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Asbestos exposure and pulmonary fiber concentrations of 300 Finnish urban men

by Antti Karjalainen, MD,[1] Esa Vanhala, MSc,[1] Pekka J Karhunen, MD,[2,3] Kaisa Lalu, MD,[2] Antti Penttilä, MD,[2] Antti Tossavainen, DTech[1]

KARJALAINEN A, VANHALA E, KARHUNEN PJ, LALU K, PENTTILÄ A, TOSSAVAINEN A. Asbestos exposure of and pulmonary fiber concentrations in 300 Finnish urban men. *Scand J Work Environ Health* 1994;20:34—41. **Objectives** — The aim of the study was to determine the pulmonary concentrations of mineral fibers in the Finnish male urban population and to evaluate the analysis of pulmonary fiber burden by scanning electron microscopy (SEM) as an indicator of past fiber exposure. **Methods** — The pulmonary concentration of mineral fibers was determined by SEM and compared with occupational history for a series of 300 autopsies of urban men aged 33 to 69 years. **Results** — The concentration of fibers (f) longer than 1 µm ranged from <0.3 to $163 \cdot 10^6$ per gram of dry tissue ($f \cdot g^{-1}$). Asbestos fiber concentrations exceeding $1 \cdot 10^6$ $f \cdot g^{-1}$ were observed in 33% of the cases with probable occupational exposure to asbestos and 1% of the cases with unlikely occupational exposure. Even asbestos fiber concentrations of 0.3 to $1 \cdot 10^6$ $f \cdot g^{-1}$, especially of crocidolite-amosite fibers, were rare among the men with unlikely occupational exposure. Fiber concentrations exceeding or equaling $1 \cdot 10^6$ $f \cdot g^{-1}$ were 10 times more frequent among the men more than 60 years of age as compared with those less than 40 years of age. Inorganic fibers other than asbestos had a weaker correlation with occupational history and age. Smoking habits had no significant effect on the pulmonary fiber counts. **Conclusions** — Asbestos fiber concentrations exceeding $1 \cdot 10^6$ $f \cdot g^{-1}$ are highly indicative of past occupational exposure to asbestos. The distribution of fiber concentrations in the different age groups of this study indicated decreasing asbestos exposure in Finland since the 1970s.

Key terms: anthophyllite, autopsy, crocidolite, electron microscopy, general population, lung burden, mineral fibers.

Determining the pulmonary concentration of mineral fibers, especially asbestos fibers, has become a widely used method for verifying past exposure both in scientific studies and in cases of medicolegal issues concerning asbestos-associated diseases. Interlaboratory comparisons have revealed great variations in fiber counts, and the importance of laboratory reference values has been emphasized (1). Such national reference values are important in Finland, as 40% of the asbestos used during the past several decades consisted of anthophyllite (2), a variety of asbestos of only minor importance in other industrialized countries. There is increasing knowledge on the pulmonary fiber concentrations of Finnish lung cancer and mesothelioma patients, but the number of reference cases representing the general population is small (3—5).

The objective of this study was to determine the pulmonary concentrations of different mineral fibers in the Finnish male urban population and to evaluate scanning electron microscopy (SEM) as a method for analyzing pulmonary fiber burden as an indicator of past occupational exposure to mineral fibers.

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Subjects and methods

Cases

Lung tissue samples from 300 autopsy cases were collected as a part of a large study on sudden deaths among men. The study included all sudden, unexpected deaths of men aged 35 to 69 years who had died in Helsinki and were autopsied between 15 January 1991 and 30 January 1992 at the Department of Forensic Medicine, University of Helsinki. Cases in which the body had been combusted or macerated were excluded. Inadvertently, two cases of men aged 33 years were included. The autopsy series comprised 30% of all deaths among men in this age group in the area. The last occupation of the men was derived from the autopsy records. One relative of each decedent was interviewed personally with a standardized questionnaire including questions on smoking habits and occupational history. The interview was conducted for 150 cases.

