



An Expert System for the Evaluation of Historical Asbestos Exposure as Diagnostic Criterion in Asbestos-related Diseases

ALEX BURDORF*† and PAUL SWUSTE†

*Department of Public Health, Erasmus University, 3000 DR Rotterdam, The Netherlands; †Safety Science Group, Delft University of Technology, Delft, The Netherlands

Compensation schemes for asbestos-related diseases have developed different strategies for attributing a specific disease to occupational exposure to asbestos in the past. In the absence of quantitative exposure information that allows a valid estimate of an individual's historical exposure, general guidelines are required to retrospectively evaluate asbestos exposure. A risk matrix has been developed that contains qualitative information on the proportion of workers exposed and the level of exposure in particular industries over time. Based on this risk matrix, stepwise decision trees were formulated for decisions regarding the decisive role of historical asbestos exposure in case ascertainment of asbestosis and mesothelioma. Application of decision schemes will serve to speed up the process of verifying compensation claims and also contribute to a uniform decision-making process in legal procedures. © 1999 British Occupational Hygiene Society. Published by Elsevier Science Ltd.

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INTRODUCTION

Asbestos is a well-recognized occupational hazard, primarily affecting the lungs, the pleura, and the peritoneum. Numerous epidemiological studies have shown that exposure to asbestos may cause asbestosis, bronchogenic cancer and mesothelioma of the pleura or the peritoneum (Mossman and Gee, 1989). These studies have established the levels of exposure associated with increased risk and thus, facilitated the development of occupational exposure standards aimed at protecting workers' health. However, in an individual asbestos-related disease, it is often questionable whether the particular case can be attributed to previous exposure to asbestos. Hence, the asbestos exposure during the work history of an individual worker has to be assessed. The ascertainment of causality in a particular case is of pivotal importance for diagnosing individual cases of asbestos-related diseases. In addition, the question of attribution usually arises when legal suits are filed by asbestos victims against their employers.

Although the clinical characteristics of asbestos-related diseases are well described in medical text-

books, there is little information on the quantitative criteria for asbestos exposure in the diagnosis of these diseases. Yet exposure criteria are important to ensure that asbestos-related diseases are correctly diagnosed and justly compensated (Anonymous, 1997). In the past few years in The Netherlands, the number of lawsuits on asbestos-related diseases has risen dramatically as a result of the improved position of claimants in legal procedures concerning occupational diseases. This development takes place against the background of a steady increase in the incidence of asbestos-related diseases, especially pleural mesothelioma, in the past two decades. In order to avoid a detailed exposure evaluation unique to each case, there is a clear need among occupational hygienists, lawyers and judges for guidelines on the evaluation of historical exposure among patients with asbestos-related diseases. With this need in mind, a procedure has been developed to evaluate historical exposure to asbestos as part of the diagnostics in asbestos-related diseases.

The aim of this paper is twofold:

- (i) to develop guidelines for the retrospective assessment of historical exposure to asbestos at the workplace and
- (ii) to suggest exposure criteria as part of the diagnostic features of compensable asbestos-related diseases.

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†Author to whom correspondence should be addressed. Tel.: +31-10-4087717; Fax: +31-10-4366831; E-mail: burdorf@mgz.fgg.eur.nl

EXPOSURE FEATURES OF ASBESTOS-RELATED DISEASES

Asbestos exposure is linked to three distinct occupational diseases: asbestosis, lung cancer, and mesothelioma. Asbestosis is an interstitial pulmonary fibrosis with clinical symptoms and radiographic features similar to other interstitial fibroses (Mossman and Gee, 1989; Parkes, 1982). Hence, in the clinical diagnosis of asbestosis, evidence of occupational exposure to asbestos is of crucial importance. A linear relationship between the development of asbestosis and cumulative asbestos exposure has been demonstrated (Parkes, 1982). Classical studies have associated the occurrence of asbestosis with occupational groups with high exposure to asbestos, such as miners and millers, insulation workers and textile workers. One of the first occupational hygiene standards assumed that 50 years of exposure to 2 fibres/cm³ (i.e. 100 fibres/cm³-year) would result in a 1% risk on persistent inspiratory crepitations, one of the clinical features of the diagnosis of asbestosis (BOHS, 1968). Follow-up studies showed an excess risk of about 0.5% clinically diagnosed asbestosis after a cumulative exposure of 100 fibres/cm³-year (Advisory Committee on Asbestos, 1979). Over the years, results from new cohort studies and re-analyses of old studies have led to a steady decrease in the estimated cumulative exposure that is still capable of causing an asbestosis. A cohort study among asbestos cement workers reported a few asbestosis deaths at cumulative exposure levels below 5 fibres/cm³-year (Dement *et al.*, 1983). In a recent analysis, the lifetime risk on asbestosis for workers exposed for 45 years at 0.1 fibres/cm³ (the current OSHA-standard) was predicted to be around 2 in 1,000. In contrast to previous risk assessments, the exposure-response relation seemed to be non-linear on a multiplicative scale with the risk of asbestosis dropping off more rapidly with a reduction in cumulative exposure (Stayner *et al.*, 1997).

