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A cohort study of Swedish man-made vitreous fiber (MMVF) production workers, part 1: fiber exposure assessment in the rock/slag wool production industry 1938--1990

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Key terms: man-made mineral fibers; misclassification; retrospective exposure assessment

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Fiber exposure assessment in the Swedish rock wool and slag wool production industry in 1938—1990

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Objective A multiplicative model was developed to assess past exposure to respirable fibers among rock wool and slag wool production workers in Sweden in 1938—1990.

Methods Information on the job titles, work tasks and employment times of 1487 workers exposed to man-made vitreous fibers was obtained from company records and interviews with older employees. A mathematical model developed earlier for assessing historical fiber exposure, based on factory averages, was further developed. Matrices of multipliers for each plant that were specific for job title were modified to assess fiber exposure with respect to job title and calendar period. The model was based on measurements made in 1977. Two methods of exposure assessment were compared, cumulative exposure based on factory average (model I) and cumulative exposure based on job title (model II).

Results The exposure changed considerably in the two factories during the period 1938—1990, and it varied also between job titles. The estimated average fiber (f) exposure level at the two plants in the middle of the 1940s was 1.32 and 0.78 $f \cdot ml^{-1}$. These values are 26 and 16 times higher, respectively, than the exposure in 1980. Process changes, as well as the addition of binders and oil, reduced the exposure drastically around 1950. The mean cumulative respirable fiber exposure for the 1487 subjects was 1.44 (range 0.05—18.40) $f \cdot ml^{-1} \cdot$ year. The cleaners had 14 times higher annual fiber exposure than the preproduction workers.

Conclusions Model II was judged to be more valid than model I in assessing exposure to man-made vitreous fibers.

Key terms man-made mineral fibers, misclassification, retrospective exposure assessment.

Mineral wool (glass wool and rock or slag wool) is used for thermal and acoustic insulation. It is produced from man-made vitreous fibers (MMVF). The wool also contains binders and dust suppressors that give the product its specific characteristics.

During the 1970s and 1980s, MMVF was reported to induce pleural and peritoneal cancers in experimental animals (1). These findings focused interest on a possible cancer hazard for exposed workers. Two large epidemiologic studies, one in Europe (2) and one in the United States (3), indicated an increased lung cancer risk for MMVF production workers after long follow-up. The lung cancer risk was slightly higher in the rock wool than in the glass wool industries in both studies.

Few exposure measurements were available for Swedish mineral wool plants, but it was considered possible to estimate past fiber exposures due to good record keeping and the existence of technical plant information. The aim of this study was to use this information to develop a model for estimating job-specific exposure to rock wool fibers. The dose estimations were used for exposure-response analyses for a Swedish cohort of mineral wool production workers. This report describes the exposure conditions, the exposure assessment procedure, and model development. The lung cancer incidence of the cohort and the results of the exposure-response analyses have been reported separately (unpublished observations).

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A model developed earlier for assessing past rock wool exposure in a specific plant was modified to reduce misclassification in assessing exposure for different job groups.

Rock and slag wool production started in Sweden in 1938. Slag, granite, and diabase were used as raw materials. The basic method for manufacturing the fibers has not changed much, but the technology and the ventilation have been improved over the years. During 1938—1990, the insulation wool product changed in composition with regard to oil content, binders, and the size distribution of the fibers (4).

In 1979 there were 4000 employees in Sweden at 10 plants (four rock wool and six glass wool) but in the early 1990s the number had decreased to 2000 at six plants (two glass wool and four rock wool). During that period the annual production rate decreased by 20%.

Only a few historical measurements of fiber exposure in the Swedish MMVF production industry are available. The first comprehensive investigation was performed in 1977 (5) as part of the European collaborative study (2). Other measurements have been performed both before and after 1977, but the results are difficult to interpret due to interlaboratory calibrating problems.

Employment time is sometimes used as a proxy for cumulative exposure when no detailed information is available. Exposure duration may be a reasonable way to assess exposure if there are possibilities to exclude unexposed subjects and unexposed work periods from the company record data. Valid assessments of time-specific exposure levels based on measurements and calculations of cumulative exposure should provide a good basis for studies of exposure-response relationships. However, if such measurements are not available, it may still be possible to differentiate exposure by job title ranking, semiquantitative grouping forming a reasonable basis for exposure classification.