The distribution of the causes of death among the study population is shown in table 1. About 60% of

the deaths were due to disease, 80% of which were cardiovascular diseases. There were no deaths due to mesothelioma or asbestosis. Two of the deaths were due to lung cancer, and in one additional case lung cancer was diagnosed but was not the primary cause of death. None of the men with lung cancer were suspected of having an asbestos-related cancer, nor was asbestosis evidenced in their autopsy.

Occupational history

The men were classified into four exposure categories (table 2) according to the last occupation as follows (codes of the Nordic Classification of Occupations (6) in parentheses):

Probable exposure: construction occupations (codes 621—629, 755, 761). There were 33 carpenters or assistant housebuilding workers, 15 painters, 4 plumbers, 3 bricklayers, 2 electricians, 2 bitumen insulators, 2 floor makers, 1 concrete reinforcement worker, 1 cement worker, and 1 glass fitter.

Possible exposure: all other industrial occupations (codes 000—007, 501—619, 631—754, 756—759, 762—902, 940—949).

Unlikely exposure: office type occupations, health care occupations, and agricultural work (codes 008—499, 903—939, 951—999).

Unknown exposure: cases without any information on occupation; most had only the notification "retired" in the autopsy record.

The information given by the relatives was further used to select a series of men with life-long employment in occupations without any plausible exposure to asbestos. The first 10 men of the series meeting the following criteria were selected: (i) last occupation classified as unlikely exposure, (ii) main occupation given by the relatives classified as unlikely exposure, and (iii) relatives denied any employment in construction or shipyard occupations and did not know of the person ever having handled asbestos products at work.

Electron microscopy

A lung tissue sample from the peripheral left upper lobe was used for the electron microscopic fiber analysis. The tissue pieces were stored in 4% formalin. A tissue piece of about 100 mg of wet weight was taken for the analysis. A previously described method including air-drying, low-temperature ashing, dispersion of the remaining ash in 0.5 N hydrochloric acid, and filtration on a Nuclepore filter with a pore size of 0.2 µm was used in the sample preparation (7). A blank sample was analyzed for each preparation series.

A sector of the sample filter was coated with gold in a sputtering device (JEOL JFX 1100), and fibers were counted on the screen with a JEOL 100 CX-ASID4D electron microscope in the SEM mode at an acceleration voltage of 40 kV. All inorganic particles having a length to width ratio of ≥3 and roughly parallel sides were defined as fibers and counted. A magnification of 5000 × was used in the counting. Fibers longer than 1 µm could be detected. A minimum of 200 viewing fields were evaluated to find at least 4 to 30 fibers per sample, depending on the density. With this procedure, an analytical sensitivity of about $0.07 \cdot 10^6$ fibers per gram of dry tissue ($f \cdot g^{-1}$) could be reached. According to Poisson statistics this value corresponds to a detection limit of $<0.3\ 10^6\ f \cdot g^{-1}$. Ten samples of life-long office workers were analyzed more thoroughly to reach an analytical sensitivity of $0.01 \cdot 10^6\ f \cdot g^{-1}$. No fibers were detected in the blank samples. The fiber dimensions were measured directly on the screen with magnifications up to 100 000 ×.

An energy dispersive X-ray microanalyzer (Tracor TN 5500) was used to determine the fiber type by comparing peak ratios to standard spectra. The concentrations of anthophyllite, crocidolite-amosite, total asbestos fibers, other inorganic fibers, and total fibers are given in the results. Amosite and crocidolite have almost similar X-ray spectra and are distinguished poorly. They have therefore not been presented separately. In a study on Finnish lung cancer patients, crocidolite fibers accounted for the great

Table 1. Causes of death for the autopsy series of 300 Finnish urban men.

Cause of death	N	Age (years)	
		Mean	Range
Disease	179	54.8	36—69
Suicide	52	48.7	33—69
Accidental[a]	41	48.3	35—65
Alcohol intoxication	21	47.7	36—62
Not defined[b]	7	46.6	37—69

[a] Includes 18 cases of accidental intoxication, 14 cases of accidental falling, 3 homicides, 2 cases of accidental suffocation, 2 traffic accidents, 1 case of accidental explosion, and 1 case of hypothermia.
[b] Could not be defined whether the death was due to an accident or suicide.