Mesothelioma is a primary tumour of the mesothelium, arising in the pleura or the peritoneum. In general, in approximately 80% of the malignant mesotheliomas among men, occupational exposure to asbestos is the only known causative agent. In some cases, exposure appears to have been solely environmental, due to residence in close proximity to asbestos mines and factories, or due to household contact with asbestos brought home by workers on their working clothes (Selikoff and Lee, 1978; Magnani *et al.*, 1993; Newhouse and Thompson, 1972). In a recent case-control study, the attributable risk for exposure to asbestos was 88% among men with pleural mesothelioma and 58% in men with peritoneal mesothelioma. For women (both sites combined), the attributable risk was about 23%, reflecting lower exposure to asbestos and greater misclassification of diagnosis (especially peritoneal mesotheliomas) among women (Spirtas *et al.*, 1994). Mesotheliomas can occur

in cases with low asbestos exposure and, hence, an occupational history of brief exposure should be considered sufficient to attribute a particular case to previous exposure to asbestos (Mossman and Gee, 1989). There is evidence that peritoneal mesotheliomas are associated with higher levels of asbestos exposure than pleural mesotheliomas, since mesotheliomas of the peritoneum are commonly found among shipyard and insulation workers, but are rare in occupations with moderate or low asbestos exposure (Selikoff *et al.*, 1979; Berry, 1994). Published dose-response relationships suggest that the risk of mesothelioma increases with the third or higher power of time since initial exposure to asbestos, sometimes adjusted for an estimated latency period (Berry, 1991; Peto *et al.*, 1982; Walker *et al.*, 1983). This pattern is characteristic for a carcinogen that chiefly acts at an early stage of the disease induction (Peto *et al.*, 1982). The risk function indicates that the mesothelioma risk is more determined by time-related aspects of asbestos exposure (age at first exposure, time since first exposure, duration of exposure) than other features of asbestos exposure (concentration).

The association between asbestos exposure and lung cancer has been demonstrated in various occupational cohort studies. The clinical signs of an asbestos-related cancer do not differ from a lung cancer attributable to other causes, most notably smoking. The presence of clinical signs and symptoms of asbestosis may also contribute an additional risk of lung cancer (Parkes, 1982). The exposure-response relationship seems to be linear with the risk of asbestos-related lung cancer as a function of cumulative exposure to asbestos in fibres/cm³-year (Lash *et al.*, 1997; Stayner *et al.*, 1997). There is a substantial heterogeneity in reported dose-response relations. Several cohort studies have reported significantly elevated mortality rates of lung cancer at cumulative exposure levels below 25 fibres/cm³-year (Neuberger and Kundi, 1990) or even below 10 fibres/cm³-year (Dement *et al.*, 1994), while other studies have failed to show a significant increase in lung cancer mortality at levels above 100 fibres/cm³-year (Lash *et al.*, 1997). Under the assumption of a linear relation without a threshold, in a recent analysis, the lifetime risk of lung cancer for workers exposed to about 5 fibres/cm³-year was predicted to be around 5 in 1,000 (Stayner *et al.*, 1997). In a number of publications, a cumulative exposure to asbestos of 25 fibres/cm³-year has been held responsible for a twofold risk of lung cancer (Ahrens *et al.*, 1993; Tossavainen, 1997).

RETROSPECTIVE ASSESSMENT OF ASBESTOS EXPOSURE

In ascertaining whether a particular disease is caused by occupational asbestos exposure, the most desirable approach is to apply an exposure algorithm based on the level and duration of exposure in the time periods most relevant to the disease initiation.

