (1983) summarized TEM results for three air samples collected from the Libby, Montana site during shift 1 on May 3, 1983. The samples were from “Libby’s plant” at the following sampling locations:

- L1 Mill, 4th Floor – Rock Circuit Conditioner Discharge End
- L2 Luis Vasquez Office
- L3 Mill, 7th Floor – Over 8M Feed Prep Derrick Screens

Samples were collected on Millipore membrane filters (37 mm) by “static” (stationary) sampling. Each sample was prepared directly using a carbon replica technique and transferred onto TEM grids. Concentration estimates for each sample were estimated using both PCM and TEM, as follows:

Sample ID	Time (min)	Flow rate (L/min)	Volume (L)	Concentration (f/cc)	
				PCM	TEM
L1	248	2.0	496	0.25	0.88
L2	480	2.0	960	0.05	0.16
L3	252	1.8	454	0.93	2.90

For each sample, several fields were scanned at a magnification of 10,000x, and up to 100 fibers having an aspect ratio greater than 3:1 were recorded. For “every elongated particle recognized as a fiber”, the size parameters measured were the “greatest true diameter and the developed length”.

Figures 10 through 12 in Sebastian (1983) provide structure dimension scatter plots (length vs. width) for each sample. Because tables of the raw dimension data were not provided, data were derived from the scatter plots. One limitation of this technique is that it is not possible to identify cases where multiple structures of the same dimension are present. Because the size distributions for all three samples were generally similar, the data from all three samples were consolidated into a single data set for use in comparison to other data sets.

DETAILED DATA

APPENDIX B-1

The detailed bivariate data from these four reports are presented in Appendix B-1 (provided as a Microsoft Excel spreadsheet). This Appendix provides all adjustments made to the data, and all calculations used to combining data from more than one TEM data set. This Appendix also includes a spreadsheet tool that was used to assist in the selection of the best TEM data set matches to each epidemiological study.

Appendix B-2

Appendix B-2 presents graphical representations of the data presented in Appendix B-1 (provided as a Microsoft Excel spreadsheet). The data are displayed as cumulative distribution functions (CDFs) for length and width data, grouped by industry and fiber type. If the minimum thickness or length included in a data set is not known, the CDFs are not extended downward.

Inspection of these distributions reveals that there is considerable variation in size and length patterns as a function of asbestos type and industry. In general, chrysotile fibers tend to be thinner and shorter than amphibole fibers, but this varies between industries. These differences are presumably a consequence of the processing and refining used by each industry to produce fibers that are most useful for their specific products.

REFERENCES

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Hwang CY; Gibbs GW. 1981. The Dimensions of Airborne Asbestos Fibres --I. Crocidolite from Kuruman Area, Cape Province, South Africa. *Annals Occupational Hygiene.* 24(1):23–41.

Sebastian, P. 1983. Analysis by Analytical Transmission Electron Microscopy of Fibrous Particles in Libby's Air Samples – Preliminary Results. Memorandum from P. Sebastian, McGill University to Henry A. Eschenback, W.R. Grace & Co. on June 10, 1983.

APPENDIX B-1
Size Distribution Data

[Provided electronically as Excel workbook]

APPENDIX B-2
PSD Grouped by Industry Graphs

[Provided electronically as Excel workbook]