Table 2. Age and occupational exposure of the 300 men in the study.

Exposure group	N	Age (years)	
		Mean	Range
Probable exposure	64	51.9	36—69
Possible exposure	134	51.7	35—69
Unlikely exposure	80	51.0	33—69
Unknown	22	60.0	42—69
All	300	52.2	33—69

majority of crocidolite-amosite fibers identified with transmission electron microscopy (TEM) (8). Chrysotile fibers are poorly detected with SEM and consequently a low concentration of chrysotile fibers was detected in one sample only in the present study. Asbestos bodies are included in the number of fibers.

Statistical analyses

The influence of smoking habits on the pulmonary concentration of mineral fibers was analyzed by multinomial logistic regression, adjusted for age.

Results

Occupation and fiber concentration in lung tissue

The concentration of asbestos fibers (>1 μm in length) ranged from $<0.3 \cdot 10^6$ to $163 \cdot 10^6$ f · g^{-1}. In 18% of the samples concentrations of at least $1 \cdot 10^6$ f · g^{-1} were detected. Figures 1 and 2 show the distribution of the concentration of asbestos fibers observed in the different occupational groups. About 33% of the samples among the men with probable exposure and 19% among the men with possible exposure contained asbestos fibers in concentrations exceeding or equaling $1 \cdot 10^6$ f · g^{-1}. Only one sample among the 80 cases with unlikely exposure exceeded this limit. Thus 98% of the samples with an asbestos content of at least $1 \cdot 10^6$ f · g^{-1} were observed among those with either probable or possible exposure. About 80% of the samples in the group of unlikely exposure contained asbestos fiber concentrations of less than $0.3 \cdot 10^6$ f · g^{-1}.

The concentration of inorganic fibers other than asbestos ranged from $<0.3 \cdot 10^6$ to $11 \cdot 10^6$ f · g^{-1}. In 9% of the samples concentrations of at least $1 \cdot 10^6$ f · g^{-1} were detected. Figures 1 and 2 show the distribution of the concentrations of these fibers according to occupational group. The differences between the occupational groups were less than those observed for asbestos fibers. Altogether 45% of the samples from the subjects with probable exposure and 30% from those with possible or unlikely exposure contained these fibers in concentrations higher than $0.3 \cdot 10^6$ f · g^{-1}.

The distribution of the total concentration of inorganic fibers (asbestos + other fibers) in the occupational groups is shown in figure 1. In 31% of the samples the total concentration of fibers equaled or exceeded $1 \cdot 10^6$ f · g^{-1}. Concentrations exceeding or equaling $1 \cdot 10^6$ f · g^{-1} were detected in about 60% of the cases with probable exposure and in 5% of the cases with unlikely exposure. Asbestos fibers were the predominant fiber type in the groups of probable and possible exposure, whereas in the group of unlikely exposure other inorganic fibers were detected ($\geq 0.3 \cdot 10^6$ f · g^{-1}) about as frequently as asbestos fib-