Dodgson et al (6) constructed a model to estimate past fiber exposure in the MMVF industry by the use of multipliers. This model was later modified by developing more multipliers in a mathematical model specific for rock or slag wool (7) so that it estimated annual fiber levels as an average level for the plants. The specificity would be improved if the exposure could be further differentiated between job groups.

Subjects and methods

Study population

Workers from two Swedish rock or slag wool plants were included in the study. The criterion for eligibility into the cohort was employment for at least one year between the time MMVF production began at the plant and 31 December 1977. Only employment time in work involving fiber exposure was considered for eligibility. The larger plant started MMVF production in 1938 and contributed 1045 men and 78 women to the cohort. The smaller plant started MMVF production in 1943 and contributed 284 men and 80 women. The 1487 subjects in this cohort represented 34 392 person-years of observation.

Most of the subjects (69%) had worked for less than five years. Seventy percent had only one job title. The mean employment time for the total cohort of 1487 persons was 111 months (9.2 years).

Exposure assessment

Model I — factory-specific exposure

A multiplicative model for assessing historical fiber exposure on the factory level (7) was used to calculate exposure for the 1487 exposed subjects. This model was used to cover the period 1938—1978 with the assumption that all of the subjects (and job titles) in a factory making MMVF products were constantly exposed to the same annual fiber (f) level ($f \cdot ml^{-1}$). The estimated level in the factory varied over the years because of changes in plant size, equipment, process, and ventilation. Each of the two factories had its own historical exposure profile, and the annual mean fiber exposure level was estimated. The model's principle is to project the respirable annual mean fiber concentration for each of the plants in 1977 backwards in time by using a multiplicative equation. The model had the following equation for predicting the past annual concentration of respirable fibers at time t:

$$C(t) = C_o \prod_{i=1}^{5} \mu_i(t), \qquad \text{(equation 1)}$$

where C_o = mean fiber concentration in 1977 for each plant, t = time, and μ = the multiplying factor (multiplier) (oil content μ_1, nominal diameter μ_2, production rate μ_3, ventilation μ_4, manual handling μ_5).

The calculated factory levels were based on a matrix of multipliers (μ) developed from dust box simulations (8, 9) and empirical data from factory simulations (7) combined with the mean exposure levels for each factory (equation 1). The details of the model construction have been described by Krantz et al (7). Exposure levels were derived from measurements performed in 1977 (5), and the model predicted exposure up to 1977 only.

To complete the exposure estimations in this study up to 1990, the multiplier μ_5 (manual handling) was modified to reflect subsequent stepwise changes in mechanization. With technical plant information as a basis, a multiplier of 0.9 was applied to reflect these changes. The selection of the multipliers followed the principal rules suggested by Krantz et al (7), a 10% decrease being assigned for minor changes. The product of the multipliers (μ_1—μ_5) also became 0.9 (equation 1). The production rate decreased by 15% from 1977 to 1990; this level has been estimated to cause a 5% reduction of the fiber concentration (10). The multiplier μ_3 (production rate) was, however, kept unchanged. The average exposure level at the two plants had decreased from 0.06 in 1977 to 0.05 $f \cdot ml^{-1}$ in 1990.

Cumulative fiber exposure was calculated for each of the 1487 subjects by adding the annual contributions to the cumulative exposure during the entire employment period.

Model II — exposure specific to job title

The model involving job title was developed in a stepwise procedure, proceeding from job group classification to the construction of matrices of multipliers and exposure calculations, with equation 1. Model II is an extension of model I.

Job group classification. All of the work periods for the 1487 MMVF exposed subjects in the rock wool plants were classified into one of 31 different job titles by a company panel of old foremen in 1982. The classification was based on work practice and information on production and technical information obtained from the plants. For this study the job titles were grouped into six job title groups (categories), A—F, judged to have similar MMVF exposure (table 1) according to measurements made in 1977 (5) and supported by later measurements by Krantz et al (7). Information on each job was obtained from a panel of long-term production workers and trade union representatives at the plants.