Table 1. Historical asbestos fibre concentrations in Dutch occupations and jobs

Occupation/job	Source of exposure	Exposure level	Year	Reference
Operator	handling of raw asbestos in coating	1.5–2 f/cm ³	1971	Pelt, 1971
Operator	handling of asbestos in gunny bag	10–15 f/cm ³		
Demolisher	removal insulation of furnace	10 f/cm ³		
Fitter/benchman	finishing asbestos cement product	50 f/cm ³		
Warehouse worker	handling asbestos cement products	0.5–1 f/cm ³		
Insulator	spraying of asbestos insulation	40 f/cm ³	1971	DLI, 1971
Mixer	Chandling of asbestos in gunny bag	14–16 f/cm ³	1970	Ruers, 1991
		1–14 f/cm ³	1974	
		0.5–1.2 f/cm ³	1978	
		<0.5 f/cm ³	1985	
Warehouse worker	raw asbestos warehouse	5.6 f/cm ³	1973	
		0.7 f/cm ³	1975	
		<0.3 f/cm ³	1985	
Operator	regrinding and pulverising of trimmings and rejected products	3.5 f/cm ³	1976	
		0.7 f/cm ³	1981	
		<0.5 f/cm ³	1985	
Fitter/benchmen	finishing asbestos cement products	6.2–18 f/cm ³	1970	
		0.3–4 f/cm ³	1975	
		0.3–0.6 f/cm ³	1980	
		0.2–0.7 f/cm ³	1985	
Operator	background in asbestos paper plant	0.1–2.8 f/cm ³	1974	TNO, 1974
Water pipe fitter	sawing of asbestos cement pipe	10–15 f/cm ³	1975	DLI, 1975
Operator	handling of dry glue mortar	0.1–0.82 f/cm ³	1976	DLI, 1976
Water pipe fitter	sawing of water pipe	1.4–4.3 f/cm ³	1976	DLI, 1976
	grind off water pipe	0.1–0.2 f/cm ³		
Operator	production asbestos cement	0.1–2.0 f/cm ³	1970 till 1984	Akkersdijk, 1984
	production friction material	0.01–2.4 f/cm ³		
	production cement and mortar	0.02–3.8 f/cm ³		
Demolisher	insulation in ships and trams	0.5–20 f/cm ³		
Car mechanic	brake servicing	0.01–5.7 f/cm ³		
Maintenance	removal of insulation	0.07–0.6 f/cm ³		
Stage designer	cutting of asbestos paper	0.01–0.3 f/cm ³		
Water pipe fitter	finishing of water pipes	0.4–3.2 f/cm ³	1986	Spuij, 1986
Demolisher	asbestos removal in power plant	4.8–28.0 f/cm ³	1989	Akkersdijk <i>et al.</i> , 1989
Maintenance in chemical plant	removal of asbestos gaskets	<0.02 f/cm ³	1996	Spence and Rocchi, 1996

Hence, air monitoring data at the workplace of the case under investigation should be available throughout the case's work history. An extensive search for historical information at the Dutch Labour Inspectorate, occupational health services and consultancy agencies revealed that data on asbestos exposure are all too few in The Netherlands.

Table 1 presents an overview of measurements of asbestos exposure in Dutch companies which the authors were able to retrieve in the past few years. Before 1945, the asbestos industry in The Netherlands was virtually non-existent. After 1945, the manufacture of asbestos products increased sharply; the most important products being asbestos cement, insulation, friction materials and brake linings, boards and floor coverings. Until 1970, only anecdotal evidence on asbestos exposure conditions in the primary and secondary asbestos industry is available. General descriptions on working conditions in Dutch vocational journals and Labour Inspectorate reports suggest a high exposure to asbestos in the insulation industry and shipbuilding, described by dust concentrations that effectively reduced vision to a few metres (Burdorf *et al.*, 1991). Such descriptions do not

differ from those about historical conditions in other countries (Selikoff and Lee, 1978; Nicholson *et al.*, 1982; Hauptverband, 1997). After 1970, in a selected number of work situations, asbestos measurements were performed, primarily initiated by publication of the first guidance notes on asbestos by the Dutch Labour Inspectorate in 1970 and 1971 (DLI, 1971). Measurement series in particular industries illustrate the introduction of control measures around 1974–1976, such as local exhaust ventilation, wet working techniques, closed machines and automated bag cutters (Akkersdijk, 1984; Ruers, 1991). In this period, new asbestos legislation was discussed and, subsequently in most industries, the exposure levels dropped considerably at the end of the 1970s. During the 1980s, on average, exposure levels decreased again, most likely by virtue of increasingly stringent legal standards. In 1994, a total ban on the use of asbestos and asbestos products was promulgated.

It must be emphasised that the exposure information in Table 1 only provides a very crude approximation of actual asbestos exposure for individual workers. Most reports lacked essential information as to measurement techniques, number of measurements,

duration of measurements and counting procedures. From most reports, it is unclear whether the data were based on static sampling or personal sampling. Many measurements were performed to evaluate particular work situations but details on periods, sites, activities and persons selected were usually absent. Most measurements probably constitute grab samples with short measurement duration and results were presented either by average exposure or by the range in measurement values. Although the limitations of these data are obvious, they represent the best quantitative information available to date. The measurement reports provide some insight into the general development of the working conditions in the Dutch asbestos industry.

The lack of sufficient quantitative exposure data and the large uncertainties in interpreting available historical measurements make it impossible to estimate the actual cumulative exposure to asbestos for an individual worker, given his specific work situation and job activities. Hence, it was regarded more appropriate to develop qualitative guidelines for retrospective assessment of asbestos exposure at an individual level. The historical information on production facilities, process changes and dust controls was used to investigate clear temporal changes in asbestos exposure in industry and to assign exposure ratings for different periods in history. A similar approach has been suggested by Checkoway *et al.* (1993), who

assigned relative weights for exposure to silica to five periods between 1940 and 1987 in a cohort study among workers in the diatomaceous earth industry.