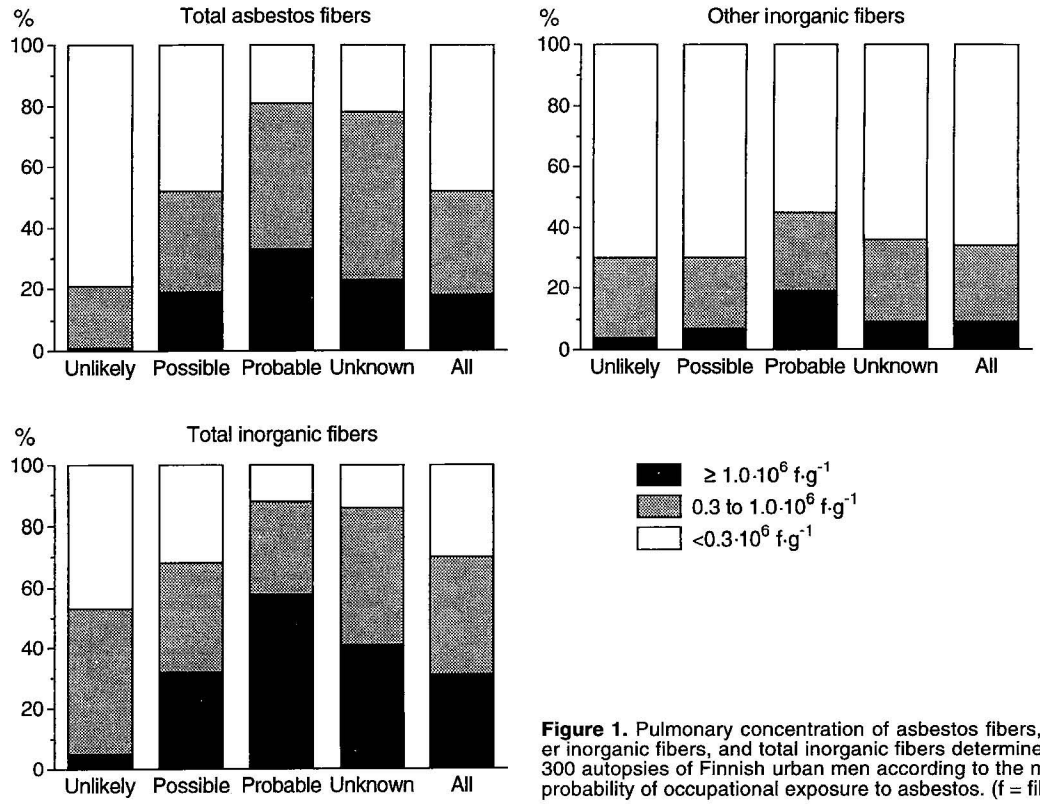

Figure 1. Pulmonary concentration of asbestos fibers, other inorganic fibers, and total inorganic fibers determined for 300 autopsies of Finnish urban men according to the men's probability of occupational exposure to asbestos. (f = fibers)

ers (21 and 29% of the samples, respectively). For the samples with fibers among the men with unlikely exposure, both the mean and the median concentrations of asbestos (mean $0.66 \cdot 10^6$ f · g^{-1}, median $0.50 \cdot 10^6$ f · g^{-1}) and other inorganic fibers (mean $0.71 \cdot 10^6$ f · g^{-1}, median $0.44 \cdot 10^6$ f · g^{-1}) were similar. The nonasbestos fibers detected in the lung specimens were mainly miscellaneous silicates and titanium oxide conforming to the criteria of a fiber. No man-made mineral fibers were detected.

Figure 2 shows the concentrations of anthophyllite and crocidolite-amosite fibers in the occupational groups. Anthophyllite fibers were detected in 36% and crocidolite-amosite fibers in 22% of the samples. Low concentrations of tremolite fibers were detected in six samples and chrysotile in one sample. Anthophyllite concentrations exceeding or equaling $1 \cdot 10^6$ f · g^{-1} were detected in 27 samples (9%); 9 (33%) of these came from the group of probable exposure and one (4%) from the group of unlikely exposure. Crocidolite-amosite concentrations exceeding or equaling $1 \cdot 10^6$ f · g^{-1} were detected in 23 samples (8%); 11 (48%) of these came from men with probable exposure and none from those with unlikely exposure. Only 3% (2 cases) of the samples in which crocidolite-amosite fibers were detected ($\geq 0.3 \cdot 10^6$ f · g^{-1}) came from the group with unlikely exposure. Correspondingly 14% of the samples with anthophyllite fibers came from the group with unlikely exposure.