Multiplying factors. The principle for constructing the matrices for each job was the same as for model I with the five independent variables. Two of these variables were associated with the product itself (oil and diameter), while the other three were associated with the process or product handling (production rate, ventilation and manual handling). In this model (II), six matrices were to be constructed for each plant, one for each of the six job title groups. With help from the plant panel, historical plant changes were reviewed to assess differences in exposure between the job groups. The multipliers were selected as for model I for all of the variables except manual handling, which was modified in three situations according to the basic principles of the model constructed by Krantz et al (7). For example, line work was assigned a higher multiplier prior to 1960 (1.6 versus 1.4), since exposure decreased when plastic wrapping was introduced for insulation sheets instead of boxes being filled (10% fiber level reduction for the multiplier μ_5). In addition the automation applied for pipe making in 1960 was assumed to decrease the exposure of secondary production workers by a multiplier reduction from 1.6 to 1.4 (according to 10% fiber level reduction), and when the wire mat workers were given binders in 1965 (secondary production workers), it resulted in an exposure decrease expressed by a reduction of the multiplier from 1.4 to 1.2 (20% exposure reduction). Major changes were estimated to give a 20% decrease, and minor changes a 10% decrease, according to the principles for multiplier estimation given in the report by Krantz et al (7). The variables and the associated multipliers for one job category (production workers) are presented in the matrix in table 2.

Only small changes occurred in the process in 1978—1990; these changes lowered the exposure by 0.9 according to model I.

The respirable fiber exposure levels in the rock wool plants had been studied in 1977 by extensive measurements conducted by the Institute of Occupational Medicine, Edinburgh (5). It obtained 176 job-related samples at 17 representative work locations at the large plant, and 66 job-related samples were collected at the small plant.

The result for each job measured in 1977 was used to calculate a time-weighted average (geometric mean) for each of the six job groups in 1977 (C_0). These measurements formed the basis for the historical fiber estimation (table 3). The weighted mean exposure level for the six groups in 1977 equaled the factory mean in 1977, used in model I.

Table 1. Distribution of the cohort into six different job groups during 1938—1990 (job title with longest employment time).

Job group	Job titles	Number of subjects	
		Large rock wool plant	Small rock wool plant
A. Preproduction	Raw material	13	10
B. Production	Line workers and furnace worker	602	154
C. Secondary production	Pipe operators and press operators	232	91
D. Warehouse	Packers and loaders	86	29
E. Maintenance	Mechanical and electrical workers	152	73
F. Cleaning	Cleaners	23	9
Total		1123	364

Table 2. Matrix of coefficients (multipliers) for job group of production workers (B) and the estimation of fiber concentration.

Date	Oil content	Nominal diameter	Production rate	Ventilation	Manual handling	Fiber · ml⁻¹
1990	1.0	1.0	1.0	1.0	0.9	0.07
1978	1.0	1.0	1.0	1.0	1.0	0.08
1965	1.0	1.0	1.0	1.5	1.2	0.15
1960	1.0	1.0	0.9	1.7	1.2	0.15
1960	1.1	1.0	0.9	1.7	1.4	0.17
1951	1.1	1.0	0.9	1.7	1.6	0.17
1951	1.1	1.0	0.9	2.1	1.6	0.25
1950	1.1	1.0	0.8	2.1	1.6	0.23
1948	1.1	1.0	0.8	2.1	1.4	0.23
1948	2.6	1.0	0.8	2.2	1.4	0.49
1947	3.4	1.0	0.8	2.3	1.4	0.67
1946	3.4	1.0	0.8	2.3	1.4	0.67
1946	4.2	1.0	0.8	2.3	1.4	0.83
1945	5.0	1.0	0.6	2.3	1.4	0.74
1945	5.0	1.0	0.6	3.4	1.3	1.02
1942	5.0	1.0	0.5	3.4	1.3	0.85
1942	5.0	1.0	0.5	3.4	1.3	0.85
1938	5.0	1.0	0.5	3.4	1.3	0.85
1938	5.0	1.0	0.5	3.4	0.6	0.39

Table 3. Mean fiber exposure in fibers per milliliter for different job groups in 1977. (GM = geometric mean, GSD = geometric standard deviation)

Job groups	Large rock wool plant[a]		Small rock wool plant[b]	
	GM	GSD	GM	GSD
A. Preproduction	0.01	1.5	0.04	1.8
B. Production	0.08	1.3	0.07	1.9
C. Secondary production	0.05	1.5	0.08	2.1
D. Warehouse	0.04	1.3	0.04	2.0
E. Maintenance	0.04	2.0	0.03	1.7
F. Cleaners	0.14	1.9	0.09	2.3

[a] N = 176, factory mean GM = 0.06 f · ml⁻¹.
[b] N = 66, factory mean GM = 0.06 f · ml⁻¹.