For the evaluation of historical asbestos exposure of individual cases, an expert system was developed, based on a so-called risk matrix. This risk matrix is presented in Table 2. Each cell in the matrix contains qualitative information on the proportion of exposed workers (P) and the level of asbestos exposure (E). The ratings in the matrix are based on expert evaluation of descriptive information on the development of industry, production data, size of the workforce, asbestos import, plant operations and activities, and on quantitative exposure data from national and international sources (Selikoff and Lee, 1978; Nicholson *et al.*, 1982; Swuste and Burdorf, 1991; Hauptverband, 1997).

In the first step, it should be ascertained whether there is sufficient evidence for occupational exposure to asbestos in the work history. A lifetime job history should be obtained by means of a general questionnaire on job history and task descriptions for each job. The risk matrix provides a qualitative assessment on the probability of exposure to asbestos for workers in those industries and jobs that are well recognized with respect to the manufacture and application of asbestos products. An ordinal scale for probability of exposure was introduced with the following ratings: each worker is likely to be exposed (P3); each blue collar worker is likely to be exposed (P2); specific blue

Table 2. Risk matrix for historical asbestos exposure in Dutch companies and occupations

Industry/occupation	1946-1955		1956-1965		1966-1975		1976-1985		1986-1995	
	Exp	Pr	Exp	Pr	Exp	Pr	Exp	Pr	Exp	Pr
Primary asbestos industry										
Asbestos insulation	E3	P3	E3	P3	E3	P3		na		na
Asbestos textile	E3	P3	E3	P3	E3	P3	E2	P1		na
Asbestos cement	E3	P3	E3	P3	E3	P3	E2	P2	E1	P1
Asbestos friction materials	E3	P3	E3	P3	E3	P3	E2	P2		na
Asbestos flooring		na		na	E3	P3	E1	P1		na
Asbestos paper and felt	E3	P3	E3	P3	E3	P3	E1	P1	E1	P1
Secondary asbestos industry										
Insulation work	E3	P2	E3	P2	E3	P2	E2	P1	E1	P1
Shipbuilding	E3	P2	E3	P2	E3	P2	E2	P1	E1	P1
Construction	E2	P1	E3	P1	E3	P1	E2	P1	E1	P1
Car service station	E2	P1	E2	P1	E2	P1	E1	P1	E0	P1
Specific occupations										
Loader/sacker	E2	P0	E2	P0	E2	P0	E1	P0	E0	P0
Stripper/demolisher of furnaces & ovens	E3	P2	E3	P2	E3	P2	E2	P1	E1	P1
Engine room worker & stationary engineer	E2	P1	E2	P1	E2	P1	E1	P0	E0	P0
Maintenance worker in power plant	E2	P1	E2	P1	E2	P1	E1	P0	E0	P0
Furnace worker	E2	P2	E2	P2	E2	P2	E1	P1	E0	P0
Electrical fitter	E2	P1	E2	P1	E2	P1	E1	P0	E0	P0
Electrician	E1	P1	E1	P1	E1	P1	E0	P0	E0	P0
Fitter/benchmen, sheet metal worker	E2	P1	E2	P1	E2	P1	E1	P0	E0	P0
Founder, caster	E2	P1	E2	P1	E2	P1	E1	P0	E0	P0

Exp (exposure category): above 5 fibres/cm³ (E3), between 2 to 5 fibres/cm³ (E2), between 0.5 to 2 fibres/cm³ (E1), below 0.5 fibres/cm³ (E0).

Pr (probability of exposure category): each worker exposed (P3), each blue collar worker exposed (P2), specific blue collar workers exposed (P1), only few blue collar workers exposed (P0).

na = not applicable (not present).

collar workers are likely to be exposed (P1); and only a few blue collar workers are likely to be exposed (P0). For situations with classification, P1 or P0, and for jobs not included in the risk matrix, an additional evaluation at individual level is required by means of a structured interview by trained experts. This interview may need to be supplemented with employment records and inquiries to their current or past workplaces. Checklists of asbestos-containing materials and trade names can be presented as part of the detailed interview.

The fraction of exposed workers in the workforce is primarily based on historical accounts of workers on the working conditions in the asbestos industry. In the early years, prevention and control of dust emission had a low priority in the asbestos industry. It was not commonplace to enclose dust-generating machines or operations, to install exhaust ventilation systems or to introduce sound house-keeping procedures. Hence, all blue collar workers are likely to be exposed, either by direct or by indirect exposure. In the primary asbestos industry, it is assumed that even the best part of the office workers will have experienced some exposure to asbestos, albeit at a lower level than production workers. From the early 1970s onwards, control measures were gradually introduced which, consequently, confined the exposed population in the workforce to specific production jobs. In general, in the secondary asbestos industry and specific occupations, the proportion of exposed workers is considerably lower than in the primary asbestos industry. For workers in these industries and occupations, a detailed work history is required to establish the probability of direct or indirect exposure to asbestos.