As most of the concentrations of the samples among those with unlikely exposure remained below our detection limit, an effort was made to determine the fiber concentrations more thoroughly among lifelong office workers. The results of 10 such persons are presented in table 3. The fiber concentrations ranged from $0.02 \cdot 10^6$ to $0.30 \cdot 10^6$ f · g^{-1} for asbestos fibers and from $0.05 \cdot 10^6$ to $0.45 \cdot 10^6$ f · g^{-1} for total inorganic fibers. Anthophyllite fibers were detected in nine samples, crocidolite-amosite fibers in four samples, and tremolite fibers in one sample. Anthophyllite fibers constituted 90% of the asbestos fibers detected in these samples.

The concentration of asbestos fibers was clearly dependent on age (figure 3). Concentrations of $\geq 1.0 \cdot 10^6$ f · g^{-1} were 10 times more frequent among the men older than 60 years than among those under 40 years of age. This difference was not due to a different distribution of occupations because 22% of the individuals in both of these groups had been classified as probably exposed and 55—57% as possibly exposed. The concentration of inorganic fibers other than asbestos showed a much weaker dependence on age (figure 3).

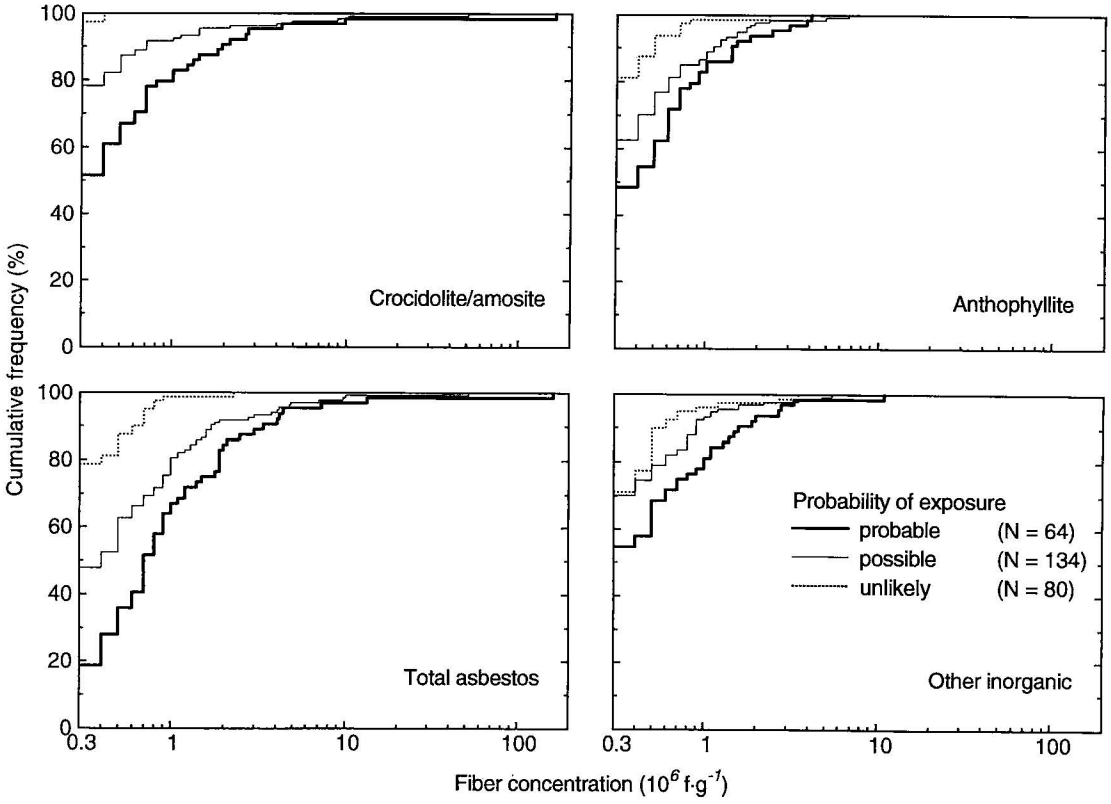

Figure 2. Pulmonary concentration of anthophyllite, crocidolite or amosite, total asbestos, and other inorganic fibers determined for 278 autopsies of Finnish urban men according to the men's probability of occupational exposure to asbestos. (f = fibers)

Table 3. Fiber concentration in the lung tissue of 10 autopsy cases of men with life-long employment in occupations with unlikely exposure to asbestos.