Calculation of cumulative exposure. Starting from the six job groups' exposure levels in 1977, we calculated the annual fiber exposure levels (C) by multiplying the values for the five multipliers (μ) with the levels in 1977 by equation 1, for each group separately. These calculated levels were plotted for each job group; see the curves for the large plant in figure 1.

Cumulative fiber exposure for each individual was calculated by adding the annual contributions of intensity level multiplied by the duration of employment in each job held during the employment at the plant.

The cumulative exposure for each cohort member was classified as low, medium, or high according to

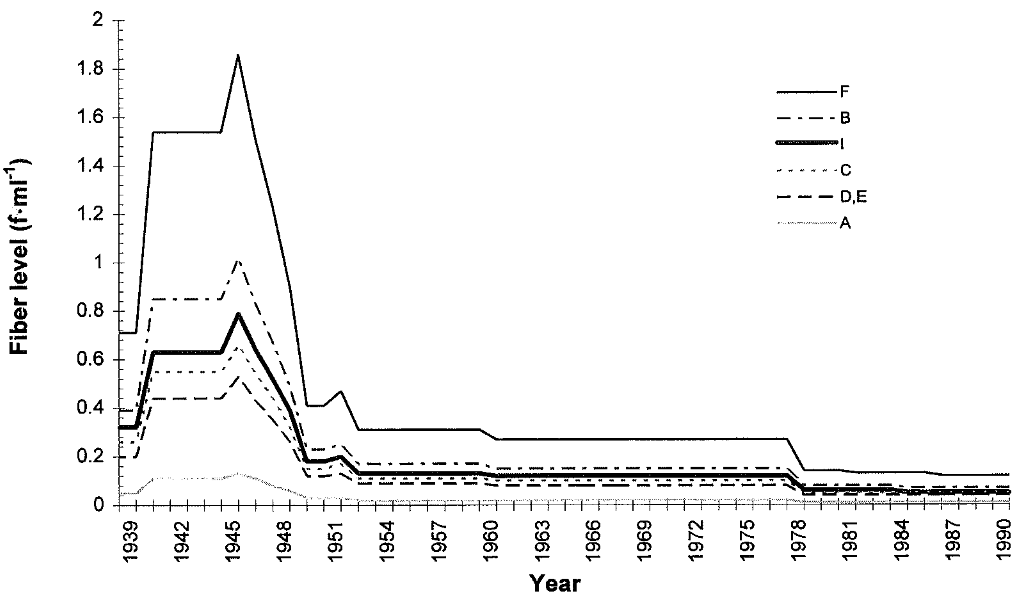

Figure 1. Past fiber level assessment (f · ml⁻¹) in the large rock wool plant for factory level by model I (black line) and six job groups (A-F) by model II (F highest and A lowest). Geometric standard deviation = 4.

Table 4. Cumulative fiber exposure calculations with models I and II for the total cohort and the lung cancer cases.

	Total cohort (N = 1487)			Lung cancer cases (N = 13)		
	Mean (f · ml · year)	SD	Range	Mean (f · ml · year)	SD	Range
Model I	1.35	1.79	0.12—15.58	1.25	0.73	0.39—2.95
Model II	1.44	1.98	0.05—18.46	1.34	0.82	0.09—3.81

the cumulative fiber exposure estimated by models I and II, respectively. The classes used were low exposure < 1.0 f · ml^{-1} · year, median exposure 1.0—2.0 f · ml^{-1} · year, and high exposure > 2.0 f · ml^{-1} · year.

Results

The calculated mean cumulative fiber exposure for the cohort (N = 1487) was 1.35 (SD 1.79, range 0.12—15.58) f · ml^{-1} · year according to model I; see table 4. The historical profiles, annual fiber exposure levels, have been plotted in a curve (black line) in figure 1 for the large rock wool plant. The fiber concentrations at the two factories were high in the beginning of the production period and decreased thereafter (around 1950) to the present levels.