In the second step, a qualitative assessment of the magnitude of asbestos exposure should be made. Since hardly any quantitative exposure information is available, the risk matrix provides exposure assignments for production workers in various industries and job titles. This part of the risk matrix resembles the approach adopted in several job-exposure matrices (Orlowski *et al.*, 1993). These exposure assignments are based on evaluations by experts of the few measurement data in The Netherlands (see Table 1), published measurement data in other countries (Selikoff and Lee, 1978; Nicholson *et al.*, 1982; Hauptverband, 1997) and on information on the introduction of dust control measures in Dutch companies (Swuste and Burdorf, 1991). Exposure categories were assigned that roughly coincide with the following levels: average exposure most likely above 5 fibres/cm³ (E3), average exposure most likely between 2 to 5 fibres/cm³ (E2), average exposure most likely between 0.5 to 2 fibres/cm³ (E1), average exposure most likely below 0.5 fibres/cm³ (E0). For exposure evaluation of job titles not included in the risk matrix, additional investigations are needed by occupational hygiene experts who can advise on the probable level of asbestos exposure using measurement data or expert knowledge.

In general, it is assumed that there was no marked trend in exposure categories over the period 1945–1975. There is anecdotal evidence that suggests that working conditions during the 1950s were worse than those during the 1960s, but concentrations over the total period were probably above 5 fibres/cm³. There is ample evidence from company records that, during the early 1970s, it became common practice to introduce specific control measures to reduce the asbestos exposure at the workplace, primarily as a response to public concern and government awareness of the carcinogenicity of asbestos. In a few companies, this is well-documented with actual measurement data (see Table 1). In the same period, the asbestos insulation industry was largely terminated by the change to the application of glass and rock wool. From 1970 onwards, the spraying of asbestos was largely abandoned and, in 1978, it became officially prohibited. In 1978, asbestos regulations were enforced that introduced a workplace standard of 2 fibres/cm³. Hence, in the risk matrix, the ratings for the exposure levels have decreased after 1975. A similar decrease in exposure is assumed around 1985 when the proposals for the 1988 asbestos regulations were first drafted with a standard of 1 fibre/cm³.

EXPOSURE CRITERIA IN CASE ASCERTAINMENT

Compensation schemes for asbestos-related diseases have developed different strategies for evaluating the contribution of occupational asbestos exposure to asbestos-related diseases. In Belgium, compensation claims for asbestosis and mesothelioma are accepted on the condition of sound evidence of asbestos exposure in the work history. It has been agreed upon that the diagnosis of both diseases is sufficiently specific for asbestos exposure. A similar procedure has been adopted by the British Columbia Workers Compensation Board for asbestosis and mesothelioma and by the German National Insurance Code for mesothelioma. In the United Kingdom, a diagnosis of asbestosis would be made when there has been a history of substantial exposure to asbestos. For mesothelioma, it is mentioned that asbestos exposure is often substantial but the period of exposure may be as short as a few months (Stidolph, 1997. Personal communication, P. N. Stidolph, UK Dept. of Social Security).

In the aforementioned compensation guidelines, the decision as to whether the disease is attributable to asbestos exposure at work is based upon a rather straightforward qualitative exposure assessment. In a positive decision, the probability is deemed sufficiently high for the particular case to be attributed to asbestos exposure, although in many cases, strict scientific evidence cannot be provided.

With respect to asbestos-related lung cancer, compensation schemes have adopted a more quantitative evaluation of asbestos exposure. In Belgium and France, employment of 10 years in an occupation

mentioned on a limited list of jobs in which direct exposure to asbestos is known to have occurred, has been considered a sufficient prerequisite for the diagnosis of lung cancer as an occupational disease. This list includes jobs in the manufacture of asbestos products, insulation work, asbestos removal, construction and the shipbuilding industry. The assumption underlying this criterion is that 10 years of employment in these jobs will have resulted in a cumulative exposure of at least 25 fibres/cm³-year. In the documentation of several compensation schemes, it is claimed that this exposure level is associated with a twofold increased risk of lung cancer, although references to supporting scientific evidence are lacking (Ahrens *et al.*, 1993; Anonymous, 1997; Tossavainen, 1997). Based on the same consideration, the Finnish compensation criteria require at least one year of heavy exposure (spraying, insulating) or at least 10 years of moderate exposure (construction work) as evidence for a twofold risk of lung cancer (Tossavainen, 1997).

A further quantification of asbestos exposure is required in Germany for recognition of asbestosis or asbestos-related lung cancer. Both diseases are only recognised as an occupational disease if there is evidence of an exposure to asbestos in the workplace over at least 25 fibres/cm³-year. Hence, a thorough quantitative assessment of the cumulative exposure to asbestos of a particular worker is required. The standardized procedure is that a qualified work history is taken to collect information on job history and, for each job, the average number of hours per week worked with particular asbestos products, the equipment and tools used, and the type of application of these tools. This information is linked to a databank of about 27,000 measurement covering a broad range of industries, jobs, activities and time periods and, consequently, the cumulative exposure is calculated (Hauptverband, 1997). When monitoring data are not available for particular work activities, experts are asked to provide an estimate of exposure relative to comparable work activities with known exposure levels.