Case number	Age (years)	Occupation	Fiber concentration in lung tissue (10^6 fibers · g dry tissue^{-1})		
			Asbestos	Other	Total
1	53	Journalist	0.05	<0.01	0.05
2	51	Managing director	0.17	0.14	0.31
3	57	Department head	0.30	0.15	0.45
4	68	Military officer	0.07	<0.01	0.07
5	54	Clerk	0.18	0.05	0.23
6	44	Waiter	0.02	0.03	0.05
7	49	Salesman, paperware	0.15	0.03	0.18
8	41	Housing agent	0.08	0.29	0.37
9	44	Physician	0.09	0.03	0.12
10	58	Taylor	0.12	0.08	0.20

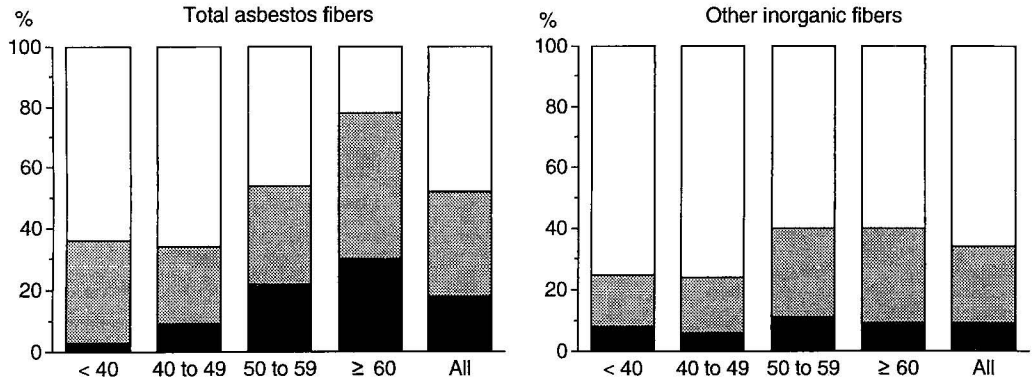

Figure 3. Pulmonary concentration of asbestos fibers and other inorganic fibers determined for 300 autopsies of Finnish urban men according to the men's age. (f = fibers)

Table 4. Fiber concentrations in two adjacent samples from the left upper lobe of the lung in 10 autopsy cases.

Case number	Comparative fiber concentrations (10^6 fibers · g dry lung tissue^{-1})			
	Asbestos		Total	
	Sample 1	Sample 2	Sample 1	Sample 2
1	14	6.3	14	6.3
2	6.0	3.0	6.4	3.6
3	2.7	2.1	3.7	2.3
4	1.1	1.0	1.5	1.0
5	0.7	0.4	1.5	0.9
6	0.7	0.5	0.9	1.3
7	0.3	<0.3	0.4	<0.3
8	<0.3	<0.3	0.4	0.4
9	<0.3	<0.3	0.4	<0.3
10	<0.3	<0.3	<0.3	<0.3

About 50% of the anthophyllite fibers, 29% of the crocidolite-amosite fibers, and 10% of the inorganic fibers other than asbestos exceeded 5 μm in length.

Analytical precision

Adjacent tissue samples from the left upper lobe were analyzed in 10 cases. The greatest differences between the concentrations of the two separate samples were about twofold (table 4). The overall analytical precision of the sample preparation and fiber counting was 31% (relative standard deviation). The interobserver reproducibility was good when two microscopists analyzed a mixed sample consisting of four samples containing a variety of fiber types. When 120 fibers per microscopist were analyzed, the difference in the fiber concentration was 9% for crocidolite-amosite, 20% for anthophyllite, and 16% for other inorganic fibers.

