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Linking Expert Judgement and Trends in Occupational Exposure into a Job-Exposure Matrix for Historical Exposure to Asbestos in The Netherlands

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The aim of this article was to describe the structure and content of a job-exposure matrix (JEM) for historical asbestos exposure in The Netherlands. The JEM contained 309 occupational job title groups in 70 branches of industry during 10 periods of 5 years during 1945–1994, resulting in 3090 evaluations. Dutch sources on asbestos exposure measurements provided quantitative guidance for 69 evaluations (2.2%) in 25 occupational title groups. In addition, three databases from the UK Health and Safety Executive contributed to 222 evaluations (7.2%) and several other sources aided in another 133 evaluations (4.3%). These evaluations resulted in seven categories of exposure levels for all 3090 combinations of occupational title groups and periods. A verification process with five experts was used to adjust the assignments of exposure categories. The trends in exposure patterns over time were described in relation to production activities, operational control measures and the presence of dust control measures. For the majority of asbestos-related diseases in the past decades, reliable information on their historical exposure patterns was lacking. The limited availability of exposure measurements in the past illustrates the need for a structured assessment of historical asbestos exposure through a JEM.

Keywords: asbestos; historical exposure; job-exposure matrix

INTRODUCTION

Asbestos is a well-recognized occupational hazard affecting primarily the lungs, the pleura and the peritoneum. Exposures to asbestos and the rare mineral erionite are the only established causes of mesothelioma of the pleura and peritoneum and, thus, the consequences of asbestos use in society are illustrated by the burden of mesothelioma. Due to the extensive use of asbestos in Western European countries up to the 1980s and the average latency period between first exposure and clinical diagnosis of almost 40 years, a steep rise in mesothelioma deaths among men has been observed which is expected to peak at 9000 cases per year around 2015–2020 (Peto *et al.*, 1999). While incidence rates of mesothelioma are still rising in Europe, in some countries a deceleration of this increase has been observed which indicates an earlier and lower peak than previously predicted (Montanaro *et al.*, 2003; Segura *et al.*, 2003).

These projections on future mesothelioma burden do not include information on levels of asbestos exposure and the proportion of exposed persons in the general population. The large geographical variation in mesothelioma occurrence strongly suggests large differences in asbestos use across countries. Scotland, England and The Netherlands are among the countries with the highest annual rates (up to 8 per 100 000 persons), whereas Spain has an almost 8-fold lower incidence (Montanaro *et al.*, 2003). In The Netherlands, a country with late start of asbestos legislation, consistently higher incidence rates (1.5–2 times) of pleural mesothelioma among men have been observed than in Sweden, a country with very

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early regulation on asbestos use (Burdorf *et al.*, 2005). A recent update of the mesothelioma prediction in Great Britain incorporated exposure information, assuming that the population exposure in 2000 was ~4% of that in the maximum exposure year 1967. This large reduction in asbestos exposure will have a profound impact on the expected annual number of mesothelioma cases after 2015–2020 (Hodgson *et al.*, 2005). Thus, insight in long-term trends in occupational exposure to asbestos is required to determine the effect of control measures on the (future) burden of mesothelioma deaths in European countries.

In order to describe long-term trends in asbestos exposure, preferably measurement information is available across all relevant industries and occupations. A well-known restriction for retrospective exposure assessment is the paucity of information on asbestos exposure before 1970. This necessitates extrapolation of more recent exposure patterns to more distant periods, taking into account development in control measures over time. In some countries, such as The Netherlands, information on asbestos exposure is limited to a few industries and some isolated exposure situations (Burdorf and Swuste, 1999). Hence, a job-exposure matrix (JEM) on historical asbestos exposure must rely heavily on qualitative descriptions of working conditions and subsequent translation into expected exposure levels by experts.

The aim of this article was to describe the development of a JEM for assessment of historical asbestos exposure in The Netherlands.