The described compensation schemes demonstrate that there are considerable differences in the criteria for evaluation of occupational asbestos exposure. While acknowledging that a quantitative exposure criterion is to be preferred, in the Dutch situation, feasibility considerations will argue for a more qualitative approach. First, the retrospective assessment of asbestos exposure will inevitably be subject to considerable misclassification. Information on work history will be collected by interviewing the claimant, since suitable company records are rarely ever available. Validation studies have indicated that jobs or work activities with short duration and jobs in the distant past may be difficult to remember (Bond *et al.*, 1988). This recall bias is very critical to mesothelioma which may occur as a result of 6 months exposure more than 40 years ago. It will also affect, although to a lesser extent, the estimate of cumulative exposure received over a number of years, as is needed for the ascertainment

of asbestosis and lung cancer. Second, quantitative exposure information on working conditions before 1970 is completely absent in The Netherlands. This is not unique to The Netherlands or to asbestos exposure, since it has been observed that for most occupational exposures, the historical exposure measurements available are rarely sufficient to permit calculation of exposure levels for the study population (Stewart *et al.*, 1991).

With these considerations in mind, it was decided to develop a stepwise decision tree for the evaluation of retrospective asbestos exposure, based upon the risk scheme that combines probability of exposure and level of exposure. The purpose of the decision tree was to present guidance to the evaluation of the best part of all asbestos-related cases without introducing too strictly defined boundaries between acceptance and rejection of a particular claim. The decision tree for ascertainment of asbestos exposure in individual cases of asbestosis is presented in Fig. 1. The first step in the decision tree distinguishes between jobs in which it is most likely that each blue-collar worker is exposed and jobs where asbestos exposure is limited to those workers who handle asbestos-containing products. For the latter group, proof of asbestos exposure is required at individual level. The second and third steps provide the qualitative cut-off points for the decision as to the attribution of asbestosis to occupational asbestos exposure. The cut-off points roughly reflect the minimum cumulative exposure of 5 fibres/cm³-year required to induce asbestosis (Dement *et al.*, 1983; Stayner *et al.*, 1997). Two branches in the decision tree result in the conclusion 'maybe'. This conclusion may be upgraded to a positive conclusion when there is additional evidence that the exposure pattern is more likely to have been close to the upper limit of the qualitative exposure level, or higher qualitative exposure levels have regularly occurred for several months, or the duration of exposure is close to the upper limit of the duration criterion. These decisions are based on the judgements of experts, facilitated by additional information on work and work activities of the case under consideration. As an additional criterion, a minimum latency period of 10 years may be considered (Hauptverband, 1997).

A similar stepwise decision tree for mesothelioma is presented in Fig. 2. The first step distinguishes industries in which each worker is probably exposed (either direct or indirect exposure) and jobs where asbestos exposure is primarily associated with the handling of asbestos-containing products. For the latter group, proof of asbestos exposure is required at an individual level. The cut-off point for minimum cumulative exposure is set to 0.5 fibres/cm³ for at least 6 months, assuming a dose-response relationship with mortality progressively increasing with time since first exposure (Peto *et al.*, 1982). A minimum latency period of 15 years may be considered (Berry, 1991).

For asbestos exposure and lung cancer, no specific stepwise decision tree was developed. A recent meta-