Smoking and fiber counts

There were no significant differences in the concentration of asbestos fibers or other inorganic fibers between the nonsmokers, smokers, and ex-smokers when adjusted for age (tables 5 and 6).

Discussion

Our findings support the previous view that a pulmonary concentration of amphibole asbestos exceeding $1 \cdot 10^6$ f · g^{-1} is highly indicative of occupation-

Table 5. Age-adjusted odds ratios for the pulmonary concentration of asbestos fibers in 150 Finnish men from urban areas according to smoking status.

Smoking status	Concentration of asbestos fibers (10^6 fibers · g dry tissue^{-1})						
	<0.3	0.3 to 0.99			≥1.0		
	Number of cases	Number of cases	OR	95% CI	Number of cases	OR	95% CI
Nonsmoker	14	11	1.0	Reference	3	1.0	Reference
Smoker	56	28	0.7	0.3—2.1	12	1.2	0.3—5.4
Ex-smoker	9	13	1.8	0.6—7.1	4	2.4	0.4—14.4

al exposure to asbestos (4, 7, 9). Such concentrations were common among the individuals with probable or possible exposure to asbestos but occurred in only one of the 80 men with unlikely exposure to asbestos according to the men's last occupation. As none of the 10 life-long office workers displayed concentrations exceeding 300 000 f · g^{-1}, it is probable that the majority of concentrations from 0.3 · 10^6 to 1 · 10^6 f · g^{-1} are related to occupational exposure. The fact that this result was particularly true for crocidolite-amosite fibers indicates that, in Finland, the distribution pattern between past occupational and environmental or domestic exposure is somewhat different for crocidolite-amosite versus anthophyllite fibers. This finding is in accordance with the data on the industrial use of these fibers in Finland. The main application for crocidolite in Finland has been asbestos spraying, which was practiced from 1955 to 1975 in shipyards, power stations, and some public buildings, but usually not in residential houses, whereas anthophyllite was used in a large variety of construction materials (2). Although widespread occupational exposure in construction, shipyard, and maintenance work has been the main source of exposure to anthophyllite, light and sporadic exposure of the general population has probably occurred during the renovation of public and residential buildings where the common insulation material of the central heating systems contained anthophyllite.

Chrysotile is cleared more rapidly from the lungs than amphiboles, and even if transmission electron microscopy is used, the chrysotile content of lung tissue is not an equally representative measure of past cumulative chrysotile exposures as is the amphibole content for amphibole exposures (10, 11). As about 40% of all asbestos used in Finland during 1918—1988 consisted of amphiboles (2) and a mixed exposure to chrysotile and amphiboles took place in most of the industrial applications, the amphibole content in the lung tissue is very probably a reasonably representative indicator of past exposure to asbestos in Finland. The results of the present study support this view. By comparison, chrysotile fibers have accounted for 10% or less of all pulmonary asbestos fibers detected with transmission electron microscopy in studies of Finnish lung cancer and mesothelioma patients (3, 8).

Table 6. Age-adjusted odds ratios for the pulmonary concentration of inorganic fibers other than asbestos in 150 Finnish men from urban areas according to smoking status.

Smoking status	Concentration of inorganic fibers (10^6 fibers · g dry lung tissue^{-1})			
	<0.3	≥0.3		
	Number of cases	Number of cases	OR	95% CI
Nonsmoker	16	12	1.0	Reference
Smoker	74	22	0.4	0.2—1.1
Ex-smoker	17	9	0.7	0.2—2.3