MATERIALS AND METHODS

Development of the JEM

The JEM was designed to provide estimates of asbestos exposure in relevant industries and jobs in the period 1945–1994. The structure of the JEM is based on branches of industry, classified according to the Classification of Industries of Statistics Netherlands (CBS, 1974), which is very similar to the International Standard of Industrial Classification. Based on a previous analysis of cases of mesothelioma in the Dutch industry, 59 branches of industry were included with at least two cases of mesothelioma in the past 15 years (Burdorf *et al.*, 2003). This list of industries was expanded to 70 branches based on information on asbestos exposure in branches of industry from UK (three industries) (P. Oldershaw and A. Phillips, unpublished results) and a comprehensive overview from Germany (eight industries) (HVGB, 1997).

For each branch of the Dutch industry, a short description was available on the historic development in number of companies and population at risk (Burdorf and Swuste, 1999). Within each branch of industry, relevant occupations were identified comprising 278 occupations from the Dutch overview of mesothelioma cases (Burdorf *et al.*, 2003). An additional 21 occupations were identified through three available UK databases: (i) ASBEDUST includes over 16 000 measurements from surveys by the British Health and Safety Executive (HSE) during the mid-1970s to early 1980s in factories producing asbestos-containing products, such as asbestos cement, textiles and friction materials, (ii) BALACLAVA holds ~1300 measurements from small- and medium-sized facilities using asbestos-containing products from 1980 to 1983 and (iii) the National Exposure Database describes over 2000 measurements in larger asbestos facilities in the period 1985–2000. Another 10 occupations were derived from a German review (HVGB, 1997). The verification with JEMs from Finland and US did not add additional industries or occupations (Hoar *et al.*, 1980; Kauppinen, 2001). Occupations were coded (by A.B.) according to the Dutch 1984 classification of occupations, which is comparable to the British 1980 version of the Categories of Occupations.

For each job title within a branch of industry, the likelihood and magnitude of asbestos exposure was estimated by the authors for 10 five-year periods, covering 1945–1994. The evaluation of the likelihood of asbestos was based on an assessment of the proportion of exposed workers expressed on a four-point ordinal scale with categories 0 (no exposed workers), 1 (a small proportion in specific situations), 2 (a fair proportion) and 3 (a large proportion). As guidance for the assessment, a proportion of 5–20% was used for Category 1, 20–80% for Category 2 and over 80% for Category 3. This assessment took into account historical overviews of working conditions in industry as presented for example in written statements to the Dutch foundation for compensation of workers with mesothelioma (Swuste *et al.*, 2004). A similar approach has been described earlier by Nicholson *et al.* on estimation of the population at risk in US (Nicholson *et al.*, 1982). Before 1975, Category 2 was assigned to all occupations outside production processes in primary asbestos industries (due to indirect exposure) and after 1975 only to occupations that required regular presence at the shop floor. This category also includes jobs with indirect exposure due to spraying of asbestos insulation, such as welders and electricians in shipyards, or due to large-scale sawing and cutting of asbestos products, such as construction workers. Category 3 basically confirms definite exposure and, for example, was assigned during the total period to all jobs in production processes of primary asbestos industries and shipbuilding and maintenance (Burdorf and Swuste, 1999).