From the modified matrix of multipliers, the annual fiber exposure level was calculated for the six job title groups in the two factories (model II); see figure 1. The highest exposure levels occurred during the 1940s with annual exposure levels of 0.78 f · ml^{-1} and 1.32 f · ml^{-1} at each plant, respectively; these values are 16 and 26 times higher than at the end of the 1980s. The rapid decrease in exposure around 1950 was due to the introduction of oil suppressors and binders. Cumulative fiber exposure for 1123 subjects at the large plant and 364 at the small plant are presented in table 5. The average cumulative exposure was nearly twice as high for the subjects who had worked at the smaller plant as compared with those at the large plant. Women at the small plant had the highest cumulative exposure mainly due to exposures during the 1940s. The average cumulative fiber exposure for the 1487 exposed subjects in the cohort was 1.44 (SD 1.98, range 0.05—18.40) f · ml^{-1} · year according to model II.

Most of the subjects were classified into the low exposure stratum <1.0 f · ml^{-1} · year. With model I there were 887 subjects in the low exposure stratum, 311 in the medium stratum, and 289 in the high stratum. With model II there were 928 subjects in the low exposure group, 285 in the medium exposure group, and 274 subjects in the high exposure group.

A cross-tabulation of classification according to models I and II is presented in table 6. The correlation between models I and II was kappa = 0.66.

Table 5. Mean cumulative fiber exposure in fibers per milliliter per year for the men and women at two Swedish rock wool plants according to model II.

Plant	N	Cumulative fiber exposure (f · ml^{-1} · year)
Large		
Men	1045	1.21
Women	78	0.90
Men + women	1123	1.19
Small		
Men	284	1.79
Women	80	3.77
Men + women	364	2.22
Large + small		
Men + women	1487	1.44

Table 6. Distribution of 1487 rock wool workers into three man-made vitreous fibers exposure strata by model I (factory level) and model II (job group level).

Model II (f · ml · year)	Model I (f · ml^{-1} · year)			
	Low < 1.0	Medium 1.0—2.0	High > 2.0	
High > 2.0	0	49	225	274
Medium 1.0—2.0	63	160	62	285
Low < 1.0	824	102	2	928
Total	887	311	289	1487

The exposure of 311 subjects was classified as medium by model I. One hundred and sixty of these exposures were also classified as medium by model II, while 49 were classified as high and 102 as low.

Discussion

A multiplicative mathematical model was developed to describe the annual fiber exposure for six job title groups between 1938 to 1990 in two Swedish rock wool production plants as a tool for retrospective exposure assessment in the absence of recorded measurement data. The model was a refinement of an earlier model designed to estimate average fiber exposure in factories. The refined model reduced the error in exposure estimation by considering jobs in addition to the overall factory exposure level. The average fiber exposure for the total cohort was 1.44 f · ml^{-1} · year.

Misclassification of exposure

All 1487 subjects, representing 31 job titles, were grouped (classified) into six job categories in model II and into one category in model I. The grouping was complicated since the exposure conditions differed between the job titles. The six groups were designed to represent homogeneous exposure conditions within each group. Misclassification increased in each step of the grouping of job titles.

Kromhout (12) showed that substantial misclassification occurs when workers are grouped into broad exposure categories. The grouping in model II decreases the misclassification when compared with model I because it accounts for some of the variability introduced by job differences.

Model II was based on measurements and their variability during a week in 1977. All of the other annual point estimates were calculated from these exposure levels, a procedure which introduces misclassification of exposure. Three to five repeated measurements per worker provided optimum reduction in the variance of the estimate of the group mean (13). Repeated measurements, preferably over a longer period, would probably give stronger support for the six mean levels chosen in 1977, but these were not available.

The relative exposure relationship between job groups was expected to remain approximately constant, as the influence of exposure factors (μ_i) other than those in the model were estimated to be small. This approach was thought to be reasonable by the panel of plant personnel. A constant relation between job titles over time has also been observed for Vermont granite workers (14).

Several authors have also used multipliers in their models (15, 16). The multiplicative model generates big variations in exposure across categories when five multipliers are multiplied, a phenomenon also seen in models using many predictive factors. Model II is an extension of model I and includes additional sources of information.

A crude estimation of the magnitude of the errors in model I was done by Krantz et al (7). They assumed the geometric means to correspond with the initial concentration and the five multipliers in the model. The geometric standard deviation for the overall estimated concentration was approximately 4. Those for other variables were assumed to be as follows: respirable fiber concentration (in 1977) 1.75, diameter 1.25, oil 1.25, production rate 2, ventilation 2, and manual handling 2. The same geometric standard deviations were assumed for model II.