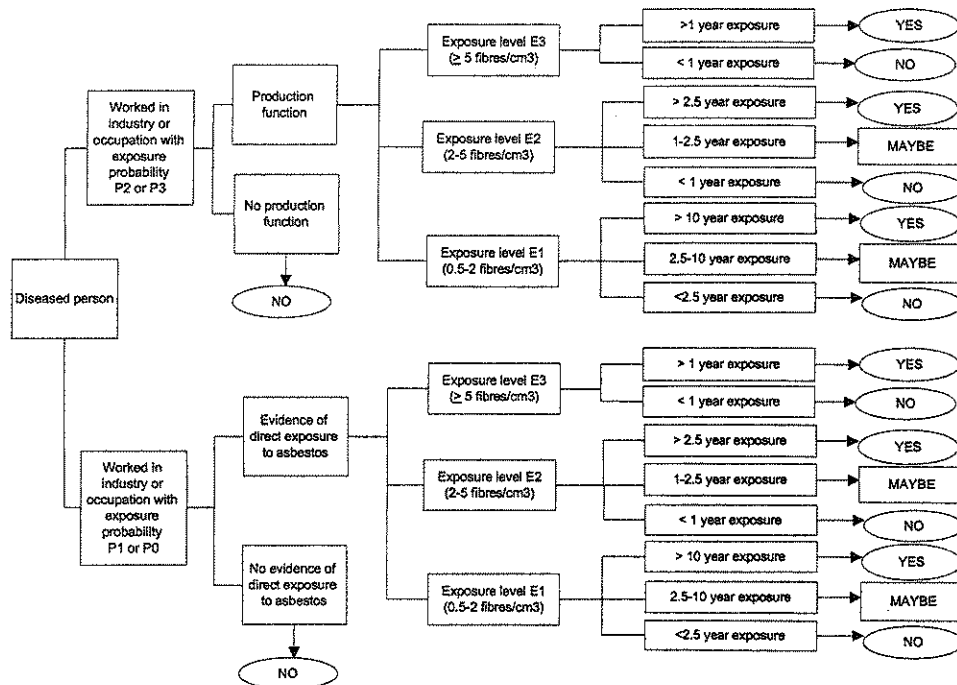


Fig. 1. Stepwise decision tree for historical evaluation of asbestos exposure in ascertainment of asbestosis.

analysis estimated that the lifetime risk of lung cancer at a cumulative exposure of about 5 fibres/cm³-year was around 5 in 1,000 (Stayner *et al.*, 1997). Given the various other risk factors associated with lung cancer and the typical mortality rates among men, at

this exposure level, only a small proportion of the lung cancer cases in an occupational population will be attributable to asbestos exposure. Various other risk factors are associated with lung cancer and the well-known multiplicative effect of cigarette smoking and

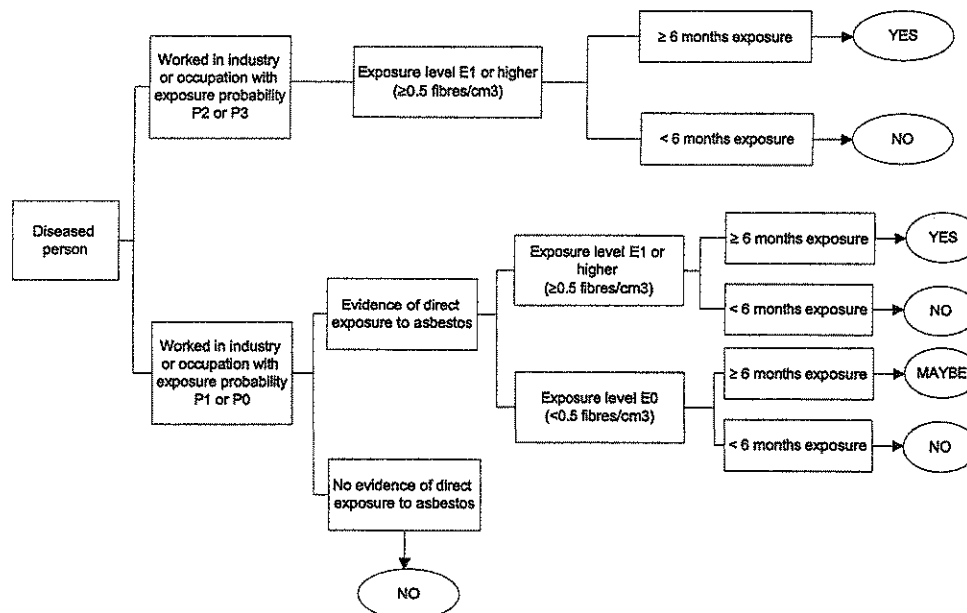


Fig. 2. Stepwise decision tree for historical evaluation of asbestos exposure in ascertainment of mesothelioma.

asbestos exposure hampers the development of a decision scheme. The probability of lung cancer being caused by asbestos exposure is relative to the effect of smoking and other risk factors in this case, and it is almost impossible to present general guidance based on evaluation of asbestos exposure alone. Hence, the decision scheme for asbestosis is clearly not applicable to lung cancer although a worker exposed to asbestos seems to be at higher risk for lung cancer than for asbestosis. Some compensation schemes have accepted a cut-off of about 25 fibres/cm³-year but, even at this level, at least half of the lung cancer cases will be due to cigarette smoking and other risk factors. Since it cannot be stated with certainty that a particular case was caused by asbestos exposure, it is considered the best scientific approach to determine the likelihood of asbestos exposure as the causative factor. Methods have been developed to estimate the relative contributions of asbestos exposure and tobacco smoking in individual lung cancer cases (Enterline, 1980; Grimson, 1987). These models take into consideration the fact that lung cancer has a multifactorial aetiology and that multiplicative effects among risk factors may occur. The apportionment of risk results in a probability statement on the role of asbestos exposure in the causation of a particular lung cancer. However, for compensation schemes, the question still remains at which value of probability individuals are eligible for compensation.

DISCUSSION

This paper presents procedures to assess historical asbestos exposure and to evaluate the role of asbestos exposure in individual patients with asbestos-related diseases. For asbestosis and mesothelioma, both diseases specific for asbestos exposure, stepwise decision trees are suggested as tools in the ascertainment of compensable occupational diseases caused by asbestos. For lung cancer, it is suggested to apply a probability model that apportions the relative contribution of asbestos exposure, amongst other risk factors.