The evaluation of the magnitude of asbestos exposure presents a judgement on the average exposure in regular work activities distinguishing seven levels of exposure: 0, 0.01–0.5, 0.5–1, 1–2, 2–5, 5–10 and 10 fibres ml^{-1} or more. The cut-off values between 0.01 and 2 fibres ml^{-1} were based on frequently used values in asbestos regulations. The categories $>$2 fibres ml^{-1} covered a larger range due to the lack of precision in assessment of these historical levels of exposure. The assignment of exposure categories was based on three steps. The first step in the procedure was based on available measurement data in 25 occupations in The Netherlands described by number of measurements, arithmetical mean, range and standard deviation (Burdorf and Swuste, 1999). These data were used to arrive at estimates of exposure levels in the jobs with measurements and in those jobs without measurements but within the same exposure group. Thus, the same exposure level was assigned to all occupational job titles within the eight different exposure groups within the branch of industry as classified in the statistical analysis described above. In the second step, available quantitative information was used from the three British databases in the period 1974–2000, the Finnish FINJEM database in the period 1980–1990 (Kauppinen, 2001) and a review on exposure levels in occupations in the German industry in the period 1970–1990 (HVGB, 1997). In the JEM, a short summary of this exposure information from foreign sources is presented by number of measurements, arithmetical mean, range and standard deviation. This quantitative information from other countries was used for assignment of exposure when no information was available from Dutch sources whatsoever. A qualitative analysis of trends in exposure over time was performed by the authors to adjust these estimates, when needed, for consistency among occupational job titles within branches of industry. In the third step, exposure levels from jobs with measurements were assigned to jobs in branches of industry without exposure information. These assignments were based on similarities among jobs across different industries assuming that comparable job titles, such as electricians and pipe fitters, encompass similar activities and, hence, have similar exposure profiles (Corn and Esmen, 1979). Separate exposure profiles were constructed for these jobs within the primary asbestos industry and the asbestos-user industry.

All assignments of exposure levels were conducted by authors A.B. and P.S. and in case of disagreement discussed until agreement was reached. As verification process, the complete estimates of jobs and periods within five branches of industry with a considerable number of cases of mesothelioma were presented to five experts with ample experience in asbestos (three labour inspectors and two occupational hygienists). In an expert meeting for 15 of 350 evaluations, the exposure estimates were upgraded or downgraded by one category.

For 31 branches of industry, a secondary level of exposure information is presented, describing in detail determinants of exposure in relation to process technology, as derived from measurement reports from the Dutch Labour Inspectorate (Burdorf and Swuste, 1999), as well as various publications in the open literature (Lynch and Ayer, 1966; Rohl *et al.*, 1976; Hammad *et al.*, 1979; First and Love, 1982; Nicholson *et al.*, 1982; Dement *et al.*, 1983; Plato *et al.*, 1995). The determinants of exposure addressed production activities, operational control methods and presence of dust control measures. The control methods were classified as indirect methods, such as remote controlled and automated processes, and direct methods that required workers to be present in close proximity to the source, such as manually conducted processes (Swuste *et al.*, 2003).

RESULTS

The available databases with asbestos exposure measurements are described in Table 1. The three British data sources contained a large number of occupations across various industries. The majority of occupational job titles could be collated into eight different exposure groups. In The Netherlands, sufficient quantitative information to describe exposure patterns among occupations was only available for the asbestos–cement industry. Table 2 presents the estimated exposure for each occupational title group per time period in the asbestos–cement industry in The Netherlands. During 1970–1974, the average exposure exceeded in three of six exposure groups, the 2-fibres ml^{-1} level, with the highest exposure among jobs involved in handling raw asbestos and finishing dry asbestos–cement products. In each consecutive period, the average exposure decreased considerably, resulting in a total reduction of over 90% during 20 years with the strongest decreases in the more distant 5-year periods. This reduction in exposure could be attributed to the introduction of local exhaust ventilation in the main production hall from 1970 onwards, vacuum cleaners instead of brooms and pressured air during cleaning activities in 1976, change to wet finishing techniques from 1977 onwards and installation of an enclosed bag cutter in 1978.

Figure 1 summarizes the JEM for the Dutch industry containing 309 occupational job title groups in 70 branches of industry during 10 periods of 5 years, resulting in 3090 evaluations of which 69 evaluations (2.2%) were based directly on available exposure measurements. Quantitative information before 1970 was scarce with only five measured situations. Most quantitative information was available for the well-known primary asbestos industries, most notably the asbestos–cement and asbestos–textile industries.