Comparison of models I and II

The job title model (model II) in this study ought to have been a better predictor for each subject's exposure than the factory model (model I), which assumed that everybody at the plant had the same mean exposure level over a year. In the large plant the preproduction workers in 1977 had a mean fiber exposure of 0.01 f · ml^{-1}, while the cleaners had a mean exposure of 0.14 f · ml^{-1}, a value 14 times higher. As a consequence of the multiplicative model, the same ratio was obtained for 1946 with a maximum of 1.84 f · ml^{-1} versus 0.15 f · ml^{-1}. The differences over time were nearly of the same magnitude, namely, 1.84 f · ml^{-1} for 1946 for cleaners versus 0.13 f · ml^{-1} for 1990, a factor of 15 or a magnitude of about one. The plant-specific model had the same differences over time, 0.79 for 1946 and 0.05 f · ml^{-1} for 1990, a value 15 times higher. The misclassification of exposure was most likely to be lower with model II than with model I.

Model II assumed that everyone in a specific job group has the same fiber exposure. They worked in the same job zones but the within-worker variability could have been large, at least for job titles like maintenance workers and cleaners with no fixed job zones. Furnace workers were grouped with line workers in the production worker group (B). Furnace workers as a group had a lower mean fiber exposure but provided merely 17% of the subjects in the job group. In addition, furnace workers were exposed to polycyclic aromatic hydrocarbons (PAH), which also may have contributed to the risk of lung cancer (17).

Most of the subjects (51% of the cohort) had worked as line workers or in other jobs within the production worker group; see table 1. The historical curve of that group was very similar to the factory curve for model I; this finding explains the overall small differences in cumulative exposure for models I and II.

The differences in cumulative fiber exposure were large between the cohort members, and the differences between the two models could also have been large. The exposure of one subject who worked 34.5 years as a maintenance worker was assessed as 13.1 f · ml^{-1} · year by model I but as 6.7 f · ml^{-1} · year by model II, while the exposure of one mat production worker after 40.5 years of employment was assessed as 13.5 f · ml^{-1} · year by model I but as 18.4 f · ml^{-1} · year by model II.

Model II correlated with model I (kappa = 0.66), for which all of the 1487 workers in the cohort were distributed into the exposure strata low, medium, or high. Table 6 shows that there were many subjects classified as having a low exposure according to model I but a medium level of exposure with model II. Thus the number of medium-exposed persons in model I was overestimated relative to model II.

Model II indicates that the variability between job groups was higher in the past than in 1977. We consider model II to be a better exposure estimator than model I, as model I did not take the variation in fiber exposure between job titles into consideration.

The women had a higher cumulative fiber exposure according to model II than the men did, mainly due to sewing machine operations during the 1940s. It was not possible to observe these distinctions with model I.

The mean fiber exposure in 1977 ($0.06 \text{ f} \cdot \text{ml}^{-1}$) in the two Swedish rock wool plants was nearly the same as in the other five plants in the European study (mean $0.07 \text{ f} \cdot \text{ml}^{-1}$) (2), but the Swedish plants had higher fiber levels in the past.

Fiber types

A fiber is defined as a particle with a length of >5 µm and an aspect ratio of $\geq 3:1$ (18). Studies in Swedish MMVF plants have shown that many of the counted fibers were not mineral fibers, for example, up to 50% in low exposure areas (18). A limited amount of data on the MMVF contents showed that the proportion varied between different job titles in the 1977 analysis, but there were no data on the true MMVF content in the past. Analyses of rock wool fibers by scanning electron microscopy at the large rock wool plant showed that most of the measured fibers were organic. The inorganic fibers varied in composition, being mainly silicates, oxides or calcium phosphate (19). In general, low exposures tended to contain lower proportions of MMVF.

For this study, it was assumed that the proportion of MMVF in the fibers for each job title had been roughly the same from 1938 to 1977. Thus the exposure-response curve would not have been affected, but the absolute levels of the true MMVF exposure may actually have been lower than what was predicted by the model. However, the same problem applies to all studies of MMVF-exposed workers, and there is no reason to believe that the Swedish MMVF manufacturing industry differs from that in the rest of Europe or in the United Sates in this respect.