The highest concentration of asbestos fibers (163 · 10^6 f · g^{-1} for crocidolite) was found in the lungs of a 54-year-old construction worker, who had a history of about 30 years as a shipyard worker (latency time about 30 years from the start of employment). Two more cases exceeding 10 · 10^6 f · g^{-1} were detected, namely, 51 · 10^6 f · g^{-1} for crocidolite in the lungs of a 52-year-old metal engineer and 13 · 10^6 f · g^{-1} for anthophyllite and crocidolite in the lungs of a 59-year-old bricklayer. No further data on the occupational history of these two cases were available. The cause of death in these three cases was not related to heavy exposure to asbestos (two cardiac attacks and a suicide), and correspondingly the lungs were not evaluated for possible asbestos-associated histological lesions. No pulmonary or other malignancy was evidenced in the autopsy. These three cases (1% of the series), with more than 10 · 10^6 f · g^{-1} in lung tissue, represent the remaining heavily exposed part of the urban population. Such cases already bear the high fiber load of past exposures in their lungs. These individuals, together with those with moderate exposure (1 to 10 · 10^6 f · g^{-1}), form the risk group for asbestos-associated diseases. Due to their long latency time, these diseases will, however, not occur until sometime in the future.

We did not find any significant difference in the pulmonary fiber concentrations of smokers and nonsmokers. This result suggests that smoking as a source of inorganic fibers, or the influence of smoking on the pulmonary clearance of fibers, is of minor importance in regard to the variability of the inhaled dose of fibers on various occasions of expo-

sure. Nonfibrous particles often constitute most of the inorganic dusts in the lungs, but their levels or compositions were not analyzed in this study.

The proportion of fibers exceeding 5 µm in length was highest for anthophyllite fibers and lowest for inorganic fibers other than asbestos. This finding is in agreement with the results of previous Finnish studies (3).

A maximum of about twofold differences was observed between adjacent lung tissue samples of the left upper lobe. These differences include the variation due to sampling site, sample preparation, and microscopic analysis. Similar results have been frequently observed by other authors, and in extreme cases nearly 10-fold differences have been reported between samples prepared from different parts of the same lung (7, 12, 13). The 10 to 20% differences in the fiber counts between the two microscopists are of minor importance in respect to the variability caused by sampling site and specimen preparation.

The concentration of asbestos fibers correlated strongly with age. This finding is partly due to the fact that persons over 60 years of age have about twice as many workyears as those under 40 years of age, and they have thus had more occasions on which to be exposed. The age dependence probably also reflects the reduction in exposure in the new use of asbestos during the last two decades. The total annual use of asbestos has dropped from more than 10 000 t in the early 1970s to less than 300 t in 1990 (2). The differences in the number of exposed individuals in the different age categories is in accordance with the estimate that the incidence of asbestos-related diseases will remain at a high level during the next two decades and then begin to decrease. On the assumption that no further exposure to asbestos will occur in the future, it can be expected that the 10 times lower proportion of individuals with a fiber concentration exceeding $1 \cdot 10^6$ f $\cdot$ g^{-1} among men under 40 years of age as compared with those over 60 years of age will be reflected by a substantial decrease in the incidence of asbestos-related diseases between the 2010s and 2030s.

The other inorganic fibers detected in the lung specimens were mainly miscellaneous silicates conforming to the widely used criteria for a fiber (length to width ratio greater than 3:1 and roughly parallel sides); also fibrous mullite (aluminum silicate component of fly ash) and rutile (a form of titanium dioxide) were frequently found. No man-made mineral fibers were detected. We do not know whether the concentrations of these fibers represent recent or cumulative old exposures. The concentration of nonasbestos fibers showed a rather weak dependence on age, and this finding suggests that these fibers do not accumulate to the same extent as asbestos fibers. One would also have expected elevated pulmonary concentrations of such fibers among the cases with probable or possible exposure to asbestos, as exposure to other miscellaneous dusts is also frequent in such occupations (eg, construction work). The concentrations of other inorganic fibers were, however, rather similar between the exposure categories, and smoking did not explain the occurrence of these fibers. These findings suggest that, in addition to occupational exposure, such fibers may be inhaled from various sources representing the overall atmospheric contamination of the urban environment. Our results are similar to previous findings in that such inorganic fibers constitute approximately one-half of the total pulmonary fiber burden of cases without occupational exposure to dust (14). Among the men with significant exposure to asbestos, asbestos fibers constituted most of the total fiber burden.

Acknowledgments

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