Table 1. Available databases with personal asbestos exposure measurements in specific branches of industries and classification into occupational title groups

Database	Period	Contents	Categories of occupational title groups with number of measurements
Asbedust (UK)	1974–1980	Industries 15	Handling raw asbestos (including installation of insulation) (1271)
		Occupations 152	Manufacturing asbestos products (4493)
		Measurements 12152	Active handling asbestos products (cutting, sawing, grinding, assembling) (3097)
			Transport, storage, package asbestos products (1138)
			Maintenance jobs such as electrician, mechanic (775)
			General supervision of work processes and inspection jobs (774)
			Handling asbestos product wastes (218)
			Cleaning activities jobs (386)
Balaclava (UK)	1980–1983	Industries 9	Active handling asbestos products (cutting, sawing, grinding, assembling) (179)
		Occupations 47	Transport, storage, package asbestos products (25)
		Measurements 211	General supervision of work processes and inspection jobs (4)
			Cleaning activities jobs (3)
National Exposure Database (UK)	1985–2000	Industries 22	Handling raw asbestos (including installation of insulation) (63)
		Occupations 49	Manufacturing asbestos products (582)
		Measurements 1060	Active handling asbestos products (cutting, sawing, grinding, assembling) (272)
			Transport, storage, package asbestos products (55)
			Maintenance jobs such as electrician, mechanic (5)
			General supervision of work processes and inspection jobs (43)
			Handling asbestos products waste (12)
			Cleaning activities (28)
(NL)	1970–1990	Industry 1	Handling raw asbestos (including installation of insulation) (38)
		Occupations 6	Manufacturing asbestos products (38)
		Measurements 192	Active handling asbestos products (cutting, sawing, grinding, assembling) (85)
			Transport, storage, package asbestos products (17)
			General supervision of work processes and inspection tasks (6)
			Handling asbestos products waste (8)

Table 2. Average exposure to asbestos (fibres ml^{-1} air) in different exposure groups in the asbestos–cement industry in The Netherlands during the period 1970–1989

	1970–1974				1975–1979				1980–1984				1985–1989			
	n	AM	GM	GSD	*n*	AM	GM	GSD	*n*	AM	GM	GSD	*n*	AM	GM	GSD
Handling raw asbestos	8	7.46	5.29	2.59	10	1.19	0.97	1.95	10	0.26	0.22	1.77	10	0.22	0.19	1.65
Manufacturing	8	2.69	1.42	4.23	10	0.89	0.67	2.09	10	0.12	0.10	1.68	10	0.09	0.06	2.87
Handling products	14	6.16	4.51	2.42	28	0.73	0.51	2.25	26	0.26	0.20	2.12	17	0.21	0.15	2.30
Transportation	2	0.75	0.71	1.63	3	0.23	0.21	1.89	7	0.09	0.08	1.57	5	0.04	0.03	2.85
Waste management	3	1.40	0.90	3.81	5	1.55	0.98	3.11	5	0.34	0.30	1.69	5	0.20	0.18	1.74
Supervision and inspection	n/a				3	0.23	0.22	1.43	n/a				n/a			

AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation; n/a, not available.

In almost all occupational job title groups, the number of available measurements was limited to a few samples. When assigning similar exposure levels to different jobs within the same exposure group, quantitative information was available for 13.5% of all evaluations on occupational exposure groups throughout the 50-year period. The JEM can be searched by branch of industry, resulting in exposure estimates across all job titles in the selected industry, or by job title, resulting in exposure estimates across all industries. The secondary level of the JEM contains detailed exposure evaluations in relation to process technology in 31 branches of industry presenting information on the impact of process characteristics