Concluding remarks

The model developed for historical fiber exposure at the job group level has probably decreased the misclassification of exposure in comparison with a plant-specific model for historical fiber exposure assessment in Swedish rock wool production plants. Employment time before 1950 contributed to a large part of the cumulative fiber exposure, since exposure levels decreased drastically at that time. This model is suitable for evaluating an exposure-response relationship in a cohort study of lung cancer mortality and fiber exposure.

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References

1. International Agency for Research on Cancer (IARC). Man-made mineral fibers and radon. Lyon: IARC, 1988. IARC monographs on the evaluation of carcinogenic risk on humans, vol 43.
2. Simonato L, Fletcher AC, Cherrie J, Andersen A, Bertazzi PA, Charnay N, et al. The man-made mineral fiber European historical cohort study: extension of the follow-up. Scand J Work Environ Health 1986;12 suppl 1:34—47
3. Marsh GM, Enterline PE, Stone RA, Henderson VL. Mortality among a cohort of US man-made mineral fiber workers: 1985 follow up. J Occup Med 1990;32:594—604.
4. Ohberg I. Technological development of the mineral wool industry in Europe. Ann Occup Hyg 1987;31:529—45.
5. Cherrie J, Dodgson J. A historical environmental investigation at thirteen European man made mineral fiber production plants. Edinburgh: Institute of Occupational Health, 1985. Report no TM/85/8.
6. Dodgson J, Cherrie J, Groat S. Estimates of past exposure to respirable man-made mineral fibers in the European MMMF industry. Ann Occup Hyg 1987;31:567—82.
7. Krantz S, Cherrie J, Schneider T, Öhberg I, Kamstrup O. Modelling of past exposure to MMMF in the European rock/slag wool industry. Stockholm: Arbetarskyddsverket, 1991:1—42. Arbete & Hälsa 1991:1.
8. Cherrie J, Dodgson J. Past exposure to airborne fibers and other potential risk factors in the European man-made mineral fiber production industry. Scand J Work Environ Health 1986;12 suppl 1:26—33.
9. Cherrie J, Krantz S, Schneider T, Öhberg I, Kamstrup O, Linander W. An experimental simulation of an early rock/slag wool production process. Ann Occup Hyg 1987;31:529—45.

10. Esmen NA, Hammad YY, Corn M Whittier D, Kotsko N, Haller M, et al. Exposure of employees to man-made mineral fibers: mineral wool production. Environ Res 1978;15:262—77.
11. Krantz S. Exposure to man-made mineral fibers at ten production plants in Sweden. Scand J work Environ Health 1988;14 suppl 1:49—51.
12. Kromhout H. From eyeballing to statistical modeling — methods of occupational exposure [dissertation]. Den Haag: CIP Data Koninklijke bibliotheek, 1994.
13. Waters M, Selvin S, Rappaport S. Optimum sample allocation within and between workers when estimating the mean exposure of a group. In: International Agency for Research on Cancer (IARC). Conference of retrospective exposure assessment in epidemiological studies, 13—15 April 1994. Lyon: IARC, 1994:33.
14. Eisen E, Smith T, Wegman D, Louis T, Froines J. Estimation of long term dust exposure in the Vermont granite sheds. Am Ind Hyg Assoc J 1985;45(2):89—94.
15. Greife Al, Hornung RW, Stayner LG, Steenland KN. Development of a model for use in estimating exposure to ethylene oxide in retrospective cohort mortality study. Scand J Work Environ Health 1988;14 suppl 1:29—30.
16. Cherrie J, Schneider T, Spankie S, Quinn M. A new scheme for structured subjective assessment of past concentrations. In: International Agency for Research on Cancer (IARC). Conference on retrospective exposure assessment, 13—15 April 1994. Lyon: IARC, 1994:18.
17. Falletin B, Kamstrup O. Simulation of past exposure in slag wool production. Ann Occup Hyg 1993;37:419—33.
18. World Health Organization, Regional Office for Europe (WHO/EURO). Reference methods for measuring airborne man-made mineral fibers (MMMF). Copenhagen: WHO/EURO, Technical Committee for Monitoring and Evaluating Airborne MMMF, 1985:16—53. Environmental health report no 4.
19. Krantz S, Tillman C. Measuring and characterization of mineral wool dust. Solna: National Board of Occupational Health (Arbetarskyddsstyrelsen), 1983. Investigation report 1983:4.

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