In decisions regarding compensable asbestos-related diseases, it is preferable to have clear-cut exposure criteria as part of the diagnostic features of these diseases. The application of such criteria raises two interrelated issues. The first issue is whether it is scientifically justifiable to maintain a particular exposure standard as diagnostic evidence in the case ascertainment. Epidemiological studies have shown significant differences in dose-response relationships and subsequent deduction of the minimum (cumulative) exposure that is assumed to be required to have caused a particular asbestos-related disease (Lash *et al.*, 1997; Stayner *et al.*, 1997). Given the considerable uncertainty in quantitative estimates of minimum exposure and the specificity of asbestosis and mesothelioma, several compensation schemes have adopted the rather lenient approach that a history of significant occupational exposure to asbestos will suffice for case

ascertainment. The benefit of the doubt is given to the applicant, given sufficient evidence of significant asbestos exposure. This requirement may cause some problems as workers and companies have not always been aware of working with asbestos-containing products. Yet, there are good arguments to favour the inclusion of explicit exposure criteria in the diagnosis of asbestos-related diseases with occupational origin. The clinical features of asbestosis may be too difficult to distinguish from other pneumoconioses, whereas the exposures profiles may clearly differentiate between silicosis and asbestosis. For mesothelioma, non-occupational sources of asbestos exposure may be involved that require evaluation in relation to occupational exposure. The need for quantitative exposure criteria is probably highest for lung cancer, since it is not possible to prove that asbestos is the causative factor for an individual patient. Attribution of causation requires a reasonable certainty that the asbestos exposure has caused or contributed to the disease and thus, an estimate of cumulative exposure is essential in weighing the relative contribution of asbestos exposure.

The second issue relates to the accuracy and precision of the assessment of relevant exposure to asbestos in the past. A primary concern for retrospective exposure assessment is the paucity of information, especially for historical periods before 1970. This necessitates extrapolation of more recent exposure levels to earlier periods, taking into account changes in workplace characteristics, production processes and dust control measures. It is obvious that this extrapolation is fraught with uncertainty and may introduce a significant degree of error into the historical exposure assessment. Even if exposure data are available, this information may be insufficiently specific to jobs, activities and individual workers. Assessment procedures have been developed to assign cumulative exposure to individual workers, using exposure algorithms based on large datasets of measurements in various industries and workplaces (Hauptverband, 1997). In general, influences of workplace characteristics on exposure are not well understood quantitatively and little will be known about the exposure distributions of individual workers over time (Stewart *et al.*, 1991). An exposure assessment based upon a few measurements under largely unknown conditions will result in a precise estimate but not necessarily in a valid estimate. Error in the assessment of a worker's cumulative asbestos exposure is inevitably introduced and large confidence intervals around the exact value of the exposure estimate will be the rule rather than the exception. Hence, the use of strict cut-off points for case ascertainment will introduce substantial misclassification of asbestos-related occupational diseases.

Given the little information available and the difficulties in interpreting the historical exposure data, the evaluation of asbestos exposure as diagnostic criterion is best served by an approach that combines qualitative and quantitative estimates of exposure.

The presented risk matrix captures both quantitative exposure data as well as qualitative information on historical developments in the asbestos industry. Consequently, this expert evaluation served as the basis for stepwise decision schemes for case ascertainment. These schemes present general decision rules as to whether the probability is sufficiently high that the historical asbestos exposure at work has resulted in an asbestos-related disease. The major advantages of these decision trees are their high degree of standardization and their rapid and consistent application when compared to the alternative approach of evaluating the role of asbestos exposure on a case-by-case basis. In addition, their application will facilitate the compensation of asbestos-associated diseases becoming more efficient and equitable. Although these decision schemes may be an improvement, they should still be subject to validation studies. Key elements in validation are the work history and the assignment of exposure to specific jobs and time periods. Work histories obtained on similar jobs by different claimants may be evaluated for consistency. The validity of work histories can be investigated by comparing information from claimants with independent reports collected from co-workers and company records. The assignment of exposure may be scrutinized by comparing measurement data from different workplaces and companies. Job-specific questionnaires may be introduced to identify principal determinants of exposure and to facilitate a better exposure classification.

CONCLUSION

The criteria for diagnosis of asbestos-related diseases cannot be confined to the clinical characteristics of disease but should also accommodate guidelines for the evaluation of the history of exposure to asbestos. A structured assessment of historical occupational exposure to asbestos is based on quantitative exposure data as well as qualitative information on historical developments in the (asbestos) industry. This expert evaluation will determine the stepwise decision schemes for case ascertainment. Application of decision schemes will serve to speed up the process of verifying compensation claims and will also contribute to a uniform decision-making process in legal procedures.

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