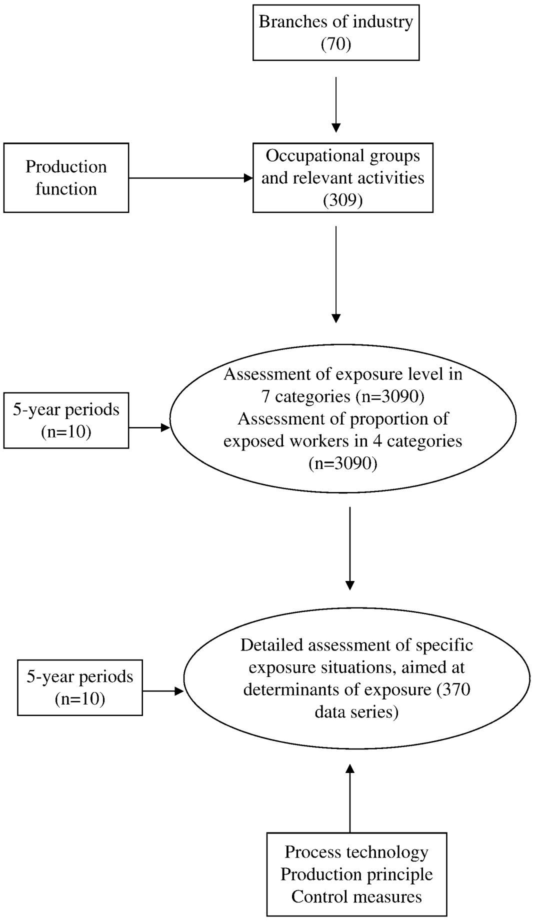

Fig. 1. Schematic structure between basic data objects of the asbestos JEM.

and control measures on the level of asbestos exposure. In addition, the JEM also has a database on ∼300 commercially available asbestos products in The Netherlands from 1938 onwards with producer, supplier, type of product with asbestos contents and trading name as search fields. The complete JEM is publicly available in the Dutch language as a web-based tool on http://www.asbestkaart.nl.

DISCUSSION

A JEM was developed on historical asbestos exposure across all relevant occupations in the Dutch industry during the period 1945–1994. Quantitative information from different sources was only available directly for 13.5% of all evaluations on occupational exposure groups throughout the 50-year period and mostly limited to exposure patterns in well-known asbestos industries after 1970.

For time periods prior to 1970, quantitative exposure information is almost completely lacking and, thus, exposure levels had to be estimated based on extrapolation of more recent measurement data. Substantial misclassification may be present for these time periods where no measurement data are available. In this asbestos JEM, it was assumed that exposure conditions have not changed dramatically for most occupations during 1945–1969. Although publications on control measures to reduce exposure to asbestos already appeared regularly in the professional and scientific literature from 1930s onwards, the introduction of control measures was not commonplace in The Netherlands before 1970. In 1971, the first guidelines were published and in 1977 the first Asbestos Regulations were enacted (Swuste and Burdorf, 1991; Swuste *et al.*, 2004). The first drafts of these Asbestos Regulations were discussed in 1973 and several branches of industry seem to have anticipated them quickly as within a few years, local exhaust ventilation, wet working techniques, closed machines, automated bag cutters and sound housekeeping procedures to reduce exposure were introduced for production workers and other personnel regularly visiting the shopfloor (Burdorf and Swuste, 1999).

After 1970, exposure information was more readily available, but still scarce in most branches of industry. Nowadays, the construction industry has the largest contribution to the annual cases of mesothelioma (Burdorf *et al.*, 2003), but in this JEM, measurements were only available for carpenters working primarily with asbestos cement (1975–1979, exposure range 2–5 fibres ml^{-1}) and for crane operators (1970–1974, mean exposure 0.45 fibres ml^{-1}). This scattered information will not allow inference of a time trend in this industry and, thus, the time trend must be derived from qualitative descriptions and developments in branches of industry with sufficient information. The Dutch dataset on trends in the asbestos–cement industry showed relatively high exposures for workers who worked most closely to the production process, either handling raw asbestos or working up asbestos products, and relatively lower exposures were observed for workers with indirect contact, primarily involved in process control activities during manufacturing or in activities that do not require manipulation of products. These measurements were collected within one facility and analysed in one laboratory according to the same measurement procedures, including a membrane filter method, a fibre-defined by, a minimal length of 5 μm, maximal diameter of 3 μm and aspect ratio larger than 3:1, use of the phase contrast microscope, and constant counting rules. Hence, for this particular company, the largest plant in The Netherlands, the observed trend over time seems to reflect a true decrease in exposure rather than a shift in measurement and counting procedures. However, it remains unknown whether this trend over time is representative for the Dutch situation in the asbestos–cement industry and also reflects the overall development in other Dutch industries. Given the abundant legislation on asbestos after 1977, it is safe to assume that occupational exposures to asbestos were generally much lower during the 1980s than they were years or decades ago. Indeed, a recent review on trends in inhalation exposure reported an annual decrease in asbestos exposure of 5% in the paper and pulp industry over 1979–1996 and 32% in the automobile repair industry between 1976 and 1986 (Creely *et al.*, 2007).

The application of a JEM has been criticized often for its potential for misclassification. The current JEM is no exception, but it has some advantages over earlier JEMs. Firstly, it presents estimates of actual levels of exposure rather than the often-used classification into exposed and unexposed jobs or the probability of exposure to asbestos (Hoar *et al.*, 1980; Ahrens *et al.*, 1993). These exposure estimates are represented in seven exposure categories, whose cut-off values reflect the development in historical exposure limits in The Netherlands (Swuste *et al.*, 2004). Secondly, the JEM presents the estimate of exposure level as well as the available exposure information which will allow the user to adjust the estimates according to his own purpose. It has to be acknowledged that the interpretation of historical asbestos measurements is surrounded with uncertainties due to the changes in measurement devices, sampling procedures and counting techniques. (Crawford and Cowie, 1984; Cherrie *et al.*, 1989; Burdett, 1998). Although almost all measurements included in the JEM were based on counting by a phase contrast microscope, no information was available on actual sampling techniques and measuring strategy choices. As a consequence, it is not easy to distinguish trends in exposure levels from trends in sampling and analytical techniques. Therefore, in the JEM, the measured concentrations in particular occupational title groups were not converted directly into an exposure category, but were subject to an expert evaluation in order to interpret these measurements relative to occupational job titles in the same branch, as well as exposures in comparable occupational job titles in other branches of industry. The validity of a JEM is difficult to demonstrate, but the verification process with occupational hygiene experts with ample, long-term experience with asbestos measurements in various companies at least ensured some form of calibration. Notwithstanding the limitations of this asbestos JEM for the Dutch industry, the structured estimation of exposure levels across jobs and industries will facilitate evaluation of historical exposures to asbestos. For specific use in epidemiologic studies, improvements may be required. Some studies have demonstrated that the combination of a JEM with job-specific questionnaires may considerably improve the exposure evaluation (Orlowski *et al.*, 1993; Tielemans *et al.*, 1999). A certain disadvantage of the current JEM is that the estimates of magnitude of exposure were based on the available measurement data in several databases, which were primarily measurements on chrysotile (HSE databases >90%). Hence, the information available was not sufficient to describe different exposure patterns for crocidolite and amosite. Since fibre type is an important determinant of the risk of pleural mesothelioma, risk assessments for occupational title groups in specific branches of industry well known for amphibole fibres will require additional information on fibre types used.

This article describes the development of a JEM for historical exposure to asbestos in The Netherlands with exposure measurements available in ∼14% of all occupational job title groups. A previous analysis of the occupational background of mesothelioma cases in The Netherlands between 1990 and 2000 showed that the majority of cases had experienced their first asbestos exposure prior to 1960 and, hence, reliable information on their historical exposure patterns was lacking (Burdorf *et al.*, 2003). The limited availability of exposure measurements in the past illustrates the need for a structured assessment of historical asbestos exposure through a JEM. This JEM presents a structured expert judgement for The Netherlands. Given the large uncertainties in the estimates presented, its applicability for exposure assessment in research and individual cases should always be accompanied by qualitative information on work processes and working techniques that will present evidence for the necessity to adjust the estimate upwards or downwards.

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